AN INTRODUCTION TO
GEOINFORMATICS

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To
My grand children,
Siddhant, Ishan, Samriddhi, Pragyan, Riddhima and Rudrakshi
For asking questions on anything and everything

PREFACE

Till recently, Photogrammetry and aerial surveying were part curriculum of Civil Engineering graduation courses. However, advent of Satellite Remote Sensing and subsequent development of Global Positioning System (GPS) and Geographical Information System (GIS) have made significant changes in surveying and map making. In light of this, many technical universities have recently upgraded their syllabus to include the above subjects under an umbrella term—Geoinformatics. Geoinformatics is the integration of different disciplines dealing with spatial information. There is no single book available in the market to give essential elements of Photogrammetry, Remote Sensing, GPS and GIS, at one place. Present book is written to fulfill this requirement for students pursuing various courses on geoinformatics.

The book may be useful for students of post graduate level, in various disciplines having a paper in Remote Sensing. It may be equally beneficial to students of Post Graduate Diploma in Remote Sensing and GIS.

Keeping the cost of the book at reasonably low level, for wider circulation, the coloured illustrations have been kept to the bare minimum. However, the line diagrams and black and white illustrations make it comprehensive and easy to understand. Any suggestion to improve the book is always welcome.

G. S. Srivastava

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FOREWORD

Geoinformatics is the latest branch of science, which includes Photogrammetry, Remote Sensing, Global Positioning System (GPS) and Geographical Information System (GIS). Basic understanding of these components is essential for carrying out various types of surveys, navigation, geodynamics, hydrology, disaster management, etc. In view of its utility in multifarious activities, Geoinformatics, as a subject, has been recently included in the syllabus for undergraduate students of engineering and postgraduate students of environment studies, geology, geography, etc. Therefore, a book on Geoinformatics is a welcome addendum to our knowledge on the subject.

Dr. G. S. Srivastava, former Deputy Director General of Geological Survey of India, is a veteran professional in geological mapping, surveying, aerial photo-interpretation and remote sensing. He is alumni of ITC (The Netherlands), life member of Indian Society of Geomatics and a Fellow of Indian Society of Remote Sensing. He has been a pioneer initiator of database management in GSI and was closely associated with the National Spatial Database Infra-structure (NSDI). He participated in the VI GSDI conference at Budapest, Hungary, as a member of Indian delegation, in 2002. He is eminently qualified to write this book on Geoinformatics. The illustrations in the book are simple and easy to understand. The narration is lucid having a systematic approach. I hope the book will be very useful to the students of Geoinformatics and professionals pursuing GPS and GIS.

I wish him success.

Maj. Gen. Dr. Shiva Kumar
Head NRDMS & CEO, NSDI,
Ministry of Science and Technology
Govt. of India

FOREWORD

The new technique of Global Positioning System (GPS) has revolutionized surveying methods of positioning. It is now possible to have maps by combining different thematic layers with the help of Geographical Information System (GIS), in a fast and economic manner. In order to keep abreast with the newer technologies, the curriculum of the universities has been upgraded to accommodate GPS and GIS along with Photogrammetry and Remote Sensing, under a broad subject of Geoinformatics. A book on Geoinformatics, incorporating the basics of different components, is very welcome, as it will serve the requirement of Engineering and Postgraduate students of Environmental Science, Geology, Geography and the likes.

Dr. G. S. Srivastava, a veteran professional and former Deputy Director General of Geological Survey of India, is well qualified to write this book. He is alumni of Indian Institute of Remote Sensing and ITC. The Netherlands, and has been visiting faculty of many universities and institutions. He has long experience in Geological Mapping, Photogrammetry, Remote Sensing, Database Management and GIS Applications. The content of the book is presented in a systematic manner, as per the syllabi of different courses in Geoinformatics. The diction of the text is simple and logical, illustrated with suitable diagrams and sketches. I am sure the book will be useful to the students and scholars pursuing Remote Sensing and GIS Applications.

PROFESSOR SUKHADEO THORAT
Chairman
University Grants Commission

ACKNOWLEDGEMENTS

At the outset, I would like to express my gratitude to all my teachers at the Indian Photo-interpretation Institute (now IIRS), Dehradun, India and ITC, The Netherlands, who supplied the notes on different topics. I have heavily drawn on these notes, updating them and making them more readable in my own way.

I have consulted many books especially for writing parts of GPS and GIS. These are listed at the end of each chapter for supplementary reading. I am thankful to the authors of these books. I have picked up relevant materials and integrated them in this book, mainly for the benefit of student community of *Geoinformatics*.

During my years with Geological Survey of India, Training Institute, Hyderabad, I along with my colleague Mr. A.V. Raju had prepared exhaustive notes on Remote Sensing and its applications in geology. These notes were utilized for writing the Remote Sensing part of the book.

I had the benefit of valuable discussions and suggestions with Prof. I.B. Singh, FNA, Dr. S. Palria, Head Department of Geoinformatics, Sh. K. P. Singh, former Chief Engineer, CWC, Sh. P. N. Shah, Director, RSAC, UP, while preparing the manuscript of the book. I am thankful to Dr. A. K. Kulshrestha for painstakingly going through the manuscript and offering valuable comments and suggestions.

I am thankful to the publishers, McGraw Hill Education (India) including its personnel Messers Mitadru Basu, Neha Sharma and Sohan Gaur, for their cooperation and valuable suggestions in bringing out the book in present form.

G. S. Srivastava

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PART I

PHOTOGRAMMETRY

1

AERIAL PHOTOGRAPH

1.1 INTRODUCTION

Photographs, taken from an aircraft, are commonly termed as aerial photographs. These play an important role in the execution of cartographic mapping on various scales and in the evaluation of natural resources of a region. All studies of natural resources basically involve qualitative examination of the terrain, correlation of the observed data and finally interpretation and evaluation of the data. The conventional methods involve detailed study of the terrain with its attendant handicaps; while modern techniques of investigation make full use of immense wealth of information recorded in an aerial photograph and thus not only economize and expedite the investigation but offer more reliable results.

The specialist investigator (be a geologist, forester or soil scientist) must know what he is looking for and how the information, which he is seeking, appears on the aerial photographs. The result of this qualitative analysis will depend on the specialist level of specialization and experience.

The quantitative analysis, which involves measurement of linear distances, angles and height differences between terrain objects as well as preparation of base map, will only be possible if the geometry of the aerial photograph and techniques of **Photogrammetry** are understood. The following chapters will deal with these aspects of Photogrammetry forming the base of photo-interpretation in various disciplines viz. geology, forestry, soil sciences, land use, urban planning, etc.

1.2 TYPES OF PHOTOGRAPHS

Photographs, which are used for mapping and photo-interpretation, can be divided into the following classes according to the direction of the camera axis:

(a) Vertical photograph
(b) Oblique photograph
(c) Convergent photographs
(d) Trimetrogon photographs
(e) Horizontal or terrestrial photograph

The terms 'vertical' and 'horizontal' refer to the direction in which the camera axis was pointing at the time of exposure.

1.2.1 Vertical Aerial Photograph

Vertical aerial photographs are taken with the axis of the aerial camera vertical or nearly vertical. A vertical photograph closely resembles a map (Fig. 1.1) and is particularly suitable for obtaining uniform coverage. As these photographs can be obtained with reasonably low tilt (tilt is deviation angle of the camera axis from the vertical), they are generally used for mapping and photo-interpretation purposes.

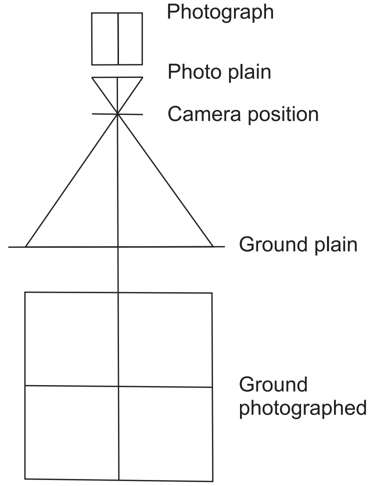


Fig. 1.1 *Vertical aerial photograph*

1.2.2 Oblique Photograph

Aerial photographs taken with the optical axis of the aerial camera tilted from the vertical are known as oblique photographs. These photographs cover large areas of ground but clarity of details diminishes towards the far end of the photograph. Low oblique photographs (Fig. 1.2a), on which the horizon does not appear, are sometimes used to compile reconnaissance maps of inaccessible areas. High oblique photographs (Fig. 1.2b) are tilted sufficiently to contain the apparent horizon. These were initially used for extension of planimetric and height control points, where the available ground control was insufficient to provide the necessary accuracy. These have very limited use at present.

1.2.3 Convergent Photographs

These are low oblique photographs taken with two cameras exposed simultaneously at successive exposure stations, with their axes tilted at a fixed inclination from the vertical in the direction of the flight line so that the forward exposure of the first station forms a stereo-pair with the backward exposure of the next station (Fig. 1.3). Special plotting instruments are required for compiling topographical maps from convergent photographs.

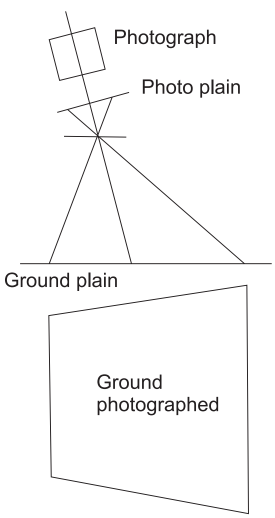


Fig. 1.2a *Low oblique aerial photograph*

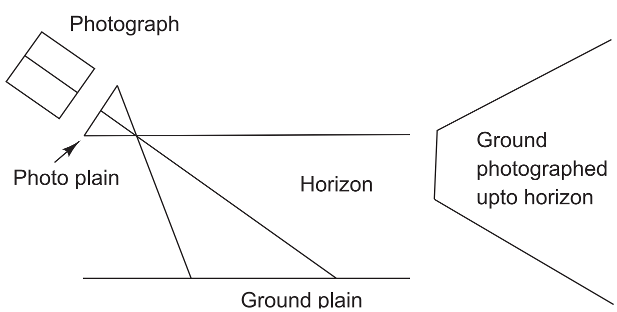


Fig. 1.2b *High oblique aerial photograph*

1.2.4 Trimetrogon Photographs

Trimetrogon photographs are a combination of one vertical and two oblique photographs (Fig. 1.4). This has been used for rapid production of reconnaissance maps on small scales.

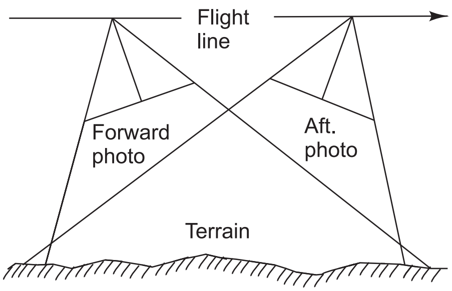


Fig. 1.3 *Convergent photography*

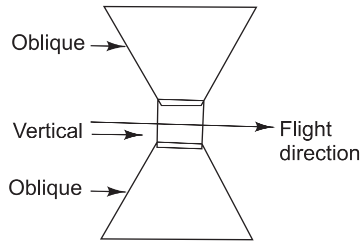


Fig. 1.4 *Trimetrogon photography*

1.2.5 Terrestrial Photographs

Terrestrial photographs are taken with photo-theodolite from camera stations on the ground with horizontal camera axis (Fig. 1.5). These photographs present more familiar elevation view. These photographs are used for survey of structures and monuments of architectural or archaeological importance. Terrestrial photographs taken with normal good cameras can also be of considerable use in supplementing photo-interpretation of vertical aerial photographs particularly so in geology and forestry. Terrestrial photographs have found immense use in glaciological studies and mapping inaccessible terrain.

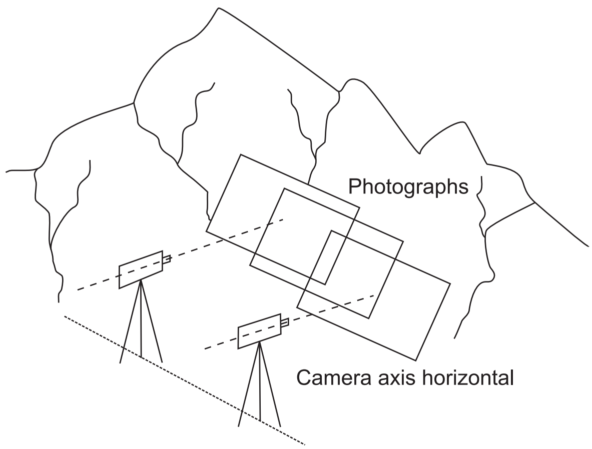


Fig. 1.5 *Terrestrial photography*

The geometrical relationship of terrestrial photographs is similar to vertical aerial photographs and is dealt in *Terrestrial Photogrammetry*. It has been successfully used in Highway Traffic Studies, Mapping of Towers and Road Intersections, big buildings and monuments for architectural and archaeological studies, etc.

Photo-theodolite is the main instrument used in terrestrial photogrammetric work. The instrument consists of a standard theodolite on which is fitted a special camera having 10×15 cm plate. The focal lengths for different cameras range between 100 and 165 mm. The camera may be used in mono or stereo mode. The principal point is located with the help of fiducial marks.

The main advantages of terrestrial photography are:

1. Long film exposure can be given (for stationary objects) thereby improving the quality of photographs.
2. Optical errors can be better controlled.
3. The shutter speed and the design of shutter in aerial photography is quite important. This not much of a problem in terrestrial photography.
4. Instruments and equipment are simple and comparatively not expensive.
5. The ground coordinates of camera station (exposure station) are known.
6. It is also possible to measure on a single photograph.
7. Slow moving as well as fast moving objects can be studied in great detail.
8. It can serve to supplement information for aerial mapping, such as in heavily wooded areas for undergrowth, etc.

The disadvantages are:

1. The main disadvantage lies in its coverage, which is limited.
2. Sometimes it is difficult to locate and find suitable camera stations.
3. It is very slow process.
4. It can not be used for mapping large areas. Its chief application lies in mapping small limited areas.

1.3 GEOMETRY OF AERIAL PHOTOGRAPHS

The aerial photograph can be considered as a projection of a part of earth surface onto a photo sensitive material.

1.3.1 Types of Projection

In order to understand the geometric qualities of a photograph it is necessary to understand what projection means in terms of geometry. This is illustrated by Fig. 1.6.

1.3.1.1 Parallel Projection

The triangle *ABC* is projected on the plane '*L*'. the projection of the triangle is "*abc*". The projecting rays, *Aa*, *Bb*, *Cc*, are all parallel in this case. (Fig. 1.6a).

1.3.1.2 Orthogonal Projection

Figure 1.6b gives an example of orthogonal projection. The projecting rays here are all perpendicular to the plane of projection 'L'.

1.3.1.3 Central Projection

Figure 1.6 c shows a central projection. The projecting rays pass through O, called perspective center. The photographic images projected by a lens system are treated as central projection and fall under the category of central perspective.

PROJECTIONS

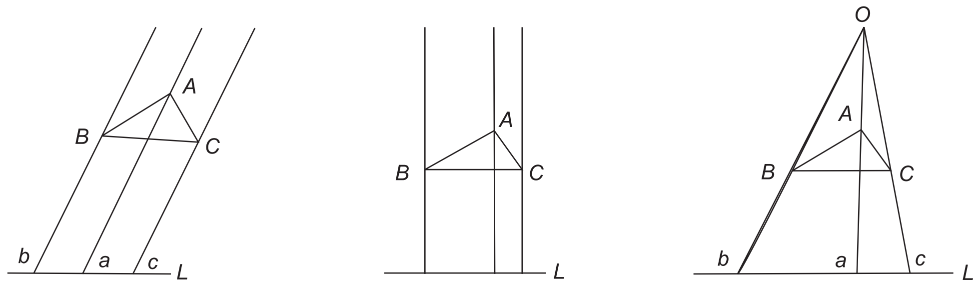


Fig. 1.6a *Parallel* **Fig. 1.6b** *Orthogonal* **Fig. 1.6c** *Perspective*

1.3.2 Mathematical Concepts

An aerial photograph is a central perspective. In an ideal case of an absolutely vertical photograph of a completely flat terrain, the aerial photograph will be geometrically the same as the corresponding map of the area. However, because of tilt of the photograph and relief variation of the ground, an aerial photograph differs geometrically from the map of the corresponding area.

The central perspective is characterized by the fact that all straight lines joining object points to their corresponding images, pass through one point. This point is known as the perspective center. Figure 1.7 illustrates this relationship.

Straight lines *AA*′, *BB*′ etc. joining corresponding points e.g. *A* in object plain and *A*′, its image in the image plain, are known as perspective rays which pass though the perspective center '*S*'. A plane in between the perspective center and the object is known as a positive plain. The consideration of a positive plain does not involve any significant geometrical change in the relationship.

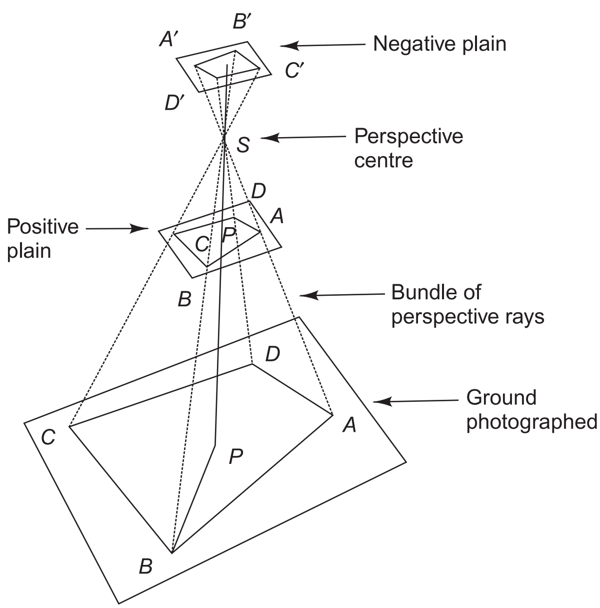


Fig. 1.7 *Geometry of perspective projection*

In order to study the properties of an aerial photograph, it is necessary to understand the geometry of central (perspective) projection. Some properties of this projection are dealt below:

Plane I can be considered as ground plane and II as positive plain of photograph (Fig. 1.8).

(a) *AB*, the line of intersection of the object and image plains, is known as *axis of homology*. It is also known as the *axis of perspective*.

(b) A plane parallel to plane I and passing through the perspective center '*S*' cuts the plane II in a line *CD* which is known as the *horizon line*. Horizon line and axis of homology are parallel to each other.

(c) Image of all objects infinitely distant on the right of *AB* will be formed on the horizon line. Points on the horizon line are known as *vanishing points*.

(d) It is a fundamental property of perspective projection that a line in one plane projects as a line in the other plane, the two lines meeting at the axis of homology.

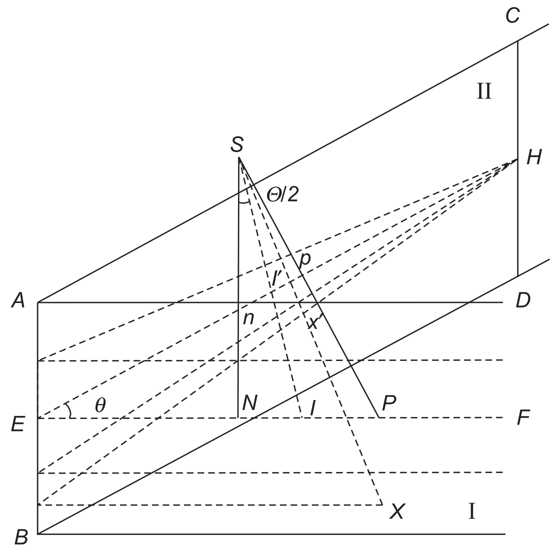


Fig. 1.8 *Geometry of tilted aerial photograph*

(e) A plane which is perpendicular to both the planes and passes through the perspective center and normal to axis of homology is known as *principal plane*. The lines of intersection of this plane with the two planes are known as *principal lines*. *EF* and *EH* are principal lines.

(f) The angle 'θ' between the principal lines in the principal plane is the angle between the perspective planes. When this angle 'θ' is equal to 0, the plane II can be considered as a vertical photograph. In normal vertical photography, this angle seldom exceeds a couple of degrees.

(g) All images of parallel lines converge to a vanishing point. Thus images of all lines parallel to the principal lines in the object plane will converge to a vanishing point '*H*'.

(h) *SN* and *SP* are the perpendiculars from *S* on to the planes I and II respectively. The angle PSN is known as tilt of the camera axis or simply *tilt*. The line bisecting the angle PSN meets the principal line of plane I and II in I′ and I. These are called *isocenters*. There are two isocenters but only one will appear on the photograph. One of the most important properties of the isocentre is that angles measured at I′ in plane I are the same as corresponding angles measured at I in plane II.

(i) Any point in plane I such as *X* has a corresponding position *X*′ in plane II. Such pairs are called *homologous points*.

(j) If two planes are projectively related, as in Fig. 1.9, certain important relationship exists between the corresponding details in planes I and II.

Lines $O'1$, $O'2$, $O'3$ and $O'4$, on plane II, are the images of lines $O1$, $O2$, $O3$ and $O4$ in plane I. Let there be another line in plane I which cuts the lines $O1$, $O2$ etc. in 1′, 2′, 3′ and 4′ then it can be shown that

$$\frac{12/13}{24/34} = \frac{1'2'/1'3'}{2'4'/3'4'} = r$$

This ratio is known as the enharmonic ratio of the four distances, because of the constancy of the ratio a unique position can be found for this line in plane II, so that 1′ falls on line $O'1$, 2′ falls on line $O'2$ and so on. This property is used in graphical rectification.

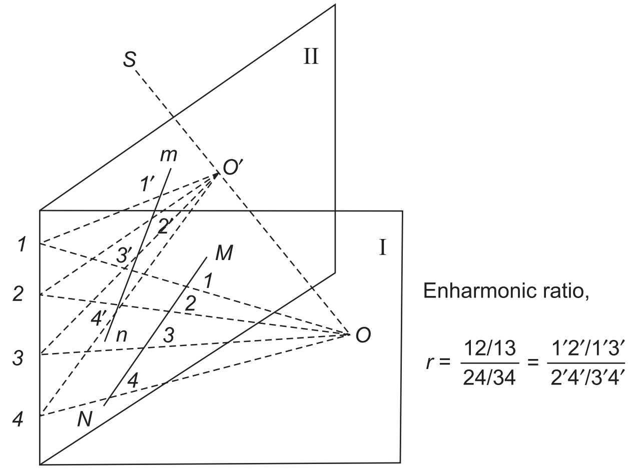


Fig. 1.9 *Enharmonic ratio*

1.3.3 Definitions of Terms

Since aerial photograph is a perspective projection, the definitions and concepts enumerated above apply to it as well. The terms, related to aerial photography, are as follows:

(a) **Perspective Center:** The lens of the camera can be taken as the perspective center. Normally two perspective centers are associated with an aerial camera, external perspective center (inner nodal point) and internal perspective center (outer nodal point) (Fig. 1.10).

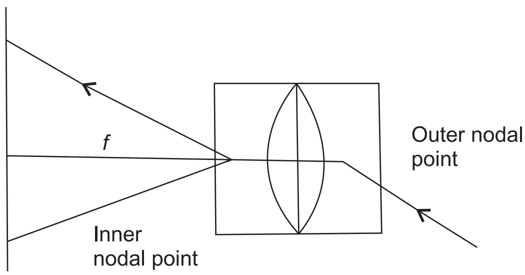


Fig. 1.10 *Nodal points*

(b) Perpendicular from the perspective centre to the ground intersects the ground at a point, which is known as *ground plumb point*. Its intersection with the photograph is termed as *photo plumb point*. In Fig. 1.8 they are ‘*N*’ and ‘*n*’ respectively.

(c) Perpendicular from the perspective center to the photograph intersects the photograph at *Principal point*. The length of this intercept, *Sp* (Fig. 1.11), is equal to the *Principal distance*, and is also referred as *focal length*.

(d) **Tilt** is the angle between the ground plane and photo plane. It can be resolved in two components; one in the direction of flight and the other at right angles to it. The direction of flight is normally taken as X and a direction perpendicular to it as Y.

(i) The component about the Y axis and along the direction of X axis is known as phi (φ) tilt or X-tilt or fore and aft tilts, tip or pitch.

(ii) The component about the X-axis and along the direction of Y-axis is known as Omega (ω) tilt or Y-tilt, lateral tilt or roll.

(iii) Rotation about Z axis, in X-Y plane, is known as kappa (κ) or crab.

(e) The bisector of tilt angle when meets ground plane (at I) and positive plane (at I') are called *isocenters* (Fig. 1.11). As mentioned earlier, the angles (directions) measured at the ground isocentre (I) are the same at photo isocentre (I'), if ground plane is flat. It is an important property used in preparing base maps.

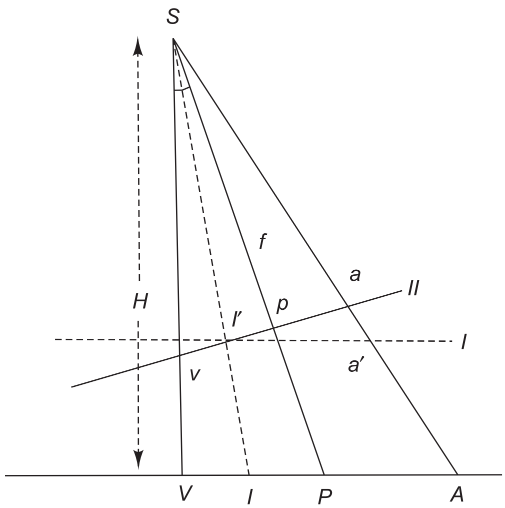


Fig. 1.11 *Homologous points*

(f) All horizontal lines parallel to the horizon line or axis of homology are termed as *plate parallel*. Thus in Fig. 1.8 all lines parallel to CD are plate parallels. The scale along a particular plate parallel is uniform. The scale along axis of homology (AB) is 1 : 1 and along line of horizon (CD) is 1 : ∞ (hence, vanishing line). The scale factors along all other plate parallels are between 1 and ∞.

(g) **Scale of Photograph:** In case of truly vertical photograph of a flat terrain, scale of photograph = f/H where f is the principal distance (focal length of aerial camera) and H is the flying height above mean terrain level. In case of tilted photograph, the scale is not constant. It is constant along any particular plate parallel but varies in different plate parallels.

(h) The plate parallel which passes through the principal point is defined as *axis of tilt*. In Fig. 1.8, a line in plane II parallel to CD and passing through p is the axis of tilt.

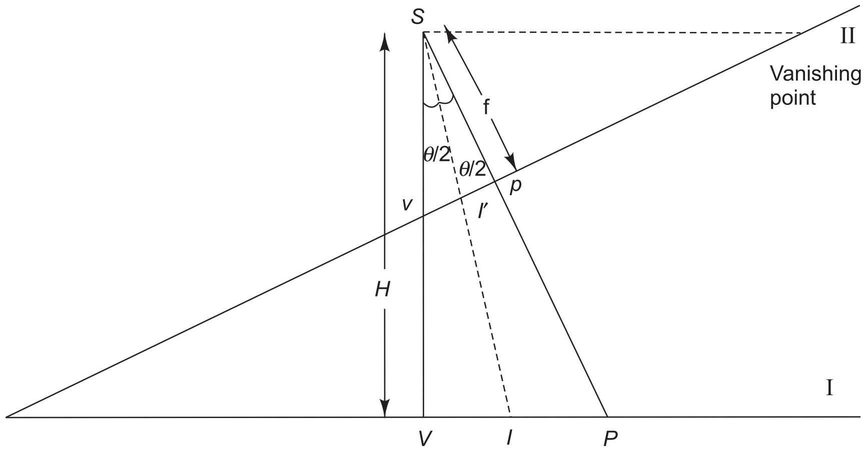
(i) **Isometric Parallel:** The plate parallel passing through the isocentre I' is termed as isometric parallel. It can be proved that this is the only plate parallel along which the scale is = f/H i.e. the same as in the case of vertical photograph (refer derivation and Fig. 1.12).

1.4 IMAGE DISPLACEMENTS

There are two types of image displacements; due to relief variation of the terrain and due to tilt of the photographs. These are dealt below in more details.

1.4.1 Image Displacement due to Relief

Let 'S' be a camera station from which a truly vertical photograph is taken. (Fig. 1.13). It will be seen that if the point P_1 has no elevation, it will photograph at P' but if it has an elevation 'h' then it will photograph at P'' i.e. the image will appear displaced by $P'P''$. This is known



Scale at v (Nadir point) $= \dfrac{Sv}{SV} = \dfrac{f \sec \theta}{H} = f / H \cos \theta$

Scale at i (Isocentre) $= \dfrac{SI'}{SI} = \dfrac{f \sec \theta/2}{H \sec \theta/2} = f / H$

Scale at p (Principal point) $= \dfrac{Sp}{SP} = f / H \sec \theta = f \cos \theta / H$

Fig. 1.12 *Scales at different plate parallels*

as relief displacement. It can be shown that its magnitude is equal to $N'P''.\ h/H$ and that it is radial from the plumb point (refer derivation and Fig. 1.13).

1.4.2 Image Displacement due to Tilt

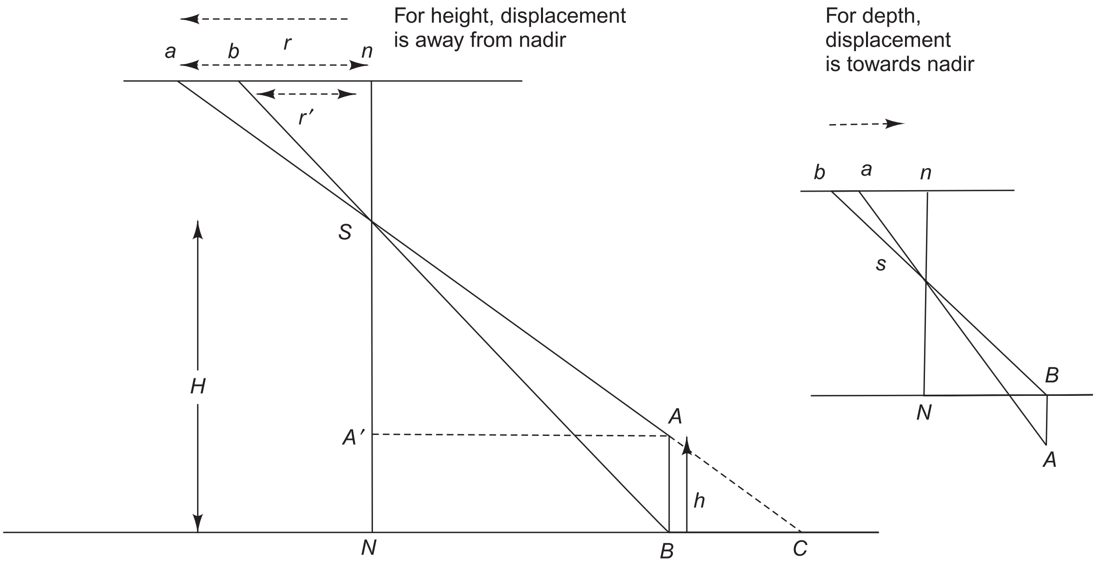
(a) For flat terrain—Let S, in Fig 1.11, be the perspective center and I and II be the positive plains for a truly vertical and tilted photograph, respectively. The figure shows a cross-section in the principal plain, for a point 'A' which appears at (a') in plane I and at (a) in plane II, the displacement is equal to $i'a' - i'a$. It can be shown that the tilt displacement is equal to $ia^2 .\ \sin \theta / f - ia \sin \theta$. The displacement is radial from the isocentre (refer derivation and Fig. 1.14).

When the point b' is non-axial in plane I and the line ib' makes an angle ∅ with the principal line then the tilt displacement, which is still radial from the isocentre, can be shown to be equal to

$$ib' - ib = \frac{ib^2 .\sin \Theta \,.\cos \varnothing}{f - ib \sin \Theta \cos \varnothing}$$

(refer derivation and Fig. 1.15).

(b) For accidented terrain—We have seen that displacement due to relief is radial from the plumb point. The displacement due to tilt, in case of flat terrain, is radial from the isocentre. There is, however, no such point on the photograph where angles are true to the corresponding angles on the ground in case of accidented terrain i.e. terrain having elevation differences (refer Fig. 1.16).



The relief displacement of $A\,B = a\,b$

The triangles $a\,b\,s$ and $S\,B\,C$ are similar, hence $\dfrac{a\,b}{B\,C} = \dfrac{a\,S}{S\,C}$ ---------------- (I)

and $\dfrac{a\,b}{B\,C} = \dfrac{b\,S}{S\,B}$ -- (II)

By considering similar triangles $a\,n\,S$ and $S\,N\,C$

$$\frac{a\,S}{S\,C} = \frac{a\,n}{N\,C} = r\,/\,N\,C$$

Substituting the value of $\dfrac{a\,S}{S\,C}$ in equation (I) we get

$$\frac{a\,b}{B\,C} = r\,/\,N\,C \qquad \text{Or } a\,b = r\,.\,\frac{B\,C}{N\,C}$$

Now by similar triangles $A\,B\,C$ and $S\,N\,C$, we have

$$\frac{B\,C}{N\,C} = h\,/\,H \qquad \text{hence } a\,b = r\,.\,h\,/\,H \qquad \text{---} \quad (1)$$

Considering the (II) case with triangles $b\,n\,S$ and $S\,B\,N$

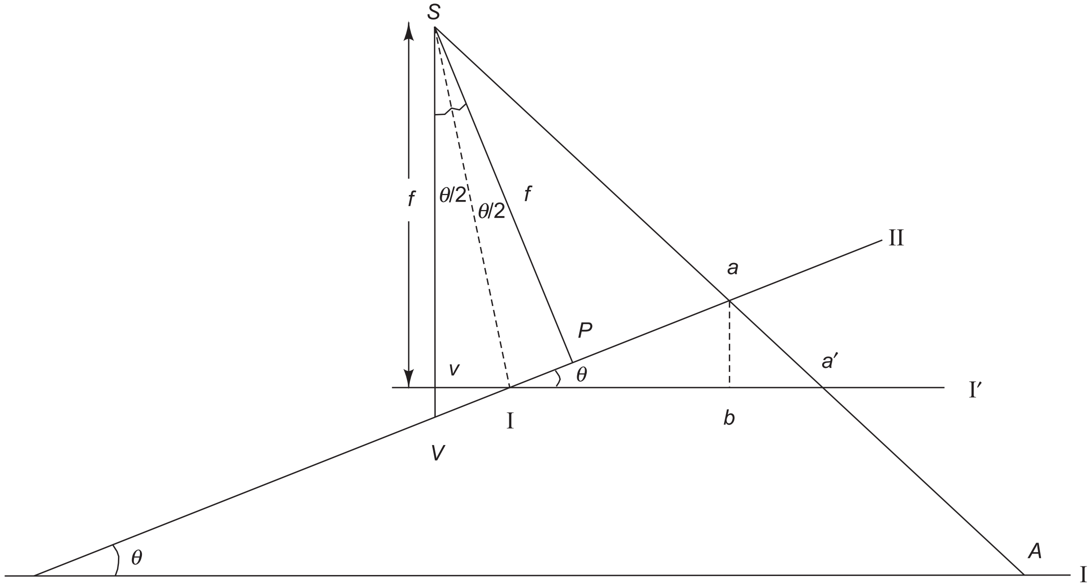
$$\frac{b\,S}{S\,B} = \frac{b\,n}{N\,B} = r'\,/\,A\,A' \qquad \text{hence } a\,b = B\,C\,.\,\frac{b\,S}{S\,B} = B\,C\,.\,r'\,/\,A\,A'$$

By similar triangles $A\,B\,C$ and $S\,A'\,A$, we have

$$\frac{B\,C}{A\,A'} = h\,/\,H - h, \quad \text{hence } a\,b = r'\,.\,h\,/\,H - h \qquad \text{------------------------------------} \quad (2)$$

Relief displacements are radial to nadir point or photo-plumb point or Principal point (in case of vertical aerial photograph)

Fig. 1.13 *Relief displacement*



Tilt displacement = $I a' - I a$, where $I a' = va' - v I$ ------------------------------- (1)

From similar triangles $S\, v\, a'$ and $a\, b\, a'$,

$$\frac{v\,a'}{f} = \frac{b\,a'}{a\,b} = \frac{I a' - I b}{I a \sin\theta} = \frac{I a' - I a\cos\theta}{I a \sin\theta}$$

Therefore $v\,a' = f.\ \dfrac{I a' - I a\cos\theta}{I a \sin\theta}$ --- (2)

Now from triangle $v\, I\, V$, $\cot\theta = \dfrac{v\,I}{v\,V}$ or $v\,I = v\,V \cot\theta$

From triangle $S\,V\,P$, we have $f + v\,V = f\sec\theta$ or $v\,V = f(\sec\theta - 1)$

Hence, $v\,I = f(\sec\theta - 1)\cot\theta$ --- (3)

Substituting the values of $v\,a'$ and $v\,I$ from equations (2) and (3), we have

$$I a' = f.\ \frac{I a' - I a\cos\theta}{I a\sin\theta} - f(\sec\theta - 1).\ \frac{\cos\theta}{\sin\theta}$$

$$= f\ (I a' - I a\cos\theta - I a + I a\cos\theta)\,/\,I a\sin\theta$$

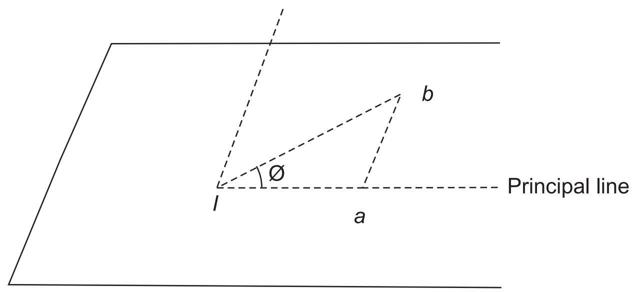
$$= f.\ (I a' - I a)\,/\,I a\sin\theta$$

Therefore, tilt displacement = $I a' - I a = f.\ \dfrac{(I a' - I a)}{I a\sin\theta} - I a$

Or $(I a' - I a)\,(1 - f\,/\,I a\sin\theta) = - I a$

Or $I a' - I a = \dfrac{I a^2 \sin\theta}{f - I a\sin\theta}$ **The tilt displacement is radial to isocentre**

Fig. 1.14 *Tilt displacement*



In non-axial case, the point is at *b*, making an angle Ø with principal line

The position of *b* can be resolved along the principal line as

$$\text{I}\,a = \text{I}\,b \cos Ø \quad \text{and likewise,}$$

$$\text{I}\,a' = \text{I}\,b' \cos Ø$$

Substituting the values of I *a* and I *a′* in tilt displacement equation, we get

$$\text{I}\,a' - \text{I}\,a = (\text{I}\,b' - \text{I}\,b)\cos Ø = \frac{\text{I}\,b^2 \sin\theta \cos^2 Ø}{f - \text{I}\,b \sin\theta \cos Ø}$$

$$\text{or } \text{I}\,b' - \text{I}\,b \text{ (net tilt displacement)} = \frac{\text{I}\,b^2 \sin\theta \cos Ø}{f - \text{I}\,b \sin\theta \cos Ø}$$

The displacement is still radial to isocentre

Fig. 1.15 *Tilt displacement in non-axial case*

1.5 COMPARISON OF AERIAL PHOTOGRAPH AND MAP

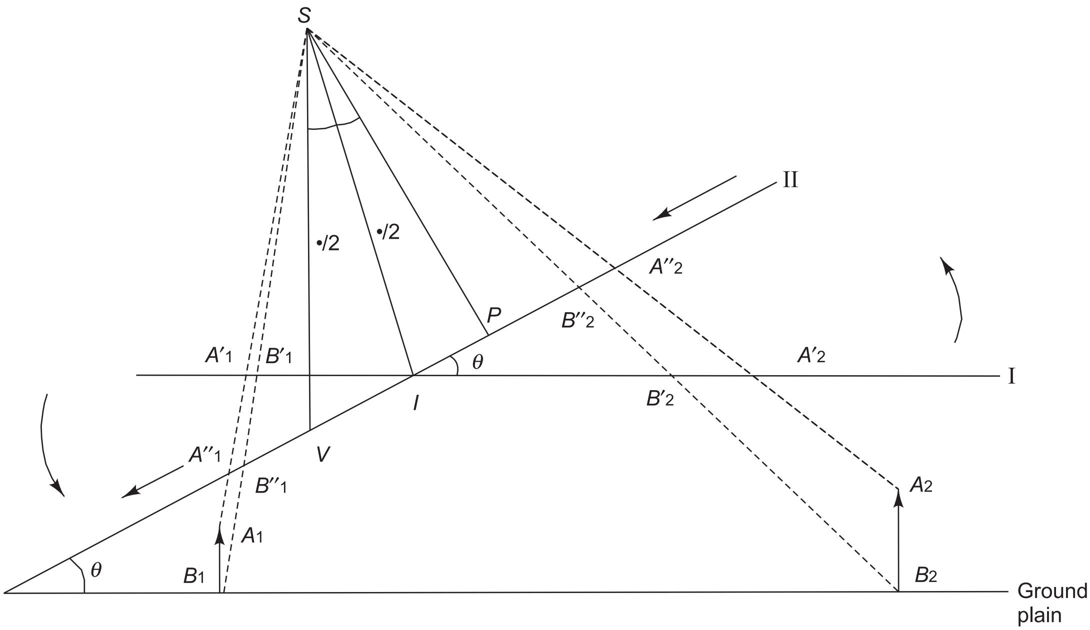
We shall hereafter deal with near-vertical photographs only, unless mentioned otherwise.

1.5.1 Production

Photographs provide fast and economical method of obtaining information about areas of interest. It does not involve extensive field work and as such it is a boon for difficult or inaccessible terrains.

The situation of the terrain, at a particular moment, is faithfully recorded on the photograph. The study can follow after the event, for example landslide, earthquake, flood, etc. Map making is laborious and time consuming process and involves extensive field work on the ground.

Enlarging or reducing coloured maps implicates redrawing; while the same is done easily for air photos for immediate use.



There are two objects, $A1\ B1$ and $A2\ B2$ on the ground plain.

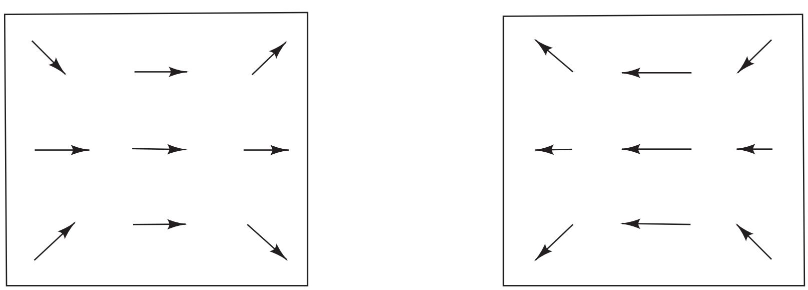
Their images on tilted positive plain (II) are $A''1\ B''1$ and $A''2\ B''2$ respectively.

An enlargement takes place on the lower side of isometric parallel, hence the image moves radially outward from the isocentre, due to tilt.

A reduction takes place for the objects on the higher side of isometric parallel and the image movement is radially inward, as shown in above figure.

In case of clockwise tilt movement, the effect will be reversed.

The image movement in both the cases are depicted below:



Clockwise tilt   Anticlockwise tilt

Fig. 1.16 *Displacement in accidented terrain*

1.5.2 Content

A map shows an abstract representation of the surface, with a selection from the nearly infinite number of features of the photograph. An air photograph shows the real structure of the earth's surface.

Maps often represent both quantitative and qualitative non-visible features (contours, spot height, lithology, etc.). Text on map is indispensable for its interpretation; while the same on aerial photographs (geographical names) reduces the value of the photo for interpretation.

Special films e.g. different types of colour films or infra red films can bring out some special features of the terrain and its culture, which can be of considerable use.

1.5.3 Planimetric Accuracy

A map is a geometrically correct representation of the terrain, while an air photo is generally not so. The map gives an orthogonal projection of the three-dimensional terrain; the air photo gives a central projection.

Due to the central projection, photographs of terrain, having height differences, show relief displacement.

The error in the photographs caused by tilt of the optical axis is called tilt displacement. These errors in case of flat terrain are radial from the isocentre. Tilt displacement can be eliminated by rectification of the photograph.

A map has the same scale throughout the sheet. The photograph normally has varying scales.

Maps on the same scale can be obtained in a series but not so with the photographs. Normally, the bearings are also not true on the photographs.

1.5.4 Training Requirement

The map is prepared with an eye to facilitate its use and understanding by ensuring that it is not over crowded. Symbolization, generalization, proper realistic colour scheme and well placed annotations ensure that the contents are understood as easily as possible. A little training and familiarity with the particular legend used in the map enables proper use to be made of the map.

A photograph on the other hand is an unedited faithful record of all the details subject to the limitation of dead ground, light condition, resolving power of the lens and the quality of the printing paper. Though initially it may, by virtue of its realistic portrayal of the earth's surface, appear to be easy to understand, in fact it is not so. To enable the user to derive sufficient benefit, photo reading requires special training in photo-interpretation. It is an interesting technique; the more one understands the photograph and gains experience in its use, better would be the content of information derived from the study of photographs.

Suggestions for Further Reading

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Frequently Asked Questions

1. What are different types of aerial photographs?
2. How Low and High Oblique photographs differ?
3. Highlight the differences between Convergent and Trimetrogon photographs.
4. What are the advantages and disadvantages of Terrestrial Photography?
5. Define the terms: Axis of Homology; Horizon Line; Vanishing Points; Principal Point; Nodal points; Homologous points; Enharmonic Ratio; Isocenters; Tilt.
6. Write short notes on: Scale of Photograph; Plate Parallel; Principal distance.
7. Derive scales at different Plate parallels in a tilted photograph.
8. Find out the displacement due to relief.
9. Find out the displacement due to tilt.
10. Compare Aerial Photograph and Map.

2

AERIAL PHOTOGRAPHY

2.1 INTRODUCTION

Aerial photography, by definition, is technique of acquiring photographs from air for studying surface of the earth. Aerial photography provides pictorial representation of an area in the form of photograph and mosaic. Aerial photographs play an important role in photogrammetric survey for preparing base maps and in photo-interpretation for natural resources. In almost all surveys for natural resources, aerial photographs are used as basic material and tool, which need to be used in appropriate manner.

Aerial photography provides a faithful reproduction of terrain, unbroken continuity of its tonal relationships and its meticulous rendering of minute details. The aerial photograph is the end result of the combined scientific and productive skills of the camera and optical lens; photographic materials; type of aircraft and its navigator; camera operator and photo-laboratory workers.

Due to advent of high resolution satellite imagery (Ikonos, 1 m; QuickBird, 0.68 m; Cartosat-2, 0.58 m, etc.), dependence on aerial photography, for preparation of maps, is much less now a days. However, basic considerations for acquiring aerial photographs are still useful in selecting satellite imagery used in specific thematic surveys.

2.1.1 Factors Influencing Aerial Photography

There are many links in the chain of image formation and lack of care at any stage may degrade the image quality. A constant emphasis on the need of having the best possible quality of the photograph is essential at all stages.

Production of aerial photographs can be divided in to three distinct activities, viz. the photographic flight mission, processing of aerial film negatives and production of photographic prints or diapositives. These activities significantly contribute towards the final image quality and success of photo-interpretation. Good resolution in aerial photography is dependent on a large number of factors, hence care at all stages is essential. Different stages involved in aerial photography and production of photographic prints are illustrated by a flow chart (Fig. 2.1).

(Flight mission)
Survey aircraft
|
Pilot and navigator
|
Flight planning and flight map
|
Aerial camera and its suspension
|
Actual flight
|
Sun illuminated terrain – Atmosphere - Camera lens - filter, etc.
|
Light sensitive emulsion on aerial film or glass plate
|
Exposure
|
(Processing of Aerial Film Negative)
Formation of latent image
|
Development – fixing – washing of negative
|
Drying of negative
|
Aerial negative
|
(Printing)
Contact/Projection printer
|
Light sensitive emulsion on paper/film/glass plate
|
Exposure
|
Developing – fixing – washing
|
Drying
|
Photographic paper prints or diapositives on film/glass plate

Fig. 2.1 *Flow chart showing various stages in production of aerial photograph*

Aerial photography in India is controlled and coordinated by Survey of India and is flown by a flying agency. Once the scale and type of photography are indicated, the Survey of India designs the photographic specifications and places the order for photography on one of the three flying agencies, viz. Indian Air Force, M/s Air Survey Company (Private) Ltd. Dum Dum and National Remote Sensing Centre, Hyderabad. The flying agency is responsible for flying the photographic task and supply of photographic prints and enlargements.

2.2 SPECIFICATIONS FOR AERIAL PHOTOGRAPHY

Before aerial photography is executed to provide suitable photographic coverage of an area, careful consideration must be given to several factors which will affect the design of flight specifications. The basic considerations are: area to be photographed, purpose, scale and type of photography, aerial camera and lens, flight directions, and time and season of photography.

2.2.1 Area to be Photographed

The area to be photographed is to be specified clearly. The limits of the area are marked on published ¼ inch or 1:250,000 scale maps, by lines drawn north, south, east and west, enclosing the area. If the area is too large, it may be divided into smaller blocks, marked Region A, B or C.

2.2.2 Purpose of Photography

The purpose for which the photography is being ordered should be stated as it helps in correct designing of photographic specifications.

2.2.3 Scale of Photography

The scale of photography used for studies of natural resources varies from1:5,000 to 1:50,000, depending on the purpose of study. The two most common scales which are likely to meet the requirements, under Indian working conditions, are 1:50.000 and 1:25,000. However, the scale of required photography should be specified.

2.2.4 Type of Photography

Vertical aerial photographs are generally used for photo-interpretation. Oblique or convergent photography is rarely used for this purpose. Different types of photograph used for interpretation purposes are: black and white, infra-red and colour. Generally B & W photographs are used. The requirement of photography should be clearly stated, considering its intended use.

2.2.5 Aerial Camera and Lens

In order to extract maximum information from aerial photographs, the image quality should be of highest order. To meet this requirement, modern distortion-free and high resolving power aerial cameras, such as Wild RC 5(a), Wild RC 8 or Zeiss RMK 11.5/18 or RMK 15/23 or RMK 21/18 should be used and should, therefore, be specified by the indenter. The lenses available in India are of focal lengths 11.5 cm (wide angle), 15 cm (wide angle) and 21 cm (normal angle), which should, preferably, be specified by the indenter, while asking for aerial photography.

2.2.6 Flight Directions

Aerial photography is flown in strips to cover the designated area. For convenience in handling, it is advisable to keep the number of strips to the minimum. The flight direction of the strip, therefore, kept along the length of the area. This direction, which may be east-west, north-south or any other direction, along any particular natural feature, should be clearly stated.

2.2.7 Time of Photography

Time of photography is very important as long and deep shadows tend to obscure details whereas small shadows tend to delineate some detail effectively and are generally advantageous in improving the interpretational value of the photograph. Based on experience, the following times of photography are recommended:

(a) Aerial photography should be taken during those periods when the sun's elevation above the horizon is more than 30°, or

(b) Aerial photography should be taken during period 3 hours before noon to 3 hours after mid-day (12 o'clock).

(c) Aerial photography should be taken between 08:00 and 10:00 hrs in the morning and between 14:00 and 16:00 hrs in the afternoon.

While the intender should specify the time he prefers, these limitations should be set only to prevent the quality of aerial photography from being seriously impaired. In Aerial photography of hilly areas, taken before the sun attains elevation of 30° above the horizon, the shadows are generally too long and dark and cover important terrain details. In flat and plain areas, where occurrence of shadow is not of great importance, the time of photography may be relaxed to the time of the day when the sun's elevation above the horizon is more than 20°.

In the tropics, one of the main difficulties is the occurrence of atmospheric haze as soon as the temperature rises after the sunrise. It is then necessary to limit the photography time between one and half hour to three hours after sunrise.

Another limitation which occurs frequently in tropical areas is the reciprocal reflection of the sun by the prevailing haze. This glare floods practically all terrain details. In such cases, the time of photography should be limited to between the sun's elevation of 30° and 60° above the horizon.

In mountainous areas the time of photography should be limited to a period around noon.

2.2.8 Season of Photography

The choice of the most suitable season for aerial photography depends on various factors, viz.:

(a) seasonal variation in light reflection

(b) seasonal change in the vegetation cover, and

(c) seasonal change in climatic factors

In the tropical countries, cloud formation during the wet monsoon or rainy season is a serious hindrance. On the other hand, a heat haze or dust layer is often developed in the tropics during the dry season, particularly during the summer. Tropical jungle areas are difficult to be photographed during the monsoon due to the formation of a humid haze as a result of the evaporation of moisture from the vegetation.

The purpose of aerial photography also dictates the season of photography to a great extent. For photogrammetric, geological and soil survey purposes, the ground should be visible as clearly as possible. In forested areas such a time will be when the trees shed their leaves. In higher latitude and altitude areas, the melting of snow cover has to be awaited. The soil should preferably be without standing crop cover. Thus for these purposes, early spring to beginning of summer is most suitable.

The density of the canopy and full foliage of tree crowns are important aspects for use of aerial photographs for forest inventory purposes. For the landuse and cropping pattern studies, it is preferable to have photography when the crops are standing. Photography for forestry purposes and for landuse mapping should, therefore, preferably be taken later in the year, from the end of rainy season to the beginning of winter.

2.2.9 Type and Number of Prints

The number of photographic prints and the type of print required by the photo-interpreter i.e. whether glossy, matt or semi-matt and on single weight or double weight paper should be clearly stated while requesting for aerial photography. Normally the costs of supply of two sets of photographic prints and two sets of photo-indexes are included in the cost of photography.

2.3 PLANNING OF PHOTOGRAPHIC FLIGHTS

After all the relevant information regarding the aerial photography has been obtained, the photographic flying mission has to be carefully planned. The fundamental requirement of flight planning is to obtain adequate stereoscopic coverage with the least number of pictures consistent with the desired accuracy. The main factors affecting flight planning are selection of aerial camera, flight altitude, forward overlap, lateral overlap, flight plan, selection of aircraft, aerial film and navigation instruments. These will be discussed in this section.

2.3.1 Selection of Aerial Camera

If the aerial camera and focal length of the lens have already been specified by the indenter, these should be used. If not, the focal length of the lens and aerial camera are to be decided by Survey of India who are responsible for designing of photographic specifications. Aerial cameras may have different format size viz. 23 cm x 23 cm or 18 cm x 18 cm. For reasons of economy, larger format size should be used as far as possible.

2.3.2 Flight Altitude

The scale of aerial photographs is defined as the ratio of focal length (f) and the flying height (H) or f/H. This has to be indicated by the indenter. Thus the photo-scale over an area is constant only when H or the flying height above mean ground level is constant. Also the height of ground level should be constant. Usually in nature, there are altitude variations in the terrain and, therefore, the scale also varies from photo to photo or even within the photograph. Thus the given photo-scale is only the mean scale which is designed to be achieved by computing flying height above mean ground level. If the height of mean ground level above mean sea level (msl) is h and the ceiling height of the aircraft, which is maximum altitude above msl, at which the aircraft can fly, is C_h, then maximum flying height above mean ground level H is given by $H = C_h - h$. This (H) is important for the pilot as he has to maintain the height of the aircraft at this level.

2.3.3 Scale Variation

As explained earlier, the photo-scale is not constant over the entire area. It is also difficult to keep the flying height constant. The determined flying height can be held within plus minus 50 feet (20 m), while the flight is in progress. Actual flying height shall generally be within plus minus 2% or 200 feet (60 m) of the computed height.

Alternatively, it is possible to maintain a near constant photo-scale over an area with terrain height variations, by computing different flying heights for each strip. The constant photo-scale is more important for preparation of semi-controlled photo-mosaic. If photo-scale is kept constant, scaling of individual photograph by means of photographic enlargers or rectifiers can be avoided, while preparing semi-controlled photo-mosaic.

The flying height is determined by means of flight altimeters that are accurately calibrated to international standard atmosphere. This calibration has to be carried out periodically on the test bench and has to be repeated during flight. The indicated altitude must be corrected for variations in pressure and temperature with altitude.

2.3.4 Data in Flight Report

For purpose of checking the scale, the following important data mentioned in the flight report are used.

(a) Altimeter calibration data
(b) Sea level or aerodrome level pressure at take-off
(c) Sea level or aerodrome level pressure at landing
(d) Sea level pressure used at the survey area
(e) Corrected outside air temperature (COAT) for every 1000 feet (300 m)
(f) Instrument's installation errors calibrated for the flying height
(g) Indicated or calculated flight altitude or flying height
(h) Required true altitude

2.3.5 Forward Overlap

For stereoscopic viewing, there should be certain amount of overlap between two consecutive photographs. In an average terrain, the overlap along flight direction or forward overlap is taken to be 60% (plus minus 5%). In no case, however, the forward overlap between two consecutive photographs should be less than 53%. Also the forward overlap between photographs No. 1, 3, 5, etc. should not be less than 6% at the highest point.

Other forward overlap percentages can be specified if special requirements are to be fulfilled. In case of block photography where saving in ground control is envisaged, an overlap of 80% to 90% is used. Suitable photographs having matching edges with adjacent strip and also having 60% overlap among the photographs of same strip, are chosen for actual work.

Where the end of the strips of one block overlaps the end of strips of another block, the overlap should be at least 3 but preferably 6 photographs. This is necessary to make use of the control points of the existing photography for the new photography.

The above recommendations are for all normal cases. However, for mountainous terrain with large relief variations, the tolerance of plus minus 5% over the minimum overlap of 53%, may not be sufficient. It is safer to have forward overlap between 60% and 65%, in such cases.

2.3.6 Lateral Overlap

The lateral overlap between strips should be sufficient to provide common details and to allow for the lateral tilts and slight deviations from course along the length of the strip. In general, for reasons of economy, lateral or side overlap of 20% of the photo- format is being specified, allowing 5% for navigational uncertainties and 5% for small terrain height differences. In terrain with relief variation not more than 5% of flying height, lateral overlap may be specified as 20% plus/minus 10% of the photo-format size. This results in a maximum value of 30% and minimum value of 10% lateral overlap.

The effect of relief in mountainous terrain results in cut in the effective coverage due to larger scale of photography at the hill top as compared to the valleys. Therefore, adequate provision should be made for relief at the planning stage. Based on past experience in the Himalayas, it has been found that a lateral overlap of 35% caters to the requirement in these areas. In mountainous areas, the specification for lateral overlap may be given as 20% plus/minus 10% + relief percentage;

where relief percentage = extreme difference in ground height × 100/height of aircraft above lowest ground level.

2.3.7 Selection of Aircraft

The selection of aircraft is done by the flying agency. Two factors, required to be considered for the selection, are ceiling height of the aircraft and its flying range. The aircraft should have requisite speed, a high rate of climb, good stability while in flight and unobstructed view in all directions for ease of navigation. It should have ceiling height equal to or higher than the highest flying altitude specified. It should be able to remain in the air long enough to take suitable photographic time, roomy enough to accommodate all necessary equipments and powerful enough to carry its full load to the maximum flying height specified.

2.3.8 Navigation Instruments and Crew

If any navigation instruments like Radar or Decca navigator are being used, these should be checked before installation. All the spare magazines should be checked. Aerial camera and viewfinder should also be checked for satisfactory operation.

The photographic crew i.e. the pilot and aerial photographer-cum-navigator should be well qualified for the photographic task assigned to them.

2.3.9 Aerial Film

A fine-grain emulsion aerial film manufactured by any of the established manufacturers e.g. Agfa, Gaevert, Ilford, Kodak, Indu, etc. should be used.

2.3.10 Flight Instruments and Aircraft Calibration

According to the International Civil Aviation Organization (ICAO) standards, the flight instruments shall be calibrated at least once in 18 months. This applies in particular to the barometric altimeter, temperature gauge, radar altimeter and for any other available scale or reference system like magnetic compass and direction gyro. This calibration shall consist of individual calibration of each instrument and of a calibration of the total instruments system in flight, in order to determine and to correct for installation errors and for operational performance errors.

2.4 EXECUTION OF FLIGHT

After finalization of flight planning, actual flight takes place. In execution of flight, a number of factors, viz. weather conditions, time of photography, straightness of flight lines, verticality of camera axis, occurrences of clouds, avoidance of crab, water surfaces and gaps are to be considered.

2.4.1 Flight Lines

Particular care should be exercised to keep all flight lines as straight and as nearly parallel as possible. Unless specified to the contrary, all photographic strips shall be flown within 5^o of the given cardinal direction. The main bearings of adjacent strips shall be within 5^o parallel. The maximum horizontal departure of any of the terrain nadir or photo-nadir point from the representative flight line shall not exceed 25% of the local flight height above terrain.

The above specifications are suitable for medium and small scale photography over large areas, where no reasonable map coverage exists. In more developed areas and for large scale photography, stricter specification is necessary. In such cases, the maximum horizontal departure of any of photo-nadir or terrain nadir shall not exceed 15% of the minimum flight altitude above terrain. For a 23 cm × 23 cm format and 15 cm wide angle photography, the above specifications correspond to a flight line positioning within 10% of lateral overlap. For long flight lines in medium or small scale photography, this specification can be adhered to only if the navigation visibility over the area is very good and if the terrain is not mountainous.

2.4.2 Crab

Crab occurs when the edges of consecutive photographs are not parallel to the air base line. This condition is caused by failure to orient the camera with respect to the track of the airplane. Normally, crab of any series of two or more consecutive photographs shall not exceed 3° or 10 mm on photograph. This requirement can be fulfilled for vertical photography taken with cameras having completely rectangular frame. For cameras having fiducial marks in the corners, the crab has to be limited to avoid lack of stereoscopic coverage in the corners where minor control points are selected for aerial triangulation. For general cases, any series of two or more photographs crabbed in excess of 10%, as measured from the line of flight, may be considered unsatisfactory and may cause rejection of that strip or part thereof.

2.4.3 Verticality

For vertical photography, special care should be taken to reduce tilt of the camera axis to a minimum. The maximum tilt shall not exceed 4° and shall not average more than 2° in any 10 mile section of the flight line. Relative tilt between any two successive negatives should be within 6°. If any photography is well flown, using a proper survey aircraft and good camera mount, guided by an auto pilot, tilts more than 2° will not normally occur. An exception can, however, be made for large scale photography where the turbulence over hilly or patched hot terrain at lower altitudes—particularly below 4,000 feet, may cause sudden roll movement of the aircraft. It may not be possible for the camera operator to correct for these movements instantaneously, resulting in large tilts.

2.4.4 Cloud

Clouds or their shadows tend to obliterate details over which they appear and should be avoided. If clouds are present in the area, care should be taken that single mass of cloud shadow should be limited to 2% of the photographed area and the total amount of clouds on any photograph should not exceed 5%. Where the flight days are limited due to preponderance of clouds, the specifications may be relaxed to 5% for single mass of cloud or cloud shadows and 10% for the total amount of clouds on any photograph. Clouds or cloud shadows should not lie over a principal point or its homologue on the two adjacent photographs; neither should they prevent stereoscopic coverage and point transfer in the lateral overlap area where minor control points are to be established for aerial triangulation.

2.4.5 Water Surface

Flight lines should be planned in such a way that no principal point or its homologue on the two adjacent photographs, lie on a water surface. Water surfaces should also be avoided in lateral overlap area, as it affects selection of minor control points for aerial triangulation.

2.4.6 Gap and Re-flight

Any space where aerial photographs fail to provide stereoscopic coverage is called a gap area. Forward overlap should be considered as insufficient if the stereoscopic coverage of the two consecutive photographs is less than 53%. Lateral overlap should be considered insufficient if the stereoscopic coverage of the terrain at any point of the adjoining strip is less than 8% of the photo size, or if it is less than 20 mm, whichever is applicable. In general, the occurrence of gap calls for rejection and re-flight of the complete strip. However, in difficult areas, stereoscopic coverage of only the gap area may be accepted.

When the end of a strip crosses a coast line, the forward overlap should be increased to the maximum, in order to provide greatest chance of two successive principal points near the coast line, falling on the ground.

2.5 AERIAL CAMERAS

2.5.1 Basic Requirements

The most important uses of aerial photographs are for production of base maps and for application of photo-interpretation techniques for natural resource surveys. In order to be useful for the above purposes, aerial photography should fulfill the following requirements:

(a) The photography should provide a faithful image of minutest detail.
(b) The definition of photography should be clear.
(c) The photography should be distortion free and continuous.
(d) The tilts and crabs are within tolerable limits.

2.5.2 Optical Aspects

In order to reduce the effect of movement of camera relative to the ground, the aerial camera should have short exposure time. Also, there is need for bright photography for interpretation purposes. To fulfill these requirements, the aerial cameras should have the following features:

(a) A large relative aperture of the taking lens to produce bright and clear photograph.
(b) The photographs produced are geometrically accurate with high degree of sharpness and good definition over a large angular field.
(c) The camera lens should be free from the following aberrations:
   (i) Spherical Aberration: It occurs when rays from various zones of a lens focus at different places along the axis; these results in an object point being imaged as a blurred circle. It is caused by the spherical shape of the lens. It is decreased as the lens aperture is reduced (Fig. 2.2).

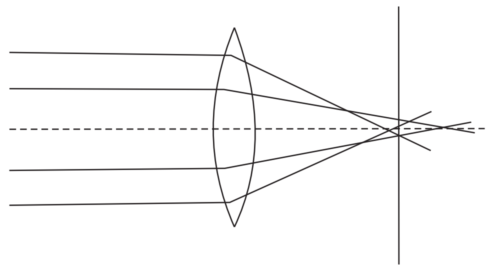

Fig. 2.2 *Spherical aberration*

(ii) Coma: It is a comet shaped blur of light formed around image points off the axis. It is partly due to spherical aberration of oblique rays.

(iii) Astigmatism: It is an aberration which causes a point object off the axis to be imaged as two mutually perpendicular short lines, located at different distances from the lens. One of these is radial and the other tangential with respect to the centre of the field (Fig. 2.3).

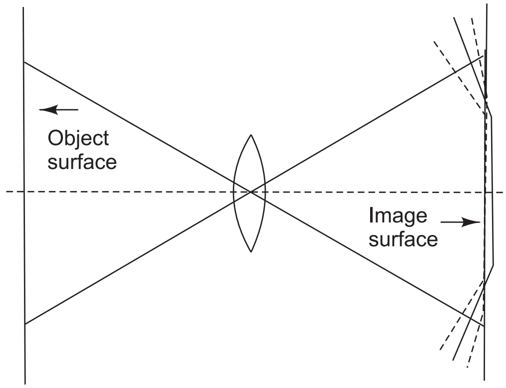

Fig. 2.3 *Astigmatism (dotted curve) and curvature of field (solid curve)*

(iv) Curvature of Field: The surface of best definition is located midway between the two radial and tangential surfaces as explained in (iii) above and its departure from flatness is termed 'curvature of field' (Fig. 2.3).

(v) Chromatic Aberration: It results when rays of various wavelengths of different colours focus at different distances from the lens. Lateral chromatic aberration is a difference in image magnification for various colours caused by chromatic aberration of oblique rays (Fig. 2.4).

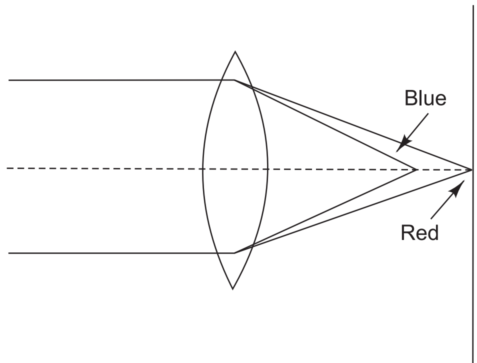

Fig. 2.4 *Chromatic aberration*

(d) The camera lens should be free from lens distortion. Linear lens distortion is the linear displacement of an image point radially to or from the centre of the image field—a positive value is being considered away from the centre. Tangential lens distortion is a small displacement in the image plain perpendicular to radial lines from the centre of the field and is caused by either lack of precision in centering of various lens elements or by improper mounting of the lenses. Due to this distortion a square will be imaged as pin cushion or barrel, since various zones of image correspond to different focal lengths and hence different scales (Fig. 2.5).

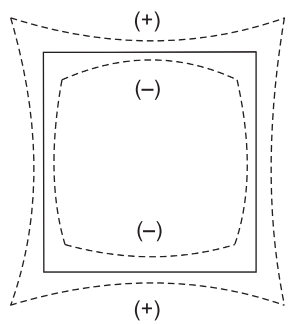

Fig. 2.5 *Effect of lens distortion*

(e) The definition or resolving power of the lens should be good. The definition concerns the ability of a lens to record fine details and can be expressed as maximum number of lines per millimeter that can be seen as separate lines in the image. Normally, a resolving power of 45 lines per mm is considered satisfactory.

2.5.3 Types of Aerial Camera

The aerial camera should be of good quality. Its optical unit holding the lens, fiducial marks and edge which define the focal plane should be a rigid mechanical structure. The main types of vertical cameras are:

(a) Normal or standard-angle camera: It has a lens with an angle of coverage up to 70° and its focal length ranges between 200 mm to 300 mm. The precision of planimetry is highest. Cameras of this type, used in Survey of India, are William Ross Eagle IX – 200 mm and 300 mm (f/5) and Wild RC 5 (a) – 210 mm (f/4.2).

(b) Wide-angle camera: It has a lens with an angle of coverage between 70° and 100° and the focal length between 100 mm to 150 mm. The precision of height measurement is higher. Cameras of this type, used in Survey of India, are Eagle IX – 152 mm (f/5.6) and Wild RC 5 (a) – 115 mm (f/5.6) and Wild RC 8 – 152 mm and 115 mm (f/5.6).

(c) Super wide-angle camera: It has a lens with an angle of coverage greater than 100^{o} and its focal length between 45 mm and 90 mm (f/8). The precision of height measurement is highest.

2.5.4 Components of Aerial Camera

The major components of an aerial camera are; lens, lens cone, shutter and diaphragm, camera body, drive mechanism, film magazine, focal plane and film flattening device.

The lens cone supports the lens and retains it at pre-determined distance and position from the film or plate negative. It serves to exclude direct light from striking the film or plate. The interior of the lens cone shall be black, fitted with baffles to reduce reflection of flare light.

The shutter and diaphragm of an aerial camera functions as a light valve and regulates the amount and period of time that light is permitted to pass through the lens and expose the film or plate. The shutter should be of between-the-lens type.

The film magazine is basically a container of film. It contains a diving mechanism which receives power from the camera drive mechanism and thereby shifts the film after each exposure. In addition, the film magazine contains a devise of holding the film flat at the focal plane, at the time of exposure. The film flattening is usually accomplished by a vacuum system. The locating back has grooves in which there are small holes which lead to a central vacuum connection, thus holds the film firmly against the focal plane frame.

2.5.5 Camera Calibration

The calibration of an aerial camera is considered essential to ensure accuracy of measurements to be made on photographs. The camera calibration consists of determination of calibrated principal distance and distortion characteristic of the camera lens. The accuracy of the calibration procedure, in general, shall be such that the mean error of the measurements is of the order of 1 micron (1/1000 mm). The surface determining the film location shall be flat to the tolerance of plus/minus 0.008 mm from the hypothetical focal plane. The average radial distortion, as measured, shall not depart by more than plus/minus 0.005 mm.

Much larger distortions than these will often occur. They are allowed if it is possible to find another point of symmetry about which the radial distortions are symmetrical to within tolerance limit. Such a point, called 'Principal point of symmetry'.

Lines joining the opposite fiducial marks shall intersect at 90^o within tolerance of plus/minus 1 minute of arc. The filter and the camera port glass shall be plane parallel to such an extent that for collimated light at normal incidence, the deviation produced by the filter or port glass shall not be larger than 5 seconds of arc; the change of deviation from place to place over the area of the filter or port glass shall be within 1 second of arc. The filter and camera port glass shall be kept clean and free from scratches.

2.5.6 Digital Mapping Camera

The digital cameras appeared in early 1970s. It had the same optical system as their analog predecessor but differs primarily in that they do not use film but capture and save photograph on digital memory cards or internal storage devices. It uses solid state charge coupled device (CCD) image sensor chip. By the end of the century, Kodak, Ricoh and Nikon brought Single Lens Reflex (SLR) cameras, with mega pixel sensors, using CCD or CMOS (complementary metal oxide-semiconductor).

Digital Mapping Cameras were developed by leading manufacturers like Intergraph-Zeiss by the turn of the century. Presently the digital mapping camera (DMC) has large format CCD digital aerial frame, high spatial resolution, 12-bit radiometric resolution, and facility for panchromatic as well as 4-band Multispectral scanning. It is also equipped with forward motion compensation. The DMC uses eight individual lenses rather than a single lens. The lenses operate simultaneously and collect color imagery (RGB), colour IR, and black-and-white panchromatic imagery. The DMC incorporates a Flight Management System allowing the aircraft to follow very precise flight lines even in the roughest of conditions. Some of the advantages of Digital Mapping Camera are:

(a) Faster turnaround time
(b) Greatly improved radiometric resolution
(c) Increased accuracy of photogrammetric measurements
(d) Electronic Forward Motion Compensation (FMC) eliminates common flight limitations
(e) Clean digital data delivers better quality image products (orthos)
(f) Increased number of flying days.

2.6 AERIAL FILMS

2.6.1 Choice of Aerial Film

A fine grained, high speed emulsion is required for aerial films, for obtaining finer details and adjusting against the short exposures used in aerial photography to avoid image movement. The aerial film should have a rated resolving power of 50 lines per mm. The aerial film on non-shrinkable topographic safety support base (mostly cellulose acetate butyrate) should be used. The aerial films may be panchromatic, infra-red, or colour infra-red (spectra-zonal). The aerial films in general use are: Aerographic Supper XX, Aerographic Tri-X, Aerographic Infra-red, Ektachrome Aero of Kodak, Aeropan of Agfa, Special Aviphotopan 30 and 33 by Gevaert and Parutz and Pervola by the Ilford Aerofilms. The aerial films are available in lengths of 100, 200, 500 and 1000 feet, the last one being used for reconnaissance photography. However, due to the advent of digital mapping cameras, the use of aerial films is much restricted now.

2.6.2 Choice of Filter

All aerial photographs are taken using filters, which are coloured plates of glass or dyed gelatin between glasses, placed over the camera lens. The filters are generally yellow or red in colour. The function of yellow filter is to absorb blue and violet light so that the photograph is made by green and red lights. It is, therefore, also referred as 'minus blue' filter. The function of red filter is to absorb blue violet and green lights thus confining the exposure to the long wavelengths of the visible spectrum (red and visible infra-red). The main purpose of using filters is to have clear rendering of ground details by atmospheric haze penetration, and for modifying the tones of objects on the ground to have better contrast.

2.6.3 Panchromatic Photography

The panchromatic emulsions are predominantly used in aerial photography. The best compromise between speed and sharpness shall be chosen, depending on the type of camera, light conditions, photo-scale and type of terrain. In general, best choice will be an emulsion of not too high in speed, in order to obtain the smallest possible graininess with short exposure to avoid image movement. The film shall be used in combination with the minus blue filter, the spectral absorption of which shall be about 500 milli-micron wavelength.

2.6.4 Infra-red (B&W) Photography

For infra-red photography, the aerial film emulsion should have infra-red sensitivity. It shall be used in combination with minus blue filter, having spectral absorption up to 500 milli-micron wavelength. The infra-red photography has some advantages and disadvantages over panchromatic photography. Infra-red photography gives better differentiation between coniferous and deciduous trees; the latter gives higher infra-red reflection. Foliage will, in general, be pictured much brighter than on panchromatic film because the infra-red content of its reflection is relatively high due to chlorophyll. Even if species identification is not the main objective of photography, the forests are often reproduced with greater detail and contrast than on panchromatic film. The enhanced contrast thus obtained makes the infra-red photograph more suitable for stereoscopic identification and point transfers for aerial triangulation and determination of minor control points.

Differentiation between water and vegetation is greatly facilitated because vegetation reflects a large proportion of infra-red whereas water and moist soil reflect practically no infra-red light. Water and moist soil appear nearly black in infra-red photography.

A disadvantage of the use of the infra-red film is that it gives a completely different terrain impression than what is observed by human eye. Recognition and identification of features on infra-red photography, therefore, require special training and adaptation. Also, the durability and storage problems of infra-red black and white film are much worse than those of panchromatic film. This somewhat restricts its general use.

2.6.5 Colour Photography

Colour photography has made considerable advances and numerous processes are available for production of transparencies and colour prints. The aero-colour film is a three-layer film and when used it should be combined with suitable filters, chosen appropriate to flying height, haze conditions and film emulsion. Exposure and processing of colour film should be such that the colour production of terrain is as constant as possible.

Aerial photographs in colour are exceedingly attractive to look at and this fact tends to obscure the details. In fact, these may convey no more information than a good black & white photograph, and sometimes even less. The aim of colour photography is to get a faithful reproduction of colour of the scene. In aerial photography, the problem is complicated by haze, which dilutes all colours with bluish-white light and changes their hue.

The available Aero-colour films are: Dufaycolor, Agfacolor, Aero Kodacolor, Anscocolor and Kodachrome. Colour photography is useful on large scales only. Medium scale photography produces such pronounced haze effects and low colour resolution that the resulting images have hardly any advantage over black and white photograph. In majority of cases, infra-red colour film is more useful than aero-colour. In general, colour photography can only be used for special tasks under favorable conditions.

2.6.6 Colour Infra-red Photography

A spectra-zonal film is a 3-layer type film which separately records spectral regions, in green, yellow-red and infra-red. This type of film is a modification of colour film, where infra-red sensitive layer is used instead of blue sensitive layer. This film, also known as colour infra-red film, is valuable in many cases where infra-red reflections help photo-interpretation.

In majority of cases, this film is of more practical value than the standard 3-layer colour film because blue content of the visible colours is hardly useful in aerial survey; on the contrary it enhances haze. Moreover, when an infra-red sensitivity is combined with two other visible primary colours, the interpretational possibilities are greater than with a film which has only infra-red recording.

2.6.7 Physical Properties of Developed Image

The degree of darkening of the film on development is expressed by a number which is called the density. The higher the density, the darker is the film. We are only interested in transmission density which is evaluated on the basis of the proportion of light which the negative will allow to pass and is defined as the logarithm of opacity. The relationship between exposure and density of corresponding negative is shown by a characteristic curve (Fig. 2.6). The curve is generated by plotting densities against the logarithm of corresponding exposures. The characteristic curve of all photographic films or papers have the same general S-shape as shown in the figure, although the form of the curve will vary with the material and the way it is developed. The lower part of the curve *AB* is known as toe region and the upper part *CD* is known as shoulder region. Between these two parts, is the part *BC*, which is more or less straight. The slope of the straight line or the tangent with its prolongations make with the exposure axis is known as gamma of the emulsion.

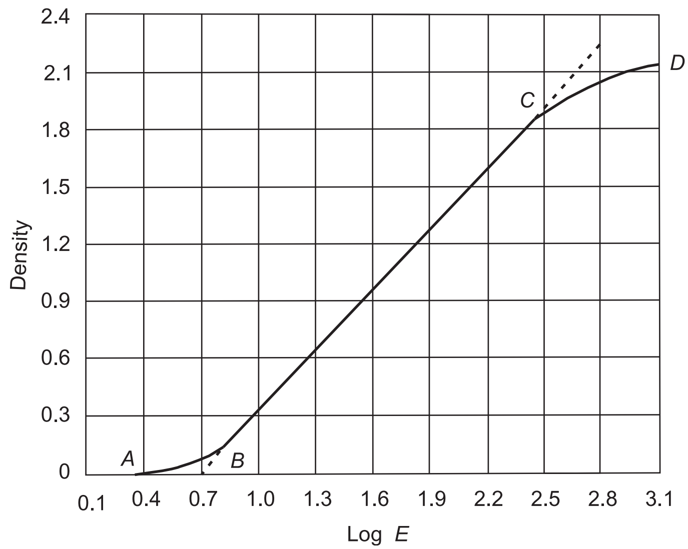

Fig. 2.6 *Characteristic curve of photographic emulsion*

Gamma is also used as a measure of the contrast of the photographic material. The higher the gamma, the greater is the contrast of the negative. For vertical aerial photography from 20,000 feet flying height, negatives having gamma between 0.9 and 1.2 will be more suitable. Still higher gamma may be necessary when exposures are made under difficult conditions of heavy haze or poor light.

When a film is developed, a uniform density may be produced over parts of the film which has not been exposed. This is known as fog. In practice, it is best to operate in a manner so that the fog value is low.

2.6.8 Shutter Speed

The speed or total open time of an aerial camera shutter refers to the duration of the exposure and is the length of time expressed as a fraction of a second from the instant when the shutter just begins to admit light to the film until the instant when the shutter finally cuts off the light. In aerial camera, having between-the-lens shutters, this time interval ranges from about 1/100 of a second to 1/500 of a second. Most aerial camera shutters of this type can be adjusted to give at least three different speeds such as 1/125, 1/250 and 1/500 of a second. The top speed of a shutter should be accurate within plus/minus 10%. The shutter should have a high degree of efficiency, capable of assuring its proper performance at all times.

2.6.9 Image Movement

The aerial camera is moving while a picture is taken of an stationary object, thus, the object point is imaged as a line of length varying with the speed of aircraft. This phenomenon is called image movement and can easily be identified because the stretching out of image is always in the direction of flight. Image movement during exposure is given by the expression:

$$M = 1.467 \times V \times T/S$$

where M = image movement in inches

V = ground speed of aircraft in miles per hour

T = camera shutter speed in seconds

S = photograph scale factor in feet per inch, given by H/f, where

H = flying height in feet

f = focal length of camera in inches.

2.6.10 Relative Aperture

The relative aperture of a photographic lens is defined as the ratio of focal length to the diameter of entrance pupil and is expressed as f/stop number. At constant shutter speed, the light and other conditions prevalent at the time of flight will govern the size of the diaphragm opening required. However, care must be taken to ensure the use of an aperture that will cover the format of the negative satisfactorily.

2.6.11 Aerial Film Exposure

The amount of exposure greatly controls the density of the resultant negative and the quality of details appearing on the negative. The estimation of exposure is mostly done with the help of tables or calculators, supplemented by the experience of photographer. The exposure meter is relatively less used.

With due consideration of available shutter speed and light conditions, all exposures shall be made at the minimum lens aperture which requires an exposure time sufficiently short not to produce appreciable image movement during the exposure. For medium and large scale photography, made in a good survey aircraft, in still air, with a good camera mount, ground speed is the main source of image motion. However, aircraft roll pitch and yaw as well as camera vibration also contribute towards it.

The combination of exposure time and diaphragm should produce a negative which results in most of the photographs being halfway between toe and shoulder on the flat part of the characteristic curve of the negative material. The minimum density of the negative in the area corresponding to field angles less than 35°, which is equivalent to 10 cm off axis on 23 × 23 cm size photograph with 15 cm lens, should be between 0.2 and 0.5 above fog. The minimum density of the negative between 35° and 45° shall not be less than 0.1 above fog. In choosing an exposure to meet these requirements, due consideration should be given to film speed, which is derived from the characteristic curve and is based on the exposure corresponding to a certain gradient in the lower part of the curve.

2.6.12 Fiducial Marks

All relevant fiducial marks or collimating marks should be distinct on every photograph. The missing of one fiducial mark should be sufficient reason for rejection, unless the position of principal point can be clearly and accurately identified even otherwise. In case of a Roseau or register glass, all crosses should be clearly visible on the photographs.

2.7 COMPLETION OF PHOTOGRAPHIC TASK

2.7.1 Numbering of Photographic Task

Every photographic task is allotted a job number by Survey of India, for easy reference and handling. The photographic tasks carried out by the Indian Air Force are allotted numbers suffixed by A, e.g. 346 – A. The photographic tasks carried out by M/s Air Survey Company, Dum Dum are allotted numbers suffixed by B, e.g. 331 – B. From operational point of view, a consecutive numbering of each photographic task presents many advantages because the numbering in the camera may then be set accordingly and the photo numbers will then automatically appear at the margin of each aerial negative, by using a small indication panel in the aerial camera.

2.7.2 Numbering of Strips and Photographs

A photographic task generally consists of a number of strips or flight lines. If the strips are flown east–west, they are numbered consecutively from north starting with strip No. 1 and increasing in numbers 2, 3, 4, etc. towards south (Fig. 2.7). If the strips are flown north–south, they are numbered consecutively from west starting with strip No. 1 and increasing in numbers 2, 3, 4, etc. towards east (Fig. 2.8).

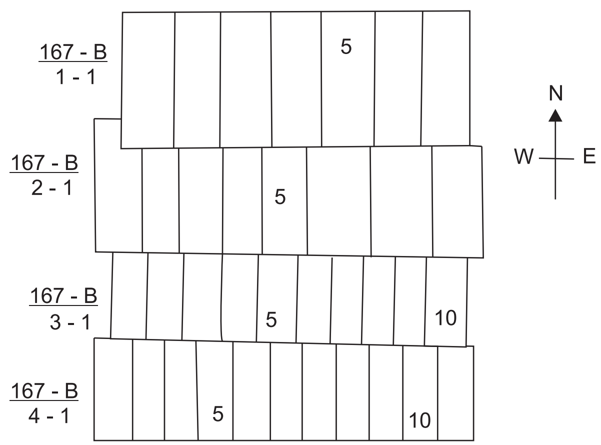

Fig. 2.7 *Numbering of strips and photographs for east-west flight*

The aerial photographs are numbered consecutively along the strip or flight direction. When the strips are flown east–west, the photographs are numbered consecutively from west starting with photograph No. 1 and increasing in numbers 2, 3, 4, etc. along the strip or flight line towards east (Fig. 2.7). When the strips are flown north–south, the photographs are numbered consecutively from south starting with photograph No. 1 and increasing to 2, 3, 4, etc. along the strip or flight line towards north (Fig. 2.8).

Sometimes the aerial photographs are numbered consecutively for the entire photographic task starting with No. 1, increasing continuously in the direction of flight. This system, however, is not suitable for regular survey photography where a large number of photographs are to be handled.

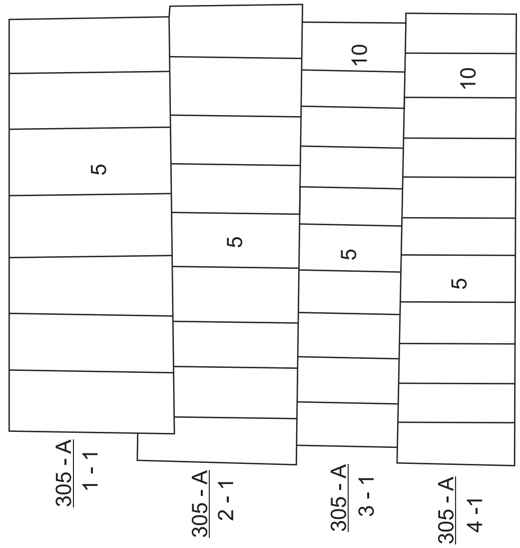

Fig. 2.8 *Numbering of strips and photographs for north-south flight*

2.7.3 Numbering of Film

The aerial film rolls of any photographic task should be numbered consecutively starting with No. 1. In India, the film rolls are designated as Sorties and are numbered with Roman numbers e.g. Sortie No. I, II, III, etc. Sometimes the sorties are prefixed by the abbreviation of place name e.g. DIB for Dibrugarh, TEZ for Tezpur, KAN for Kanpur, AG for Agra, etc. A film should be in one continuous length without joints. A film roll may include unrequired negatives of extra exposures.

End of each film roll should be clearly marked with the following information:

(a) Number of the job in block letters
(b) Number of the film that is Sortie No.
(c) Date of photography
(d) Time of first and last exposure
(e) Scale of photography
(f) Number of camera optical unit and lens, and the principal distance
(g) Flying height of the photography above mean sea level.
(h) Number of air exposures
(i) Number of ground exposures.

The film rolls should be kept in metal containers or cylindrical tin cans. The metal container for each roll of film shall be neatly labeled with the number of the photographic task and other details as for the film roll as given above.

2.7.4 Numbering of Film Negatives

All usable negatives will be numbered consecutively irrespective of whether they are up to the standard of the specifications or not and irrespective of whether they cover the task area or not. Negatives which are rendered useless, being entirely covered by sea or cloud may not be numbered and may be scored out across both diagonals. The figures for numbering should be $3/16^{th}$ inch high; the figure is placed $1/8^{th}$ inch below the top edge and $1/4^{th}$ inch from the left edge of the exposed portion of the negative.

The negative numbering can be shown within the frame of the photo size or outside of the frame; the latter is more common. The numbering should preferably be carried out automatically by a built-in system in the aerial camera.

2.7.5 Photo-index

The purpose of photo indexing is to show the position of any one photograph with respect to other photographs. Their approximate geographical position is marked on a published map. Photo indexes commonly used are of two types—the photographic index and line index.

The photographic index is normally prepared for accurate aerial photography of areas where no reliable maps are available. It is also useful for other operations such as reconnaissance, area studies and control planning. Aerial photography for photographic index is normally carried out on a smaller scale. The photographic index is useful for more accurate navigation in places where no suitable maps for flight exist.

The line photo index is a reproduction of an overlay of the area, showing by lines the photo layout as it covers the terrain and the flight lines. The layout is further annotated with the flight line number, indicated at the beginning and the end of each flight line. Some of the photo numbers, say first and last and every fifth photo, are shown clearly. The photo index is prepared on ¼ inch or 4 miles to an inch, or 1:250,000 scale map, having graticule lines for both latitude and longitude, drawn at intervals of 15 minutes, with their values properly entered. The following information is provided on the top margin of the index: Photographic specification or task number, scale of index, scale of photography, aerial camera and focal length of the lens with its number, and date of photography (Fig. 2.9). The index also contains a legend at the bottom which indicates the sortie numbers with their dates of flights and strips flown in each sortie.

The photo index is essential for easy handling and reference of individual photograph. A single photographic task may contain hundreds of aerial photographs which would be difficult to handle without a photo index.

As soon as the photographic task is completed, prints should be obtained and the photo index should be prepared on a published map. This will reveal whether any gaps have been left. If necessary, the gaps are then covered by re-flights. The line photo index is then prepared and number of prints are generated for supplying to the user.

Spec. No. 167 - B
Scale of index 1” = 4 miles
Mean scale of photos 1” = 1 mile
Camera: Wild RC 5 (a) No. 245, lens 5 cm
Camera: Wild RC 5 (b) No. 155, lens 11.5 cm
Date of Photography : Nov. – Dec. 1956,
Nov. – Dec. 1957, Oct. – Nov. 1958 and
Oct. – Nov. 1960

Fig. 2.9 *Title of photo-index*

2.7.6 Inspection of Aerial Photographs

After completion of photographic flying and processing of the negatives, one set of glossy contact prints are prepared. The prints are assembled strip-wise and the coverage and quality of aerial photography are checked. The aerial photography should be inspected for excessive drift or crab, adequacy of forward and lateral overlaps, incidence of clouds and shadows and suitability of tone, sharpness and dimensional stability. The aerial photography should be inspected for complete stereoscopic coverage of the area ordered for photography.

2.8 PRODUCTION OF POSITIVE COPIES

On completion of a photographic task, preparation of positive prints, enlargements, etc., as demanded by the user, is taken up.

2.8.1 Positive Materials

The aerial film negatives form unique record of aerial photography but are seldom used for actual survey or interpretation. Positive prints prepared from aerial negatives are used for photogrammetric survey or photo-interpretation. The criteria of good positive prints are that they should represent the brightness and reproduce all the details in the negative in a manner which permits easy recognition. The positive materials in use are paper, film and glass plate. Positive transparency, which is also called 'diapositive', is better as it records all the details present in the negative. Diapositives are used when higher precision or quality is aimed at. Paper prints are, however, much easier to handle and they are always used for photo-interpretation and field checking purposes.

2.8.2 Photographic Paper

The characteristics of a paper printing material differ from film as it is made on an opaque paper and is viewed by reflected light. Surface reflection imposes a limitation on the total range of tones obtainable in a paper print. The density range and exposure scale of printing papers are always less than those of the negative materials. The characteristic curves of photographic papers are given in Fig. 2.10. Printing papers are available in a wide range of contrasts. It is possible to select a paper grade so that good brightness

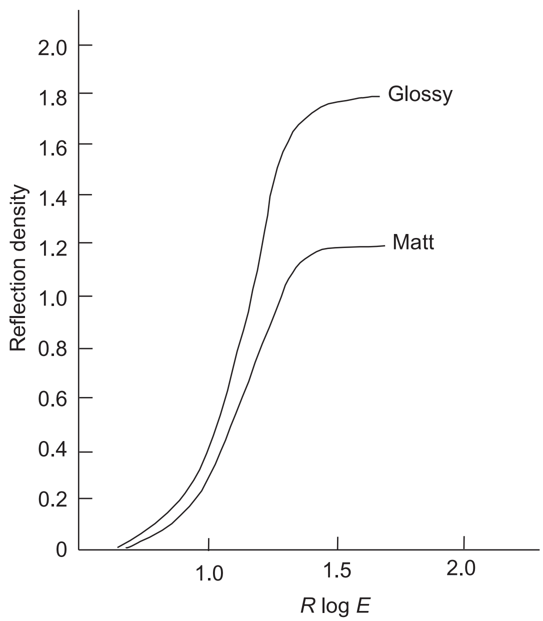

Fig. 2.10 *Characteristic curves for glossy and matt papers*

reproduction is obtained over most of the useful tonal region. To identify the contrast and exposure-scale characteristics of papers, various grades such as ‘soft’, ‘medium’ and ‘hard’ are used. Papers of various speeds are also available. The slow (chloride) papers are used foe contact printing and the faster (bromide) papers for projection printing. However, the choice between two types of paper depends on individual preference. The choice of surface texture and paper thickness depends upon the application. Single weight glossy prints are commonly used for making mosaics. The double-weight semi-matt papers are used for chalking and plotting.

For photo-interpretation purposes, contact prints are made on double-weight semi-matt paper having its surface smooth and free of gloss, so that it is possible to apply ink or coloured pencil or grease pencil on its surface. The reflection density of good paper prints varies from a minimum of 0.2 D to a maximum of 1.1 D, when made from correctly exposed negatives. Good paper prints should show ample details throughout the full range of tones over the whole photograph, enabling identification and recognition of all fine details. Prints should be trimmed in such a way so as to leave blank areas of about 6 mm on all four sides.

2.8.3 Film Diapositive

Film diapositives are used instead of paper prints in various types of photogrammetric plotting instruments. These are made on bromide or chloride emulsions.

In a film diapositive, contrast can be controlled by development solutions. Better quality can be ensured by proper adjustment of processing factors. Positive transparencies are capable of giving results of high quality and provide full tonal range of the negative to be transformed on them.

The desirable minimum density in diapositive copies, to be used in photogrammetric restitution, is of the order of 0.3 D and the maximum density of the order of 1.3 D. When diapositives are intended for use in projection type plotters, such as Multiplex or Kelsh Plotter, the density scale should be much smaller. It is desirable to have a range of positive density minimum of 0.2 D and maximum of 0.8 D. For direct viewing stereo-plotters such as Wild A-6, A-7, A-8, B-8 or Zeiss C-8, Kern PG-2, etc., a range of positive density of 1.0 to 1.3 D is desirable.

2.8.4 Glass Diapositive

Diapositives on glass plates are used in all accurate photogrammetric works. The plates are usually of extremely fine grain, are blue sensitive, have anti-halation backing and are made in medium and high contrast types. The desirable density range of glass diapositives is the same as for the film diapositives.

Various thicknesses and tolerance of flatness of glass plates are available. In general, the flatter glass plates are thicker i.e. 2.2 or 3.2 mm. thick than ordinary plates which are 1.6 to 1.7 mm thick. The Aerographic glass plates have a flatness tolerance of 1:2,000 and Supper Aerographic glass plates have a tolerance of 1:5,000, whereas the plotting glass plates have tolerance of 1:1,000. Another manufacturer guarantees the largest vertical deviation of 0.035 mm, from flat surface for ordinary glass plates and 0.02 mm for ultra-flat glass plates of 15 cm × 15 cm size.

2.8.5 Special Positive Material

Ordinary photographic paper which is made of a matting of cellulose fibers coated continuously in a web, undergoes dimensional change when wet and again when dried. In order to reduce dimensional changes, 'waterproof' papers have been introduced. In waterproof paper, the water absorption is greatly reduced by a coating of water resisting lacquer and dimensional changes are significantly reduced. Kodak Resisto N and Resisto Rapid N are examples of this type of paper. Single weight waterproof paper, after 7 minutes of complete processing and drying in free air, changes in dimension by about 0.25% along the length and 0.30% across. Humidity changes, in the range of 40 to 80% relative humidity, produce change in dimension at the rate of 0.10% in length and 0.20% across for each 10% change in humidity. For precision work, the humidity should be controlled.

The requirements of minimum shrinkage in photogrammetric work have led to the production of special printing materials in which bromide emulsion is coated on to aluminum foil, or on to a special paper base having interleaving of aluminum foil. These materials are processed normally. Agfa Corectostat and Agfa Corectostat Rapid are examples of this type of paper.

2.8.6 Printing

Chloride and bromide papers are usually developed in methol-hydroquinone. Chloride papers should be developed in the Kodak formula D–72. Bromide papers are much more tolerant and can be developed successfully in almost any standard methol-hydroquinone formula. Bromide papers are fully developed in about two minutes, while chloride paper in one and a half minutes. Papers are fixed in acid hypo, but hardening is not usually required. Formula IF-4 is recommended for general use, while IF-1 is advisable in hot climates. An acid rinse (2 percent acetic acid) is advisable between development and fixation, especially with chloride papers.

Thorough washing of paper prints is more difficult than film and glass plate and should be done carefully, especially where prints have to be kept for many years.

In contact printers and projection printing, there is imminent danger of the printer becoming warm after prolonged use. This may cause dangerous dimensional changes particularly during the process of diapositive printing. It is, therefore, imperative that contact printers be equipped with 'cold light', in order that no element of the printer which is in contact with the film, is heated to a temperature higher than 25^{o} C when the printer is in continuous and prolonged use.

The light distribution during the positive copying process should be adjusted to counter balance any uneven distribution of light during exposure. Uneven distribution of light may have been caused by:

(a) The light distribution functions of the lens over the image from centre to corner.
(b) Vectorial effect of haze diffusion acting like a reflector of the sun illumination
(c) Sun's direction and occurrence of mainly sunlit areas at one side of the photographs, and mainly shadow areas at the other side of the photograph.
(d) Prevalence of reflection of the sun or near horizontal surfaces at one side of the photograph and absence of such reflections at the other side of the photograph.

The light balance in the finished positive copies should be such that the same positive density is obtained also in the areas where adjoining copies match.

2.8.7 Transformation Printing

Transformation or reduction printers are used to change the size of the photograph and to change the principal distance and distortion characteristics. Change of size is always connected with change of scale and of principal distance. Transformation or reduction printing is also connected with change of distortion characteristics, even when reproducing on 1:1 scale, because the distortion of the projection system is also introduced. Together with transformed or reduced diapositive copies, a statement as to what is the residual distortion of the transformed copy should be supplied. The corresponding plotting principal distance of the transformed diapositive should also be stated. This can also be checked by comparing the fiducial mark distances on the final diapositives with the corresponding fiducial mark distances on the aerial camera as stated in the calibration report.

2.8.8 Dodging Printing

Electronic dodging printing method is used to control the exposure of photo-sensitive material, in order to produce blemish-free and high quality photographic prints. The electronic dodger printers in common use are: Log Electronic Contact Printer (U.S.A.), Cintel (U.K.) and Parallel Light Printer (PLP) by Kern (Switzerland). If electronic dodging or scanning spot printing is applied, the density compression shall be never uniform over the whole range of tonal values and not limited to either the foot or the shoulder of the positive material's characteristic curve. The question of how much dodging compression is most favourable in any particular case is not well established and opinions may differ on this point. In order to be reasonably effective, the dodging compression shall be of the order of 1:2 or 1:3.

The desirable size of the effective scanning and dodging spot also depends on circumstances. The dodging of large areas reduces the average density differences of these areas, leaving small size areas un-dodged. This means that the contrasts of these smaller size details, which are of particular importance for feature recognition, become apparent whereas the contrasts of large size areas are leveled.

In forest regions, it may be favourable to have density differences of the forest patches and non-forest patches compressed to a lower level. This brings the density level of important small detail, such as texture differentiation in each tree, into the straight part of the characteristic curve of the positive emulsion. The grade of such an emulsion is then chosen to be more contrasty so that the overall density differences on the positive copy are reduced but the contrast in the small details such as texture may be enhanced.

2.8.9 Print Defects

The major defects in preparation of photographic prints, which need to be guarded, are given below:

(a) Blurred areas – caused by lack of contact between paper and negative,

(b) Finger prints – are avoided by handling photographic papers by their extreme edges and corners,

(c) Streaks and scratches – are avoided by careful handling,

(d) Fog – is caused by excessive development or inadequate safe lights, or use of over-age paper,

(e) Irregular white spots – caused by dust on surface of negative during exposure,

(f) Irregular black spots – caused by pin holes on the negative,

(g) Flat prints – caused by over-exposure and under-development,

(h) Excessive contrast – caused by using too hard a paper to fit the negative,

(i) High density – caused by over-exposure or over-development,

(j) Low density – caused by under-exposure or under-development,

(k) Yellow stain – caused by using exhausted developer or fixing solution, insufficient washing or using over-age paper,

(l) Fading – may be caused by insufficient fixing, exhausted fixing bath, or inadequate washing.

Suggestions for Further Reading

American Society of Photogrammetry and Remote Sensing, *Manual of Color Aerial Photography*. Falls Church, Va, 1968.

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Paine, D.P. and R.J. McCadden, *Aerial Photography and Image Interpretation for Resource Management*. Wiley, New York, 1981.

Simon, I., *Infrared Radiation*. Litton Educational, New York, 1966.

Slater, P.N., *Remote Sensing: Optics and Optical Systems*. Addison-Wesley, Reading, MA, 1980.

Frequently Asked Questions

1. Describe the different stages involved in Aerial Photography.
2. What are the specifications to be provided for Aerial Photography?
3. How do you select Time and Season for Aerial Photography?
4. Define Forward and Lateral overlaps.
5. Write short notes on: Crab; spherical aberration; Stigmatism; Chromatic aberration; coma; Image movement; Fiducial marks; Transformation and Dodging printing.
6. Describe briefly the Digital Mapping Camera and its advantages.
7. What are the advantages of Colour Infra-Red photography?
8. Describe Characteristic curves for photographic emulsion and paper
9. How numbering of aerial photographs is carried out in Survey of India?
10. How do you prepare Photo-index and Line-index?

3

STEREOSCOPIC VISION

3.1 INTRODUCTION

Aerial photographs are studied under stereoscopic fusion, for deriving maximum information. A pair of photographs, taken from two camera stations, covering some common area, constitutes a stereoscopic pair. When viewed in a certain manner, it gives an impression of a three dimensional model of the common area. The basis of this subjective impression, called stereoscopic vision, will be dealt hereafter.

3.1.1 Depth Perception

Human being can distinguish depth instinctively. However, there are many aids to depth perception, for instance the estimation of depth by the relative apparent size of identifiable objects, while at closer distances, by the use of binocular vision. The technique of binocular vision is of interest to Photogrammetry, as it enables to obtain a spatial impression of a "model" formed by two photographs of an object (or objects) taken from different viewpoints.

Normally, our eyes give us two slightly different views, which are fused physiologically by the brain and result in a sensation of seeing a 'model' having three dimensions. This three-dimensional effect due to binocular vision is very limited. It is decreasing rapidly beyond a viewing distance of one meter. Thus, it may be concluded that binocular vision is primarily an aid in controlling and directing the movements of one's limbs.

3.1.2 Stereoscopic Photographs

Instead of looking at the original scene, if we observe photographs of that scene taken from two different view points, we can, under suitable conditions, obtain a three dimensional impression from the two dimensional photographs. This impression may be very *similar* to the impression given by the original scene, but not precisely the *same*.

In order to produce a spatial model, the two photographs of a scene must fulfill certain conditions, enumerated below.

(a) The camera (optical) axes should be approximately in one plane, though the eyes can accommodate the departure to a limited degree.

(b) The B/H ratio, in which B = the distance between the exposure stations and H = the vertical distance between an object point and the line joining the two stations, must have an appropriate value. In Photogrammetry, this ratio is called the base-height ratio. If this ratio is too small, say smaller than 0.02, we can obtain a fusion of the two pictures, but the depth perception will not be stronger than if only one photograph was used. The ideal value of B/H is not known, but is probably not far from 0.25. In Photogrammetry, values up to 2 are used, although, depending on the object, sometimes much grater values may be appropriate.

(c) The scale of the two photographs should be approximately the same. Differences up to 15% may, however, be successfully fused. For continuous observation and measurement differences greater than 5% may be disadvantageous.

(d) Each photograph of the pair should be viewed by one eye only i.e. each eye should have a different view of the common overlap area.

(e) The brightness of both the photographs should be similar.

Vertical aerial photography is most commonly used in aerial survey for stereoscopic studies. The terrain is covered with strips of photographs. Overlap between two successive photographs, in the same strip, varies from 55% to 90%. Overlap of adjacent strips varies from 5% to 55%. The most usual overlap along the strip is 60% and between the two adjacent strips is 15%.

3.1.3 Mathematical Consideration

In order to know how a three dimensional model is obtained from a stereoscopic pair of photographs, we will consider some definitions first.

Figure 3.1 shows two convergent photographs in positive position. Thus, the perspective centers (O_1 and O_2) are on one side, the scene $ABCD$ is behind the positive planes. The line joining the perspective centers $O_1 - O_2$ (the base) is called the *epipolar axis*. The points of intersection of epipolar axis with the positive planes are the *epipoles* (E_1, E_2). Planes through the epipolar axis and an object point (e.g. plane $O_1O_2 A$) are *epipolar planes*. Lines of intersection of epipolar planes with the positive planes e.g. E_1A_1, E_2A_2, etc. are known as *epipolar lines*.

In natural stereoscopic vision, we always observe in an epipolar plane, determined by the two eyes and the object. In artificial stereoscopic vision, we have to create this situation. This can be achieved:

(a) by giving the photographs relatively the same position as they had during exposure and placing the eyes in the perspective centers.

(b) by positioning the photographs, if they are observed in one plane (e.g. on the table), in such a way that corresponding epipolar lines are collinear and in one plane with the two eyes. In case of convergent photography, where epipolar lines are not parallel, rotation of the photographs is necessary during scanning. If the optical axes are parallel, the epipolar axis will be parallel to the negative planes. Then the epipolar lines are all parallel to the epipolar axis. Thus, vertical photographs need no rotation during scanning.

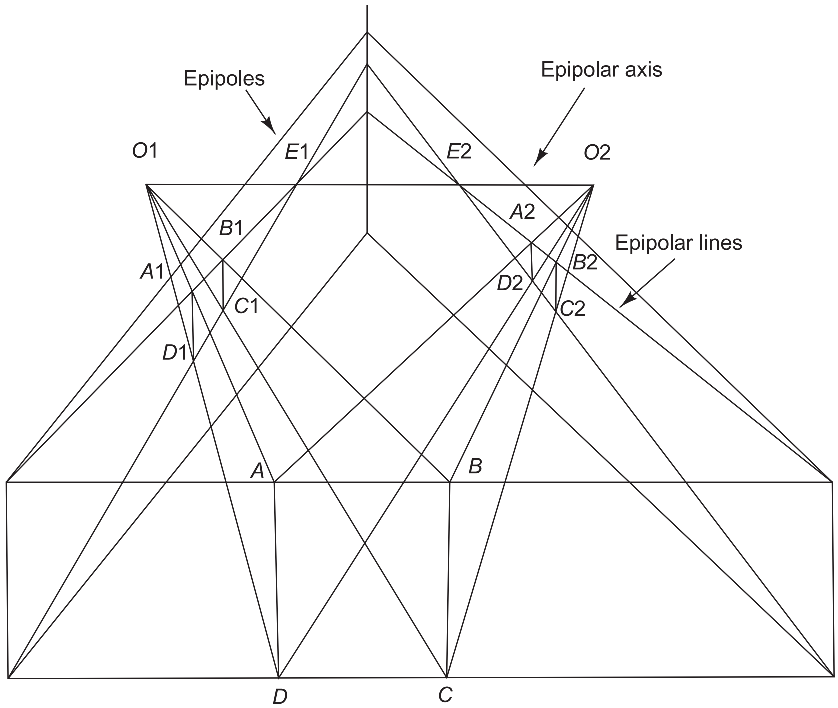


Fig. 3.1 *Geometry of convergent photographs*

3.2 BINOCULAR OBSERVATION

3.2.1 Accommodation and Convergence

If we have a pair of stereoscopic photographs (on paper, glass plates or projected on a screen) in front of us and they are oriented in such a way that epipolar lines are situated in the way described earlier, we can observe them in different ways. In this process, we have to use the terms accommodation and convergence. *Accommodation* means focusing the eye-lens at a certain distance, for instance, at normal reading distance of 250 mm, at infinity, or in between. The eye muscle can adjust the focal length of eye lens between 250 mm to infinity. *Convergence* is the simultaneous directing of both the eye-axes on a certain point. For instance, if we observe an object at a distance of 250 mm, the eye axes meet at that distance at an angle of about 16°30′.

Normally, accommodation and convergence are "automatically" linked, if we look at a point at a certain distance, accommodation and convergence are "set" at that distance. We can disconnect these two mechanisms, but that needs an effort which is, rather tiring, especially for untrained eyes.

3.2.2 Crossed Eye Axes

In normal method of viewing, the eye axes are convergent and as such it is most natural and least tiring. However, in order to view the photographs stereoscopically, they have to be superimposed, at the same time, it has to be ensured that each eye sees only one photograph. Accordingly, the images must be separated. The left eye should see only the left hand photograph and the right eye only the right hand photograph. The resulting stereoscopic perception is similar to that of a normal three-dimensional (3-D) perception.

Sometimes, the left eye gets directed to the right hand photograph and the right eye towards left hand photograph i.e. the eye-photo axes cross each other. This may happen by chance (this is known as crossed eye axes) or by design. In the latter case, the images having been separated are presented to the eyes in such a manner that the left eye sees the right hand photograph and vice-versa. In this situation, the resulting perception though 3-dimensional, is not the normal perception but is reversed. The dimension perpendicular to the base in the model space becomes reversed i.e. depressions appear as elevations and elevations become depressions. Mathematically speaking, if base is parallel to X–Y direction, then in model space $+Z$ becomes $-Z$ and vice-versa. This is known as **pseudoscopy**. In the initial stages, to avoid pseudoscopic view, it is desirable to view the photographs such that the shadows in the photograph fall towards the observer.

3.3 SEPARATION OF STEREOSCOPIC PAIR

3.3.1 Separation by Colour Filter

The photographs are either projected or printed in two different colours. By placing a filter of the same colour over each eye, corresponding picture is observed by one eye only. In practice this problem is difficult to solve completely. The human eye is sensitive for light with wavelengths from 400 to 720 millimicrons (mμ). Figure 3.2 shows the spectral sensitivity curve of human eye. The vertex lies at about 560 mμ. A possibility for separation of the two superimposed images would be to use filters of which one cuts off all wave length over 560 mμ (its colour would be blue-green) and the other all under 560 mμ (orange-red).

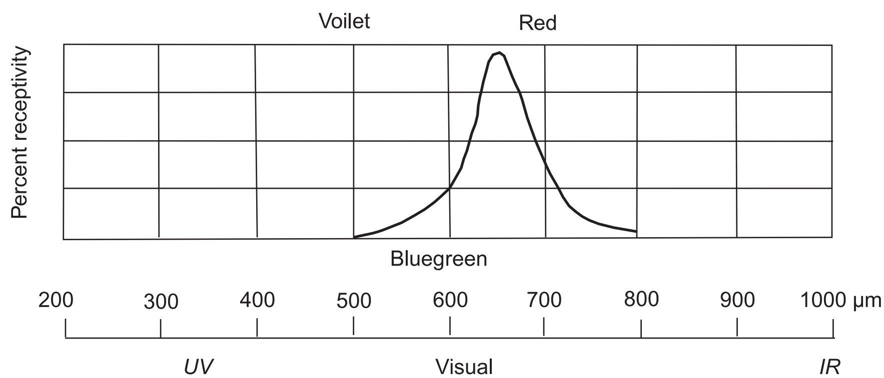


Fig. 3.2 *Spectral sensitivity curve of human eye*

The image projected in orange-red can be observed with an orange-red glass in front of the eye. With the blue-green image it is just the opposite. This means, we have on one of our retina a bluish image from one projector and on the other, a red one from the other projector. We seem to be able to fuse these different images to one stereoscopic black and white image. In practice, the manufacturing of such filters is not very simple, but investigations have shown that the exact colours of the filters are not very critical.

In the case of anaglyphs printed on paper, the condition is different from that described above. The two images are printed in red and blue. The eye covered with the red filter sees both the red image and the white paper as red, therefore, the red image is indistinguishable and only the blue image is visible as varying shades of grey. Similarly the eye covered with a blue filter sees the red image only. Thus, we see 3-D impression. If the spectacles are reversed, we see the left hand photograph with the right eye and vice-versa. A pseudoscopic image will result.

3.3.2 Separation by Polarized Filter

Light has the characteristics of a wave motion in which the waves vibrate in all possible planes perpendicular to the direction of propagation. These are called transverse waves. It is possible to analyze these traverse waves into separate components along two axes perpendicular to each other and to the direction of propagation, by means of filters. If only one of these components is selected, the light rays are said to be polarized.

In order to polarize light a filter is used, consisting of a thin film of plastic prepared in such a way that the molecules, which are long and thin, are laid end to end, thus only allowing one phase of the light to pass through the filter, the others being reflected by the molecules.

Polarized viewing is usually carried out by means of a Vectograph. This is a stereoscopic picture whose 3-dimensional effect is obtained by means of light polarization. To the unaided eye, it appears as a blurred image similar to that of a double exposure. However, when the Vectograph is observed through Polaroid glasses, the superimposed images are readily fused in a single 3-D impression. The Vectograph is prepared by forming the right-eye picture of a stereoscopic pair on polarized film with its polarization axis at 90^{o} to the polarization axis of the left eye image. The resultant transparency when viewed with similarly oriented Polaroid glasses conveys to the right eye the right picture and to the left eye the left picture.

Another means of polaroid portrayal is the projection of the two images of a stereoscopic pair of photographs onto a viewing screen. One picture is illuminated and projected through a polarized screen having a vertical polarization axis and the other picture a horizontal axis (i.e. 90 degrees to the other). The resultant blurred image is transformed into a single 3-D impression when viewed through corresponding polaroid spectacles.

3.3.3 Separation by Parallel Eye Axes

This method is possible without any optical aids, but is tiring, as the eyes are converged on infinity, yet accommodating at approximately 250 mm. It is less tiresome if positive lenses are placed between the eyes and the photographs, so that the photos are placed at the focal length of the lenses. The accommodation then corresponds with the convergence and the eyes are viewing naturally. The ‘pocket stereoscope’ was developed on this principle.

3.4 TYPES OF STEREOSCOPE

3.4.1 Pocket Stereoscope

Pocket stereoscope usually has plano-convex lenses, having a focal length of 100 mm (Fig. 3.3). Its upper side is flat. The rays entering the eyes through the lens are parallel and converge at infinity; while the eyes are accommodated (focused) at 100 mm distance. Since the normal viewing distance is 250 mm—a closer view at 100 mm results in magnification, which is 250/100 = 2.5. More expensive types of pocket stereoscope have a changeable eye base. Such a refinement is not necessary for operators with an average eye-base range between 60 and 68 mm. The pocket stereoscope is cheap, transportable, and has a large field of view. It has two big disadvantages:

(a) Limited magnification: Pocket stereoscopes with more than three times magnification cannot be equipped with simple plano-convex lenses, due to large increase in lens aberrations. In addition the distance between the head and the photographs becomes too small for adequate illumination without making undue complications.

(b) The distance between conjugate points on the photographs must be equal to or smaller than the eye base. With normal size photographs, this becomes difficult or impossible without bending or folding the photographs.

It should not be forgotten, however, that due to the simple optical system, the image quality of the pocket stereoscope is very good.

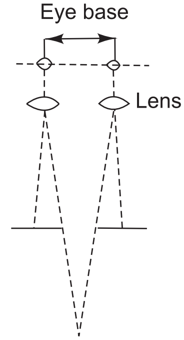


Fig. 3.3 *Pocket stereoscope*

3.4.2 Mirror Stereoscope

The two aforementioned drawbacks have led to the development of the mirror stereoscope. The lenses usually have a focal length of 300 mm, which gives approximately 250/300 = 0.8 magnification or rather reduction. The distance between corresponding points on the two photographs is generally 240 mm (large enough for 9″ × 9″ photograph). To achieve this, mirrors or prisms are placed between the lens and photograph as shown in Fig. 3.4. Over the lenses, telescopes having an enlargement factor of from 4 to 8 X are placed. The following points should be considered while analyzing performance of Mirror Stereoscopes.

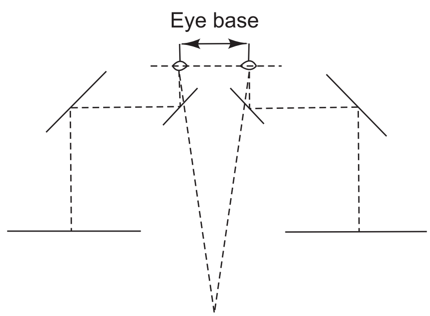


Fig. 3.4 *Mirror stereoscope*

3.4.2.1 *Optical Qualities*

(i) Magnification: Most stereoscopes can be used with two different magnifications. One generally somewhat smaller than 1, the other from 3 to 8 times. A large magnification is necessary for identifying very small details or for taking measurements. For interpretation purpose, a 4 times enlargement is generally considered sufficient.

(ii) Field of view: This must be large. The table below shows the diameter of the field of view one may expect for some of the magnifications.

Magnification	*Diameter of field of view*
0.75	200 mm
1.00	150 mm
1.5	100 mm
2.0	75 mm
3.0	50 mm
4.0	37 mm
6.0	25 mm
8.0	18 mm

(iii) Image quality: This is difficult to test by the user. However, a comparison of test targets with different stereoscopes may help. The following criteria can be kept in view.

(a) Aberration, particularly towards the periphery of the field of observation, should be at the minimum.

(b) Brightness should be uniform and as much as possible, throughout the field of observation.

3.4.2.2 *Mechanical Qualities*

The instrument must be of a stable construction. The instrument base i.e. the distance between corresponding points during observation, must be about 240 mm, so that photographs of 9″ × 9″ size can be scanned conveniently. The inter-pupilar distance must be variable from 55 to 75 mm. The instrument must be built so high that tracing on the photograph can easily be done without touching the mirrors.

During observation, the head must be in a convenient position. The eyepiece angle with the horizon must be from 20° to 50°. Vertical eyepieces are not recommended.

As the mirrors are very sensitive part of the instrument, there should be good handgrips, which would cut down the temptation, and habit of touching the mirrors (Fig. 3.4).

3.5 MEASUREMENTS OF HEIGHT FROM PHOTOGRAPHS

Measurement of height differences of objects with the help of a stereoscopic pair of photographs is the most important activity of photo-interpretation. This is achieved by measuring parallaxes on the photographs. What is then parallax?

3.5.1 Parallax

The term parallax is applied to the apparent change in the position of an object caused by change in position of the observer. The term is widely used in optics, astronomy and other sciences and has different significance in each case. In photogrammetry, we are generally concerned with stereoscopic parallax. The aerial camera does not take aerial photographs continuously but takes them at certain exposure intervals. Suppose, instead of the negative film, there was a ground glass on which ground images could be seen, then, as the aircraft is moving, the ground photographed keeps on changing with respect to the camera frame. A point say *P* which is vertically below the principal point *P′* would appear at *P″* after some time. This shift in its position *P′P″* is the parallax. For any other point *Q*, it will similarly be *Q′Q″* and is equal to the algebraic difference of its projection on the base line, of intercepts joining the principal point on any one of the two photographs forming a stereoscopic pair, to the corresponding images of the point under consideration. It is known as stereoscopic parallax or X-parallax (Fig. 3.5a).

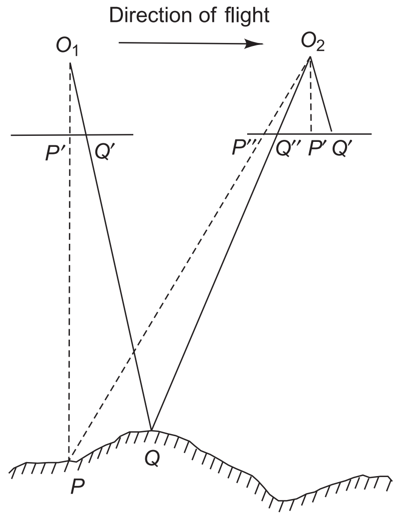


Fig. 3.5a *Stereoscopic parallax*

In Fig. 3.5 b, $P_1P'_2$ and P'_1P_2 are the principal point bases. A_1 and A_2 are the images of the same point. P_1A_1 and P_2A_2 can be resolved into two mutually perpendicular directions; one along the principal point bases and the other perpendicular to it. Then if X_1, X_2 and Y_1, Y_2 are the projections we have

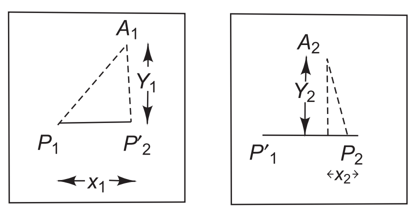


Fig. 3.5b *X and Y parallax*

Absolute *X*-parallax for point $A = X_1 - (-X_2) = X_1 + X_2$.

Similarly the algebraic difference perpendicular to the base line is known as *Y*-parallax.

Absolute *Y*-parallax for point $A = Y_1 - Y_2$.

Normally, if photographs are without tilt and if the flying height has also not changed between two consecutive exposures, the resulting stereoscopic pair does not have any *Y*-parallax.

3.5.2 Parallax Difference

It is the *X*-parallax differences which are of importance in determining elevation. In Fig. 3.6a, the parallax for a point *A* can be obtained by drawing a line from O_2 parallel to O_1A. Let it cut the positive plane at a_3. The *X*-parallax for point *A* is $a_2\, a_3$.

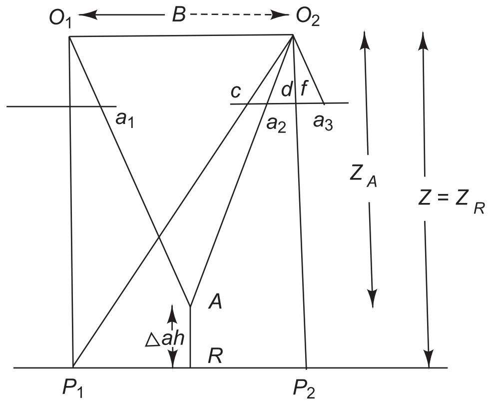


Fig. 3.6a *Parallax difference*

From similar triangles $O_2\, a_2\, a_3$ and $O_1\, O_2 A$

$$a_2 a_3 / f = B/Z - \Delta ha \qquad \text{...(I)}$$

Therefore, $\quad P_A = a_2\, a_3 = \text{B.f}/Z_A$

Similarly for any other point *B*,

$$P_B = \text{B.f}/Z_B \text{ where, } Z_B = Z - \Delta h_B$$

(Fig. 3.6b)

And parallax difference:

$$\Delta p = P_B - P_A$$

The principal point of the left hand photograph is normally taken as the reference point *A* and then $\text{B.f}/Z_A$ can be substituted for P_A, likewise $\text{B.f}/Z_B$ for P_B, hence

$$\Delta p = -\,\text{B.f}/Z_A + \text{B.f}/Z_B$$

$$= \text{B.f}\,(-\,Z_B + Z_A)/Z_A \,.\, Z_B$$

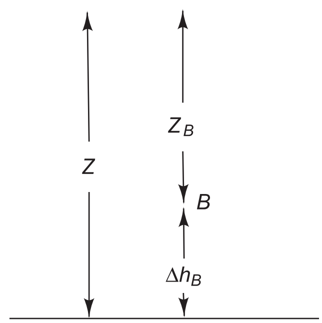
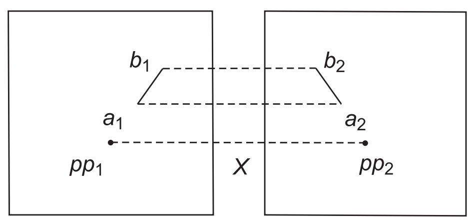


Fig. 3.6b *Height of point B*

If height difference between points *A* and *B* is $\Delta h = Z_A - Z_B$, or $Z_B = Z_A - \Delta h$, then

$$\Delta p = P_A \,.\, \Delta h / Z_A - \Delta h \qquad \text{...(II)}$$

In interpretation work, however, the principal points are placed at a fixed distance apart with principal point bases in one straight line, and the parallax differences are measured by measuring $a_1\, a_2$ for point '*A*' and $b_1\, b_2$ for any other point *B* and taking out their difference (Fig. 3.6c).



$P_a = X$ (arbitrary distance) – $a_1 a_2$

$P_b = X$ (arbitrary distance) – $b_1 b_2$

$\Delta p = P_a - P_b = X - a_1 a_2 - X + b_1 b_2 = -\,(a_1 a_2 - b_1 b_2)$

Hence the parallax difference is negative for heights

Fig. 3.6c *Measurement of parallax difference*

Thus parallax of *A* is taken as

$$P_a = x \text{ (arbitrary dist)} - a_1\, a_2$$

$$P_b = x \text{ (same arbitrary dist)} - b_1\, b_2$$

Subtracting

$P_a - P_b = b_1\, b_2 - a_1\, a_2 = -\,(a_1\, a_2 - b_1\, b_2)$, hence parallax difference is negative for heights.

Therefore $\Delta p = -\,P_R \,.\, \Delta h / Z_R - \Delta h \qquad$ ...(III)

It can also be shown (Fig. 3.6d) that parallax difference = sum of relief displacements in left and right photographs.

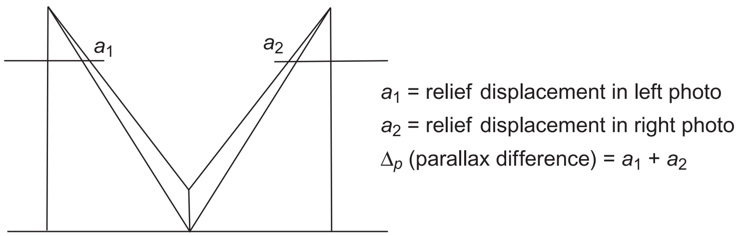


Fig. 3.6d *Relief displacement and parallax*

It will be seen that if the left hand photograph has been taken as the reference point, then $P_R = cd$ (Fig. 3.6a) i.e. distance between principal points, on the right hand photographs.

From (III) by cross multiplying and rearranging

$$\Delta p\,(Z_R - \Delta h) = -\Delta h\,.\,P_R$$

$$\Delta p\,.\,Z_R = -\Delta h\,.\,P_R + \Delta h\,.\,\Delta p = -\Delta h\,(P_R - \Delta p)$$

i.e. $$\Delta h = -Z_R\,.\,\Delta p/P_R - \Delta p \qquad \text{...(IV)}$$

The formulae (III) and (IV) are very important but are often employed in their simplified form as

$$\Delta p = -P_R\,.\,\Delta h/Z_R \qquad \text{...(V)}$$

ignoring Δh from the denominator and,

$$\Delta h = -Z_R\,.\,\Delta p/P_R \qquad \text{...(VI)}$$

ignoring Δp from the denominator

An illustrative example will clarify the use of these formulae. Let the data be as follows.

(a) Flying height above reference plane (Z_R) = 5, 000 m.

(b) Base as measured in right hand photograph (P_R)= 70 mm

(c) Height difference above reference plane (Δh) = 100 meters,

Then the parallax difference (Δp) vide equation III, by substituting the values,

$$= -70 \times 100/5000 - 100 = -7000/4900 = -1.43 \text{ mm}$$

Similarly knowing parallax difference, which can be measured with the parallax bar, height difference Δh, can be determined. For the same example, vide equation IV, by substituting the values,

$$\Delta h = -5000\,.\,(-1.43)/70 - (-1.43)$$

$$= +7150/71.43 \text{ meters}$$

$$= 100 \text{ meters}$$

It must be kept in mind that these formulae give correct result only when the photographs are truly vertical. The presence of tilt in either one or both of the photographs disturbs the relationship. This will be dealt with later.

3.5.3 Parallax Scale

From equation VI, we have $\Delta h/\Delta p = Z_R/P_R = H/Bm$, where H is flying height and PR is taken as mean base of the two photographs. This is called parallax scale. This scale helps in determining better height and planimetric accuracy. For better height accuracy, Δh should be small, therefore (i) flying height should be low or focal length of the camera should be small, for keeping the scale constant, and (ii) B should be large (choosing large B/H ratio).

For better planimetric accuracy, Δp should be small, therefore, (i) the flying height should be high or focal length of the camera should be large (narrow angle) commensurate to the scale, and (ii) B should be small (more overlap), choosing smaller B/H ratio.

3.5.4 Floating Marks

If the eyes are focused on the point A (Fig. 3.7), then two identical marks (known as floating marks) will be seen as one mark on the point A. If one photograph is slightly moved inward, the floating mark is seen spatially above A at A', as shown in the diagram.

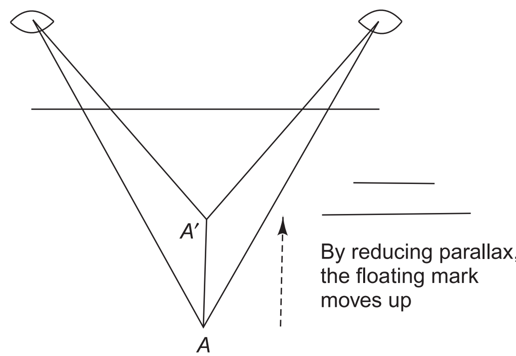


Fig. 3.7 *Principle of floating mark*

The principle of the floating mark is used for height measurements on photographs. If the two marks are on corresponding points on a stereo-pair of photographs they are seen as one mark "on the ground". If one photograph is shifted inwards or outwards, it is seen to float over or dig under the ground respectively. The eyes are very sensitive in assessing whether the mark is on the ground or not, as a result, any person, with a normal stereoscopic vision, can measure stereoscopically much more accurately, than monocularly. The floating marks are especially useful for drawing contour lines (lines of equal height).

3.5.5 Measurement of Parallax Difference

Parallax difference can be measured with an ordinary ruler but, for the purpose of accuracy, a parallax bar or parallax wedge is used instead. The difference in distance gives the parallax difference which, in turn, can be expressed as a height difference.

3.5.6 Parallax Bar

A parallax bar consists of two glasses engraved with measuring marks, connected by a bar whose length can be changed by a micrometer screw. The micrometers are mostly numbered increasingly as distance between corresponding points is decreasing. It means that a point with a larger parallax gives a higher reading, corresponding with a point of larger elevation.

Some models are equipped with a pencil holder, in order to use it as a tool for mapping. On some other models, there is also a 'Y' displacement mechanism on one of the floating mark holders, so that the bar can be used on a parallel guidance mechanism, and allowances made for '*Y*' parallax elimination without moving the photos (Fig. 3.8a).

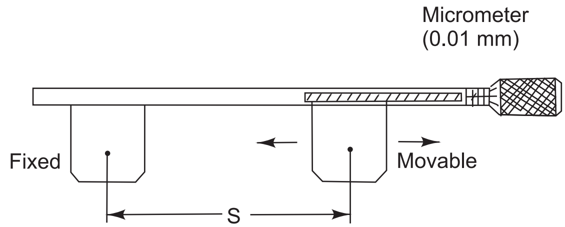


Fig. 3.8a *Parallax bar*

3.5.7 Parallax Wedge

This is a sheet of transparent material with two converging rows of dots. The wedge is slid backwards and forwards in '*Y*' direction until two dots fuse as one dot on the ground, the reading then being noted. The dots are numbered in accordance with corresponding parallax values (Fig. 3.8 b).

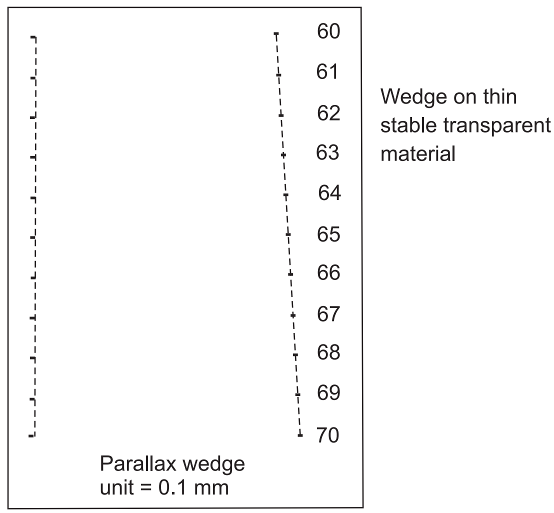


Fig. 3.8b *Parallax wedge*

3.6 STEREO MODEL

3.6.1 Introduction

The subjective spacial model observed through stereoscope by viewing photographs, having common overlap area, is called stereo model. It presents a three dimensional picture, similar to a view seen from an aeroplane. However, it is not the same; if someone observes the ground from an aeroplane, one does not see a spatial model. The eye base is so small (65 mm average) compared with the flying height of the aeroplane that the two retina images are virtually the same. Therefore, there is no true comparison between the natural view and the stereoscopic view of a model.

It may be assumed that we see natural relief if we observe an object with a normal base-height ratio. As mentioned earlier, the binocular vision is mainly an aid in controlling the movements of the limbs, we could say that a normal base height ratio is near about 65/250 i.e. about ¼ (0.25). As base height ratios used for aerial photography vary from 1:3 to 1:1 or even 1:0.6 this could lead to the conclusion that the stereoscopic image formed by aerial photographs is always different and distorted. However, there are other factors, which influence the subjective model. These are enumerated below:

(a) Assume that the photographs are taken with a vertical optical axis and that they are observed flat on a table, oriented according to the epipolar rays. The first difference is that the eye base has been changed from say 800 m to 65 mm. This change only alters the scale of the model and the two views remain similar in every other respect.

(b) The second difference is that the photographs are observed at a distance which is not equal to the principal distance. This not only alters the magnification of the model but simultaneously alters the ratios between the *X*, *Y* scales against the *Z* scale. We get flattened or an affined model, if this distance is smaller than principal distance, exaggerated if it is greater than principal distance. This corresponds with what one finds in practice.

(c) The third difference is that our eyes are moved away from the vertical through the principal points. This produces deformations difficult to construct or visualize in a diagram.

(d) The fourth difference is that one of the photographs is moved during observation, so that the conjugate points are seen vertically. This shift is equal to the stereoscopic parallax (p) and makes the rays from the conjugate points to the respective eyes parallel which is the normal condition of stereoscopic observation. However, this parallelism renders the construction of the spatial image impossible, as it means that the spatial model should be formed at infinity. In practice the image does not appear at infinity but at an indeterminate distance varying from 250 mm to 1 meter according to the personal idiosyncrasies of the operator.

(e) Lastly the shape of the object, the shadows, the natural association of observed date and relative distances all influence the process of depth perception.

3.6.2 Stereoscopic Exaggeration

The stereoscopic exaggeration is the ratio between the heights of an object as you see it (relative to horizontal dimensions) and as it is. However, it is not fully understood as yet. Various authors have given different empirical formulae for stereoscopic exaggeration (SE).

In considering SE we can consider the following variables.

(a) *Photo variables*
   (i) Air base (B)
   (ii) Focal length (f)
   (iii) Flying height (H)

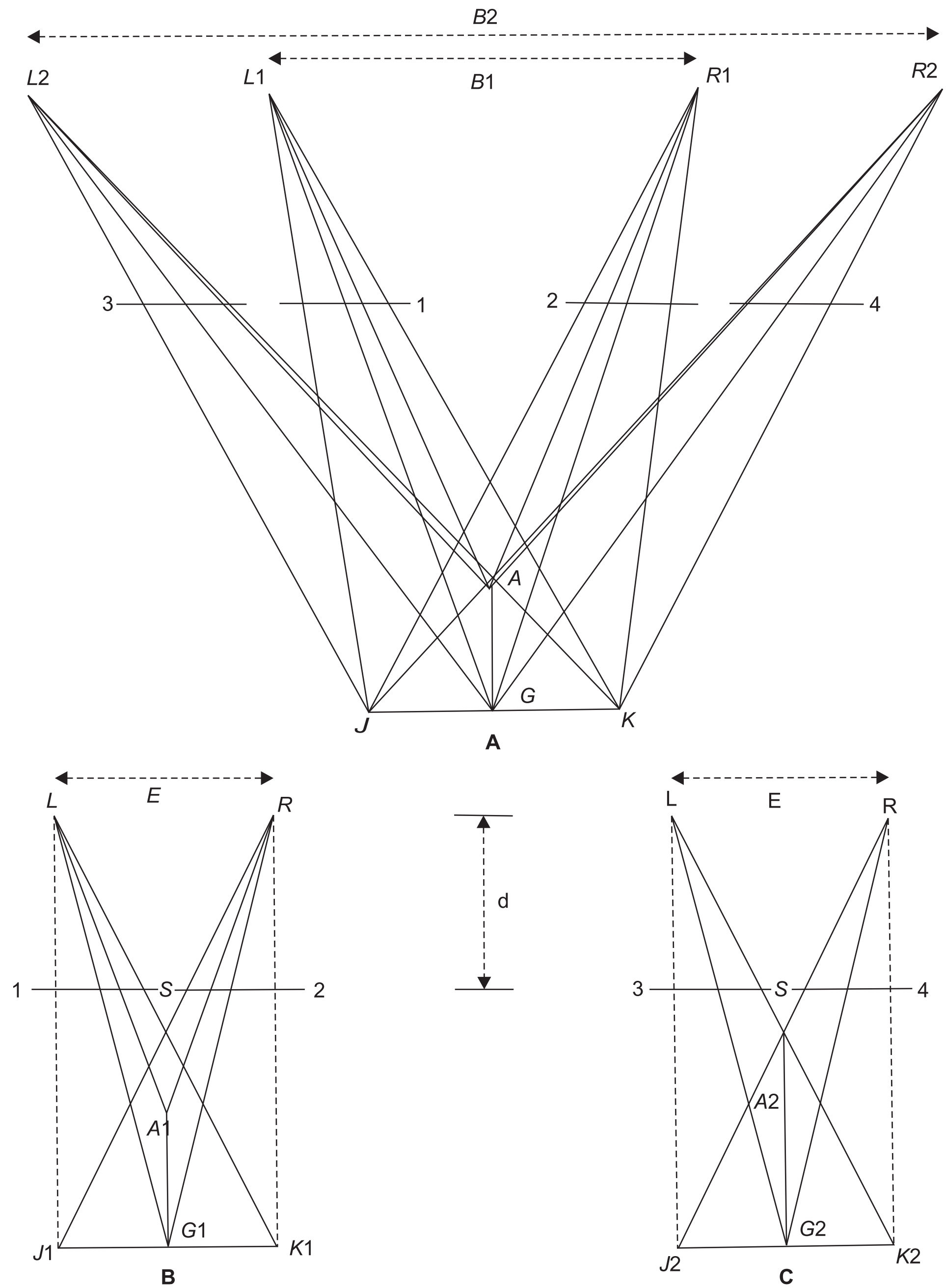
(b) *Viewing variables*
   (i) Viewing distance (d)
   (ii) Separation of photographs (s)
   (iii) Eye base (E)

Figures 3.9 to 3.12 (based on diagrams of Miller, 1961) show the effect of these variables, taken one at a time and keeping others variables constant. It would appear that the relationship is as follows:

$$SE \propto B$$
$$\propto 1/f$$
$$\propto 1/H$$
$$\propto d$$
$$\propto s$$
$$\propto 1/E$$

i.e. if combined $SE \propto Bds/fHE$

$$\propto B/H \,.\, ds/fE$$

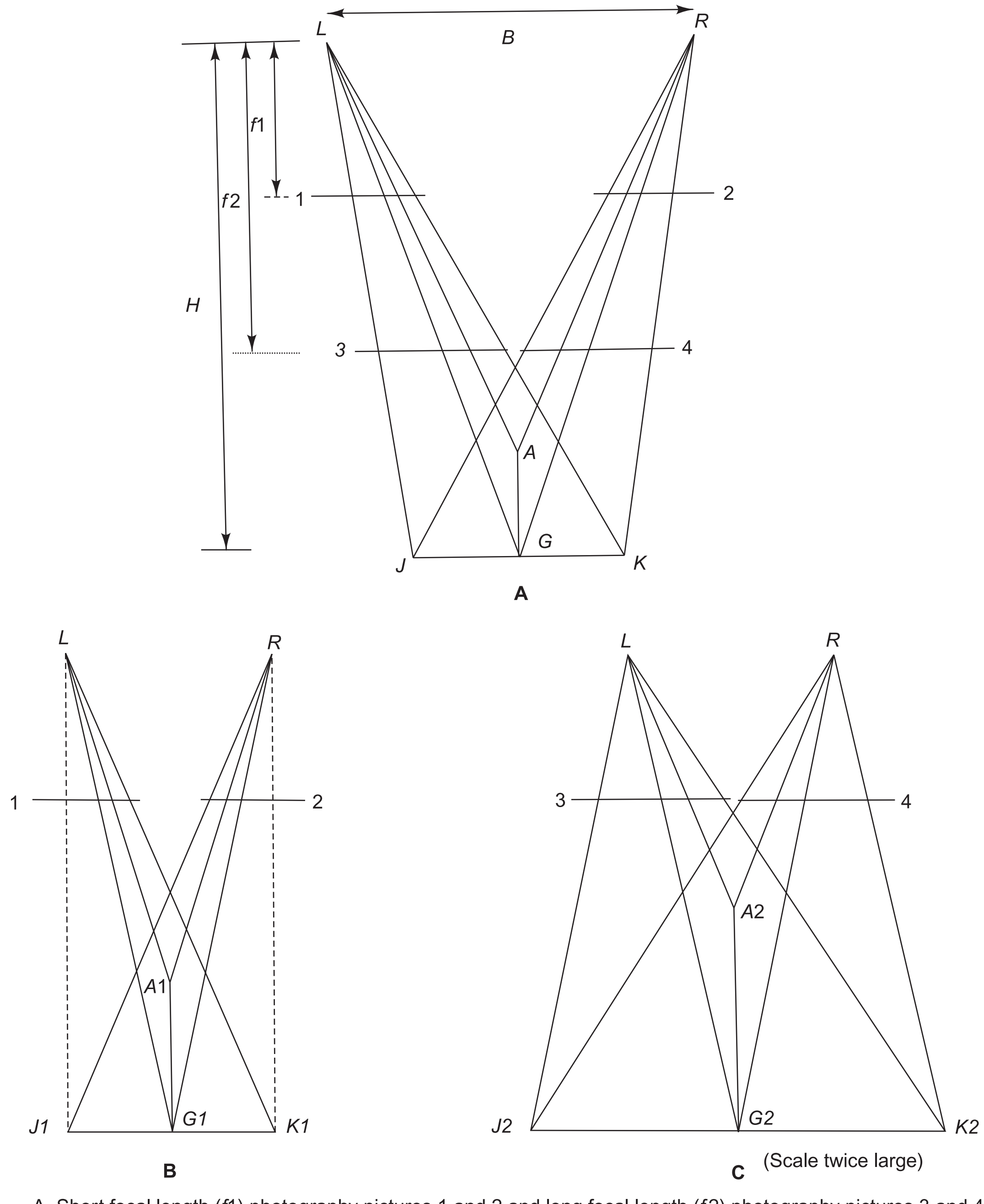


A. Overlap photography from camera stations *L*1 and *R*1 (short base – *B*1) and from *L*2 and *R*2 (long base – *B*2)

B. Viewing photographs 1 and 2 – short airbase photography

C. Viewing photographs 3 and 4 – long airbase photography

Fig. 3.9 *Effect of air base (overlap) on vertical exaggeration*

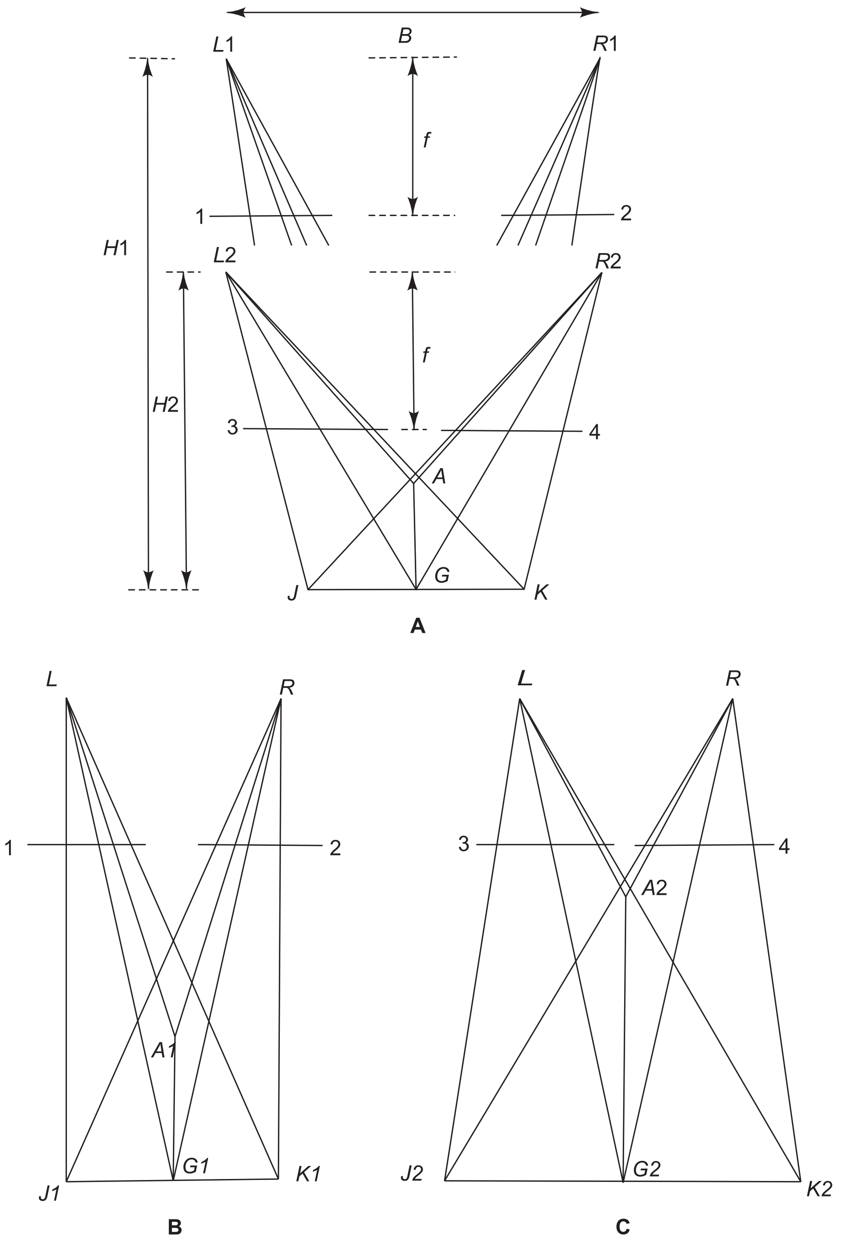


A. Short focal length (*f*1) photography pictures 1 and 2 and long focal length (*f*2) photography pictures 3 and 4

B. Viewing of photograph 1 and 2 (short focal length photography)

C. Viewing of photograph 3 and 4 (long focal length photography)

Fig. 3.10 *Effect of focal length on vertical exaggeration*

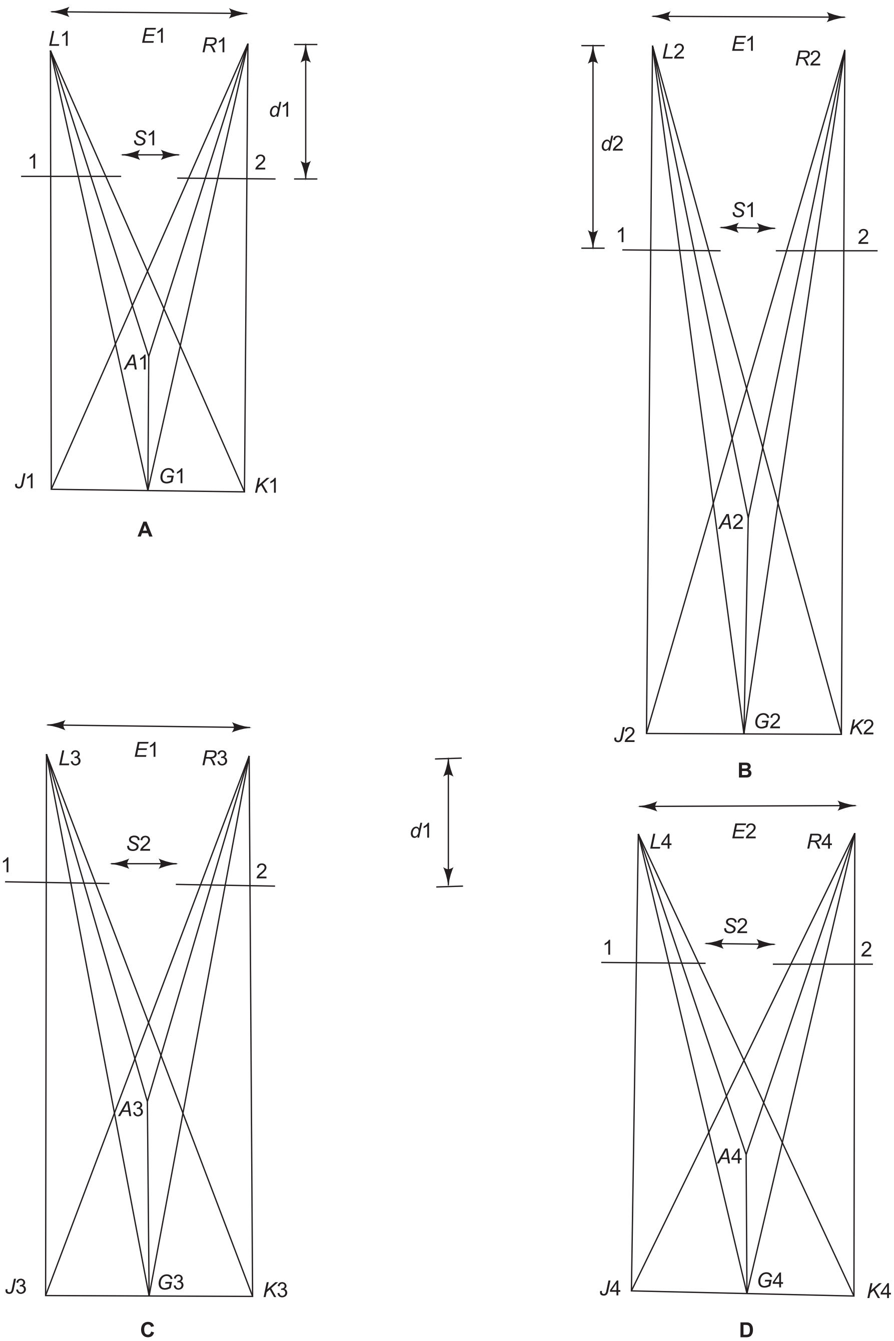


A. Photographs 1 and 2 are taken from greater height *H*1 than photographs 3 and 4, which are taken from *H*2.

B. Viewing photograph 1 and 2

C. Viewing photographs 3 and 4

Fig. 3.11 *Effect of flying height on vertical exaggeration*



A and *B*. Viewing with increased distance from *d1* to *d*2
A and *C*. Viewing with increased separation from *S*1 to *S*2
C and *D*. Viewing with increased eye base from *E*1 to *E*2

Fig. 3.12 *Effect of stereoscopic variables on vertical exaggeration*

Thurrell (1953) stressed the significance of airbase and camera height. He stated that for any one stereoscopic viewing arrangement, exaggeration is essentially determined by the base-height (B/H) ratio. Raasveldt (1956) arrived at a similar equation through geometrical derivations to

S.E. = $B/Z \cdot Z'/E$, in which.

B/Z = base height ratio during exposure

E = Eye base and Z'= the distance at which we see the objects

The latter quantity is rather indefinite, which renders the formula doubtful for practical use.

In many cases it will be better to determine stereoscopic exaggeration empirically. This may be done by estimating some heights and subsequently determining the same by parallax-bar measurement and linear measurements.

In his paper, Fischer (1955) gives tests charts for the determination of the stereoscopic exaggeration. The first one consists of a stereoscopic drawing of a pyramid (Fig. 3.13). One must estimate its height in terms of the parallax difference. This gives a factor K (stereoscopic constant), which after multiplication with the base height ratio, gives the exaggeration factor. Thus exaggeration is $B/Z \cdot h/p$, in which h is the estimated height of the pyramid and p is the parallax difference. Fischer (1955) himself considers other diagrams given in the same publication better, but we tend to prefer the one given here.

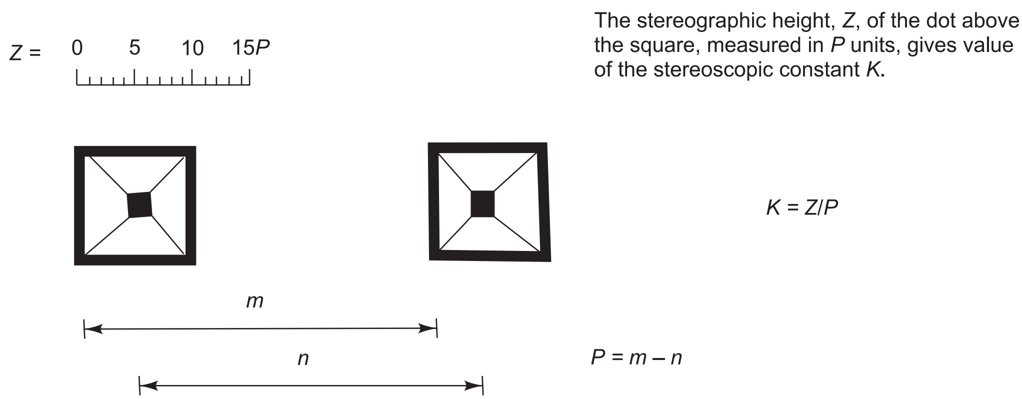


Fig. 3.13 *Stereogram showing stereoscopic constant*

The value of K is found to be anywhere between 7 to 12 and consequently that of stereoscopic exaggeration anything between 2 and 5. Normally the value of S E is about 2½ to 3½.

3.6.3 Estimation of Slope

As the stereoscopic exaggeration is a difficult quantity to determine, it will be clear that estimation of slope or dip angles must also be very difficult. When a stereoscopic image, projected on a screen by means of polaroid filters in which considerable depth is apparent, is observed, it may be noted that points closer to the observer are moving with the observer. This is so with the tops of the mountains. They seem to point always towards the observer. It is clear that the slope estimation is highly dependent on the position of the observer's eyes. In spite of the apparent difficulties some authors have given methods for slope determination based on estimations. Two of them are given here.

(a) Fischer (1955), in his publication gives the formula for determination of slope as:

$$\cot \delta = R \cot S + d/f \sin \beta, \text{ where.}$$

δ = true dip

R = vertical exaggeration

S = apparent dip

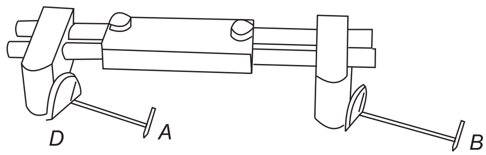
f = principal distance

d = distance of the slope from the center of the model '*O*'.

β = angle of the slope direction with the line joining the principal points

This is a rather complicated formula and is not very practical for quick determination of slopes.

(b) Hackman (1956) measured slopes with the help of Stereoslope comparator (Fig. 3.14). The stereoscope is always used in such a way that the lenses are over the flight line. For each eye there is a rod of say, 30 mm which is observed stereoscopically and put in such a position that the rod appears parallel with the slope. The apparent slope is read on a dial which must be converted by means of a nomogram into the actual slope. For this conversion one must know one's personal exaggeration factor. This is determined by means of a "supplementary slope model" on which a slope is drawn. One puts one's stereoscope over this "slope" and measures, the apparent angle. The true angle is known, so the exaggeration factor is equal to true slope/apparent slope.



A and *B* are viewed stereoscopically and angles are read on disc *D*.

Fig. 3.14 *Stereoslope comparator*

In practice slope is often determined by conversion of estimated slope with a simple factor containing an exaggeration ratio. Such methods must be considered as reliable. However, in many cases scores of photographs must be interpreted in a very short time.

The slopes can be determined in the stereo model by estimation. These slopes/dips are only the apparent slopes/dips because of stereoscopic exaggeration and must be converted to true values. This conversion can be done with the help of graphs after working out the exaggeration factor (Fig. 3.15), based on U. S. Geological Survey Professional paper 373 by Ray (1960).

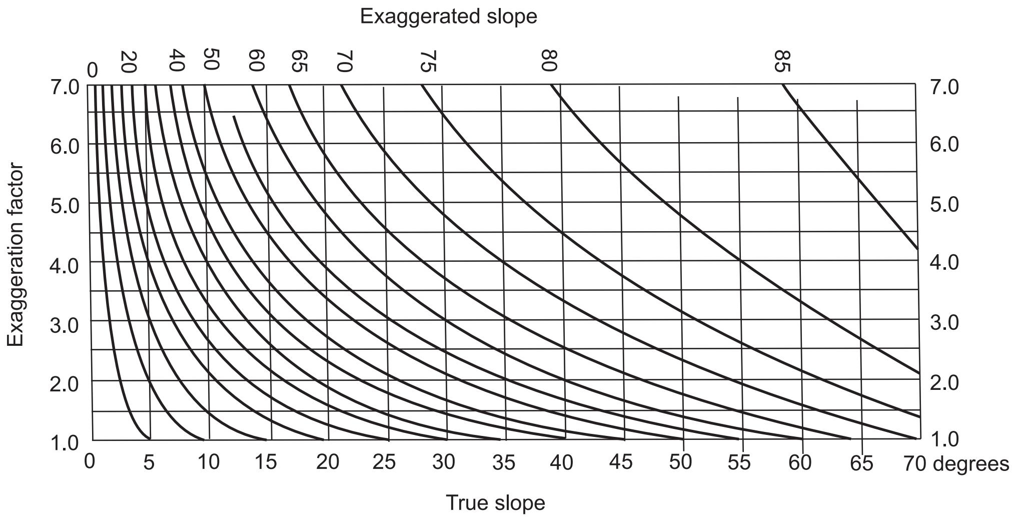


Fig. 3.15 *Slope conversion chart*

3.6.4 ITC Slope Finder

The slope can also be estimated under stereo-fusion by manufacturing a small plane surface 4 cm × 4 cm which can be rotated along horizontal axis. The plane surface is viewed in the model system. But it is not seen stereoscopically and as such is at best a subjective approximation. The slope can be directly read on a calibrated dial for various exaggeration factors (Fig. 3.16).

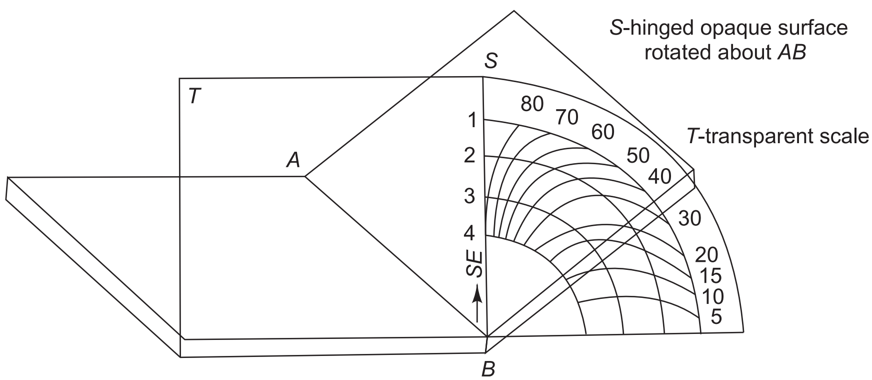


Fig. 3.16 *ITC slope finder*

If very simple methods are used, it is strongly recommended to check the results from time to time with more exact procedures. These are based on observations with a parallax bar. The parallax bar reading gives the height differences.

In order to compute the dip/slope the horizontal distance has to be determined which due to relief displacement is not very easy. A good but not very quick method is as follows:

Put a piece of tracing paper on one of the photographs and draw the flight line, the radial line to the point *A* and the radial line to the point *B* (Fig. 3.17). Now put the tracing paper over the other photographs, flight lines are coinciding and the point *A* is coinciding. Draw the radial line to point *B*. Now the distance '*D*' from point *A* to the point of intersection of the radial lines to point *B* gives the distance *A B* at photo-scale; we then have

(a) horizontal distance = $D \times H_R/f$

(b) difference in height = $H_R \,.\, \Delta p/P_R$

(c) tan slope = Difference in height/Horizontal distance

$$= H_R \,.\, \Delta p/P_R \text{ divided by } D.\, H_R/f$$

$$= \frac{\Delta p}{P_R} \cdot \frac{f}{D}$$

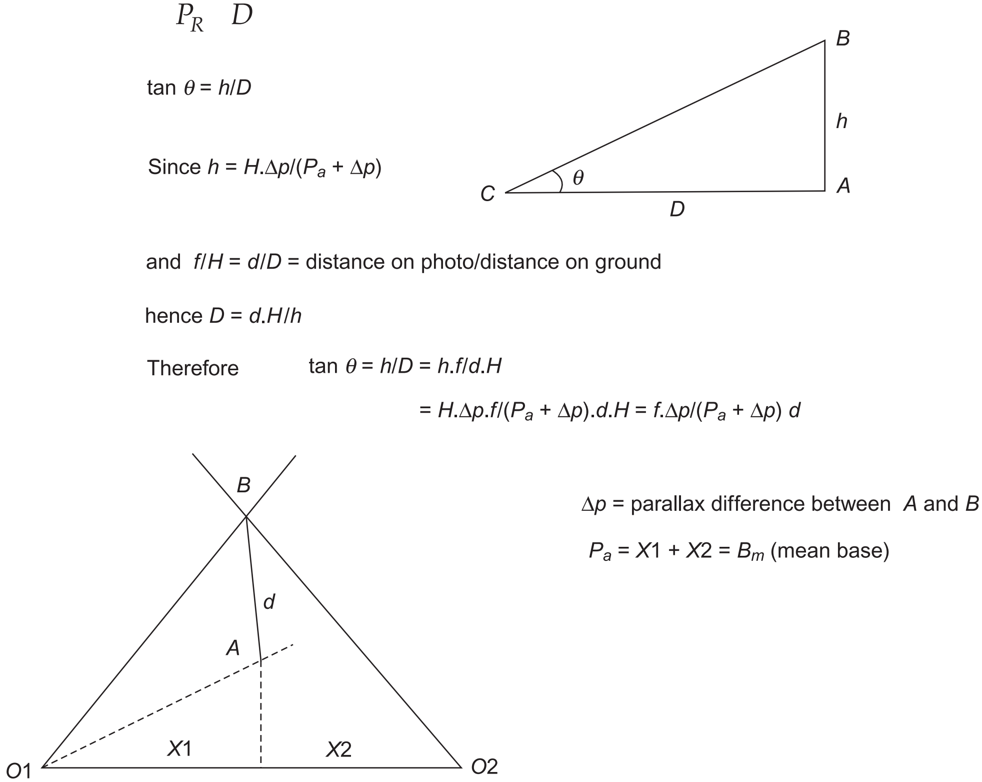


Fig. 3.17 *Determination of slope*

3.6.5 ITC Slope Template

The slope between two points *A* and *B* is determined by $\cot \delta = AB/\Delta h$.

Now if we wish to determine the slope from photographs we must express *AB* (horizontal distance between points) and Δh (the height difference) in measurable quantities.

We then have

$$(AB)^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2$$

and

$$\Delta h = Z_a \, \Delta P_{ab}/P_a + P_{ab}$$

The ground coordinates can be expressed in terms of photo coordinates—focal length and the flying height. The photo coordinates can be expressed in terms of axes which are parallel to line joining *AB* (say *V*) and perpendicular to the line joining *AB* (say *U*). But transferring and simplifying we get.

$$\cot \delta^2 = (P_a/\Delta P \,.\, V_a \,.\, V_b/c + V_a/c)^2 \, Uh^2/C^2$$

$$= Q^2 + S^2$$

For reading $Va/c = ta$ and $Vb/c = tb$ and *Uh* template have been prepared. Thus after finding *Pa* and ΔP we can calculate *Q* and *S* and the cot δ can be determined. The calculation is simplified by use of a nomogram (Fig. 3.18). For details see ITC publication B 26, *Determination of Slopes*, by Mekel, Savage and Zorn (1964, revised 1967).

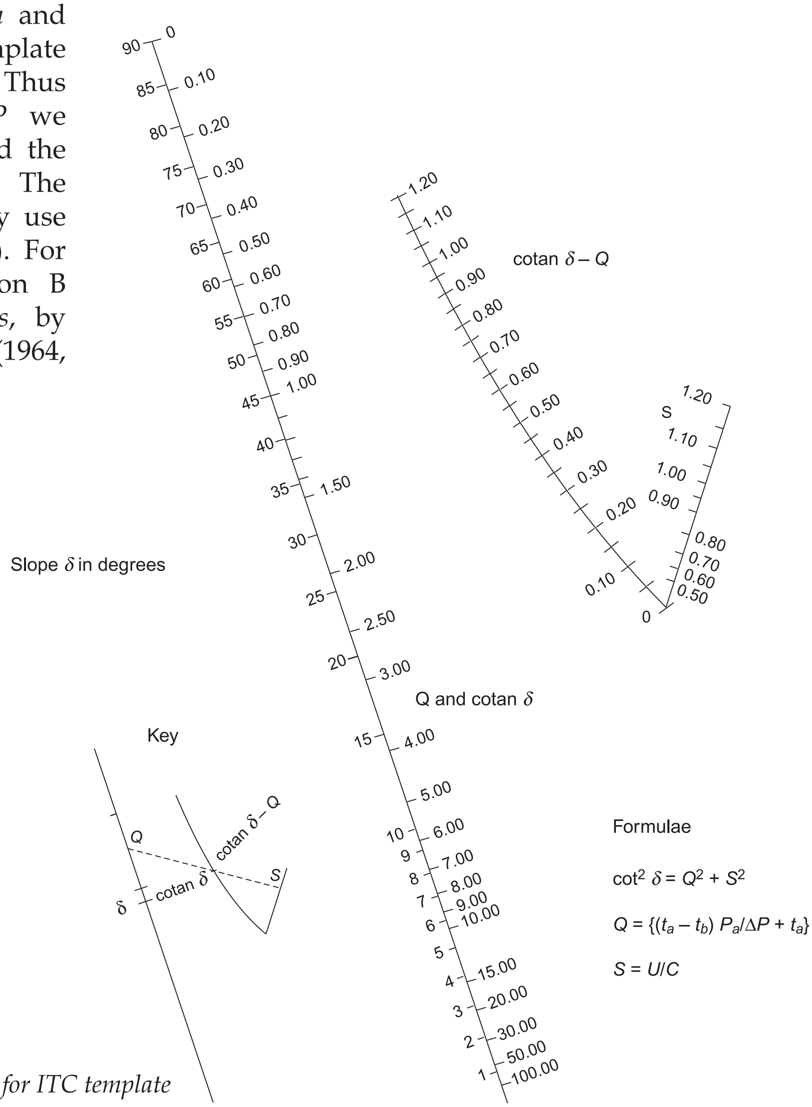


Fig. 3.18 *Nomogram for ITC template*

3.7 MODEL DEFORMATION

It has been explained that in stereo-photogrammetry, heights of points relative to each other are determined by making use of difference of *X*-parallaxes of various points. The parallax formula was derived with the assumptions that

(a) The photographs are central projections. In actual fact it is not strictly so. The lens system introduces distortion.

(b) The base '*B*' is exactly horizontal. In actual practice the two exposure stations are seldom at the same relative attitude.

(c) The camera axis is vertical at the time of exposure. It is seldom the case; at best, the axis is near vertical.

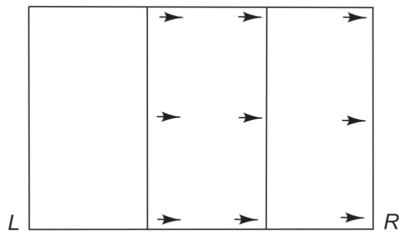


Fig. 3.19 *Effect of 'bx'*

Non-fulfillment of these conditions, as stated above, causes certain *X*-parallaxes further,

(a) The paper on which prints are made is not generally dimensionally stable.

(b) The two photographs of a model are seldom in their exact relative position with respect to each other.

This last shortcoming introduces additional *X*-parallaxes which vary in different parts of the model and give rise to varying deformation in various parts of the model. Thus a model of a flat ground under these circumstances would appear warped**.**

In a normal near vertical photograph, small *X* and *Y* displacements are inherent as it is not as yet possible to take absolutely vertical photograph and as such when parallaxes are burdened with such discrepancies, it produces a model which is deformed. The pattern and extent of deformation can best be studied by keeping the left hand projection correct and by considering the effect of one element of exterior orientation at a time, on the right hand projection.

(a) Influence of '*bx*' (In all the diagrams that follow, the tip of the arrow shows the new position of points in right hand projection.)

Figure 3.19 shows the effect of '*bx*' in the right hand projection. Since there is a constant shift in all points it does not result in any deformation but only results in a shift of height scale.

(b) Influence of '*by*'

'*by*' gives a constant shift in *Y*-direction only and has no influence on *X*-parallax and hence does not result in any deformations (Fig. 3.20).

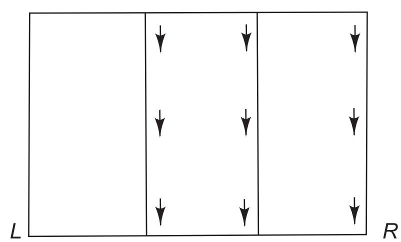


Fig. 3.20 *Effect of 'by'*

(c) Influence of '*bz*'

The *x* and *y* movement of points because of *bz* is as shown in Fig. 3.21. In points 1, 3 and 5 an erroneous *X*-parallax is introduced. This error is the same in all points. The deformation in the model will be as shown in Fig. 3.22.

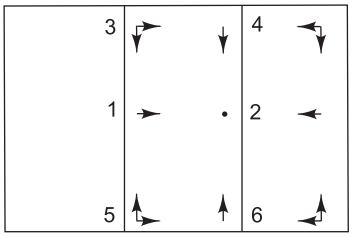


Fig. 3.21 *Effect of 'bz'*

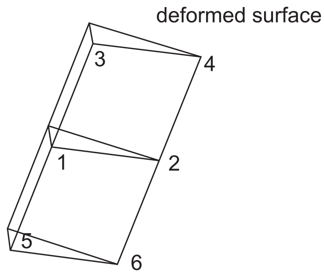


Fig. 3.22 *Deformed surface due to 'bz'*

(d) Influence of phi 'φ' tilt

The effect of phi 'φ' tilt is as shown in Fig. 3.23. The X-parallax discrepancies in a section through point 1 are more than in section through point 2. The variation of *X*-parallax is quadratic in the direction X. This gives a cylindrical deformation surface, as shown in Fig. 3.24.

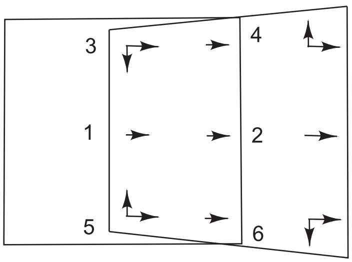


Fig. 3.23 *Effect of Φ tilt*

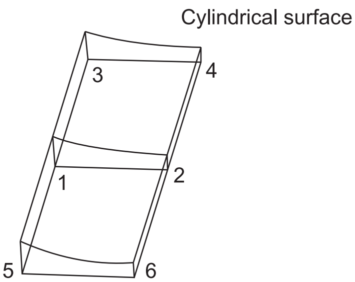


Fig. 3.24 *Deformed surface due to Φ tilt*

(e) Influence of Omega 'ω' tilt

It will be seen from Fig. 3.25 that the change in *X*-parallax in points 3 and 5 is in opposite direction while there is no *X*-parallax change at point 1, 2, 4 and 6. The resulting model deformation is as shown in Fig. 3.26, which is well known as 'ω' twist effect and is, mathematically, a hyperboloid.

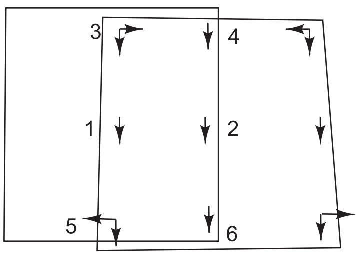


Fig. 3.25 *Effect of ω tilt*

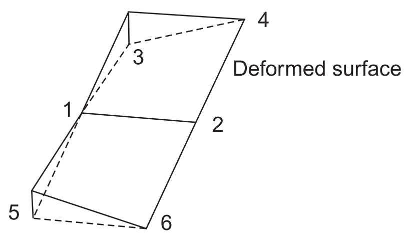


Fig. 3.26 *Deformed surface due to ω tilt*

(f) Influence of kappa 'K'

It can be seen from Fig. 3.27 that there is no parallax at points 1 and 2, while at points 3 and 4, it is equal and opposite to that at points 5 and 6. This results in certain tilt in the model, as shown in Fig. 3.28.

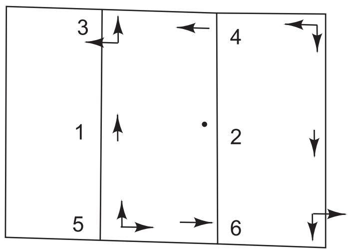


Fig. 3.27 *Effect of kappa rotation*

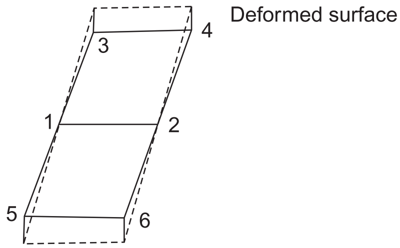


Fig. 3.28 *Deformed surface due to kappa rotation*

A little scrutiny of the deformed surfaces will make it clear that the effects of phi 'φ' and omega 'ω' are only non-linear.

Suggestions for Further Reading

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Frequently Asked Questions

1. Write short notes on: Depth perception; Stereoscopic vision; Accommodation and Convergence; Pseudoscopy; Anaglyphs; Parallax.
2. Describe separation of stereoscopic images by colour filters.
3. Describe separation of stereoscopic images by polarized filter.
4. Write about the principles of Pocket Stereoscope and Mirror Stereoscope.
5. Derive formula for measurement of height from parallax difference.
6. Write about the principle of Floating Marks and its usefulness.
7. Describe Parallax Bar and Parallax Wedge.
8. Write about the Stereoscopic Exaggeration.
9. Write short notes on: Measurement of Slopes: Stereoscopic Constant; Personal Exaggeration Factor; Slope Conversion Chart; ITC Slope Finder; ITC Slope Template; Geometrical Method.
10. Describe briefly about Model deformation and orientation.

4

RADIAL LINE METHODS AND MAP COMPILATION

4.1 INTRODUCTION

Map making essentially aims at portraying the physical and man made features in their correct relative position, both planimetrically and vertically. This is done on an appropriate scale. The survey consists of two parts:

(a) Providing a number of control points (i.e. such points whose latitude and longitude is known) along the periphery of the area and evenly distributed within the area. These control points are generally provided by geodetic triangulation or traversing. Triangulation, in its simplest form, makes use of the elementary property of a triangle, being fully determinable if one side and two angles of the triangle are known.

(b) Once a network of control points is available, the other details are surveyed to fit within the triangle defined by the control points. This survey can also be done by graphical triangulation i.e. if a point on either end of a line, say *A* and *B*, are known then any other point *C* can be found, if angles *BAC* and *ABC* are known (Fig. 4.1). This can be done by drawing lines from *A* and *B* in the appropriate directions. Similarly other points can be found by intersection of the radial lines from *A* and *B*. We should only make sure that the angle *ACB* is not acute. Once '*C*' is found, it is obvious, that we can proceed on the base *BC* or *AC* and proceed as described earlier. In this manner all the planimetric details can be surveyed.

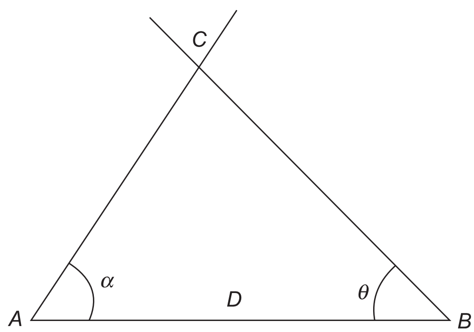

Fig. 4.1 *Radial triangulation*

However, surveying by conventional method is quite expensive. The cost as well as the work load can be cut down with the help of vertical aerial photographs. This is possible only if we could measure angles correctly on the photographs. We know that this can be done under certain circumstances. It is this property which is made use of in Radial Line methods.

4.1.1 Radial Line Methods

The basic principle of radial line method is that on a truly vertical photograph, the angles measured at the principal point in the plane of photograph to the images on the photograph are horizontal angles to the corresponding points on the ground. Thus the aerial photographs can be used for measuring horizontal directions.

Radial line methods can be utilized both for extension of planimetric control over large areas (radial triangulation) and for detailed plotting (radial plotting) and contouring. The equipment is comparatively modest and the technique is simple in principle. The radial line methods are, therefore, of much practical value, particularly so in developing countries.

4.1.2 Choice of Radial Centre

A photograph is a perspective projection of the terrain on a plane, and the angles are true at the principal point, only when the optical axis of the camera has been exactly vertical at the moment of exposure. In such a case the principal point is usually chosen as the radial centre (i.e. a point at which angles can be measured graphically in all directions) for radial line triangulation. Since aerial photograph is a perspective projection, there is certain amount of relief displacement of the images. The relief displacement is radial from the nadir point.

The condition of ideal verticality of the optical axis is normally not feasible, as such we must discuss the effect of non-verticality of the optical axis under different circumstances.

(a) If the ground is having a uniform level, the angles are true at the isocentre and as such it could be used as radial centre.

(b) If the ground is accidented the image of each point is the resultant of two displacements

   (i) radial to the isocentre due to tilt

   (ii) radial to nadir point due to relief

This being so, it is not possible to find any particular point on the photograph at which angles will be true to the corresponding angles on the ground.

The most common situation is as in (b) above. In practical work, it is difficult to find nadir point and isocentre, unless amount and direction of photo-tilt is known. However, for survey from near vertical photographs, it is not worthwhile to go through this tedious process. The principal point is easily determined on the photograph and angles are measured at this point. The angular errors involved are:

(a) error in the angle due to tilt is

$\Delta\Phi_t = -\frac{1}{2}\,\Delta t^2 \sin\Phi \cos\Phi$

(b) error in the angle due to height of the point under consideration

$\Delta\Phi_h = \Delta t \tan\beta \cos\Phi$

These errors are for a point which joined to the principal point, makes an angle 'ϕ' with the principal line and has such a relative height that it subtends an angle 'β' at the principal point (Fig. 4.2). The photo-tilt is Δt.

It will be seen that errors due to relief are much more serious than due to tilt alone. So long as these errors are kept within reasonable limits, say within 50 minutes or so, the map produced is good enough for developmental surveys.

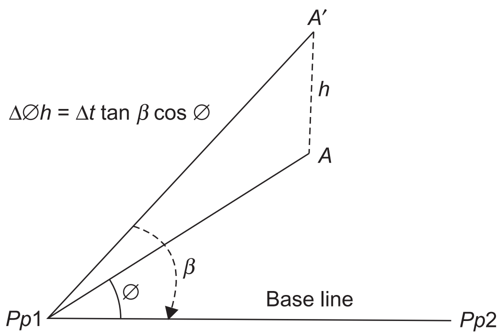

Fig. 4.2 *Error due to relief*

4.1.3 Radial Triangulation

Extension of planimetric control between known control points is carried out by radial triangulation using radial line principle. A minimum of 9 points per photograph, distributed as shown in Fig. 4.3, are provided. Control points so obtained are called minor control points or pass points. Radial triangulation is a method of supplementing of planimetric control. The number of necessary ground control points can be reduced to a minimum by using radial triangulation. Provision of ground control points constitutes a major portion of survey cost, and therefore, by using radial triangulation methods, the time and cost of the survey is reduced.

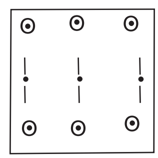

Fig. 4.3 *Minor control points*

The radial triangulation can be carried out by one of the following three methods:

(a) Graphical Radial Triangulation
(b) Mechanical Radial Triangulation
(c) Analytical Radial Triangulation

Analytical radial triangulation is a precise form of aerial triangulation in which the angles are measured by a precision instrument called a radial triangulator under stereoscopic condition and the planimetric coordinates are obtained by numerical computation and adjustment. The graphical and mechanical radial triangulation methods do not involve elaborate computations and are simple and easy in practice.

4.1.4 Radial Plotting

The technique of preparation of planimetric maps by radial line methods is simple and has practical importance. The radial line plotting can be carried out by the following two methods:

(a) Graphical (Arundel) method
(b) Radial Line Plotters

Both the above methods for preparation of maps will be dealt with in the following sections.

4.2 GRAPHICAL RADIAL TRIANGULATION

4.2.1 Basic Problem

Graphical radial triangulation is the simplest of the three methods mentioned in Section 4.1.3. The graphical triangulation method is also called the 'Arundel method', as it was first tried in U.K. on an area near Arundel village. The basic problems in transforming the aerial photographic images into planimetric map are:

(a) to obtain control necessary to establish the true position of principal point of each photograph, and

(b) to obtain positions of other image points with the help of which the detail plotting can be carried out. The minimum ground control points (GCPs) necessary for bringing a strip of aerial photographs to a desired scale and their correct position has to be provided by ground triangulation or traversing. The position of these GCPs are carefully identified in the field and marked on the aerial photographs. A number of suitably located image points are chosen on either side of the principal points in order to develop a chain of radial triangulation. The principle in its simplest form is evident from Fig. 4.4.

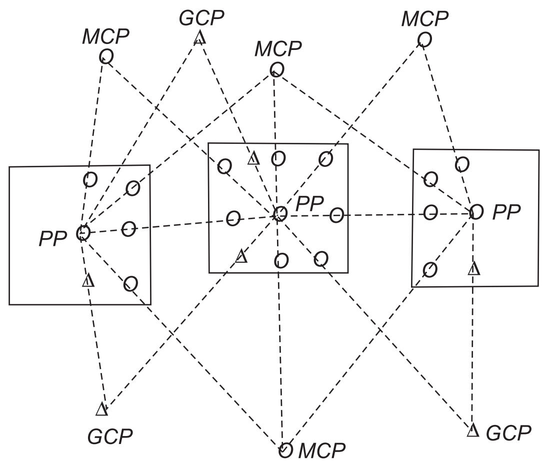

Fig. 4.4 *Radial line principle*

4.2.2 Steps in Graphical Triangulation

Graphical radial triangulation is performed with simple instruments such as mirror stereoscope, a ruler, a piece of Kodatrace, pen and pencil. The graphical radial triangulation is carried out in the following steps:

(a) Preparation
(b) Marking and transfer of principal points
(c) Selection and transfer of minor control points
(d) Selection and transfer of lateral control points
(e) Base-lining and drawing of radial lines
(f) Minor Control Plot
(g) Scaling and combination
(h) Completion

These are elaborated below.

4.2.3 Preparation

Before starting the work all available materials, i.e. photographs, photo indexes, stereoscopes, existing largest scale map of the area, ground control data, etc. are collected. A thorough check is made of the available records and information and a plan of operations is chalked out. The photographs are laid out in strips and all ground control points are identified on the photographs and their numbers marked in black.

4.2.4 Marking and Transfer of Principal Points

In case of 23 × 23 cm aerial photography (viz. Eagle IX camera), a cross appearing at the centre of aerial photograph, represents the principal point. In case of 18 × 18 cm photographs (viz. Wild RC 5(a) or RC 8 cameras), the position of principal point is obtained by intersection of the lines joining diagonally opposite Collimating or Fiducial marks (see Fig. 4.5). The principal point is used as the radial centre. The principal points are then stereoscopically transferred to the adjoining photographs.

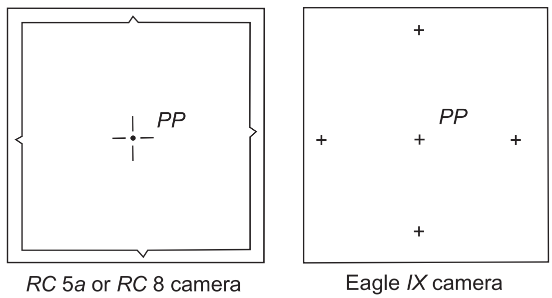

Fig. 4.5 *Fiducial marks*

4.2.5 Selection and Transfer of Minor Control Points

Besides the principal points, two more points, called minor control points (also called pass points or wing points) are selected on both sides of the principal point, at about 2 cm from the upper and lower edge of the photograph, which fulfill the following conditions:

(a) The two points should be as nearly at the same elevation as the principal point.
(b) The points should be at a distance from the principal point, which is equal to twice the mean base of the adjoining photographs.
(c) The points should lie approximately on the bisector of the base angle on either side, and
(d) The point should serve as lateral point as well.

The minor control points (MCPs) are designated by the suffix of strip number, photo number and one letter; the letter U being used for upper and L for the lower edge. The MCP marked as 5/17 U means the upper point of photograph No. 17 of strip No. 5. The numbering is essential to avoid confusion at later stages. The MCPs are then transferred stereoscopically to adjoining photographs.

4.2.6 Selection and Transfer of Lateral Control Points

Lateral control points (LCPs) are selected in the centre of the lateral overlaps of the adjacent strips to serve as connecting points between different strips. These LCPs are selected at least at the beginning and the end of the strip and on every third photo of the strip. These are stereoscopically transferred to photographs of adjoining strips. Such point is numbered with double numbering, e.g. 4/16 L divided by 5/17 U, which means it is a LCP between strips 4 and 5 and lower point of photograph No. 16 and upper point of photograph No. 17.

4.2.7 Base-lining and Drawing of Radial Lines

The principal point bases are then ruled on the photographs. A straight edge is placed along the two points and the line is ruled in red ink right across the half of the photograph and extended for about 2 cm inwards from the opposite margins.

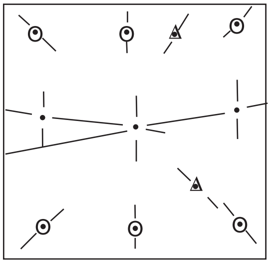

Fig. 4.6 *Photograph showing radial lines*

The radial directions from the principal point to all minor control, lateral control and ground control points appearing on the photograph are drawn in red, through the points for a distance of 2 cm (without crossing over the points). A photograph on completion of the above process looks as given in Fig. 4.6.

4.2.8 Minor Control Plot

Due to elevation differences of the country and variations in the flying height of the aircraft, the scale of photographs varies considerably. The photographs of a strip are brought to one scale through a type of graphical triangulation. The plot of the strip where all the photographs, having uniform scale, are fixed in their correct relative position is called a Minor Control Plot.

The preparation of minor control plot starts with the photograph whose scale is the mean of the scales of all the photos of the strip. It is preferable to start somewhere in the middle of the strip to avoid accumulation of azimuthal errors. Each strip is plotted on a strip of Kodatrace on matted side to facilitate drawing. The photographs are laid out in their correct relative directions so that the plotting may be carried out in the right direction. With the first photograph in position below the Kodatrace, the principal point base is ruled on the Kodatrace in blue ink. The base line is extended about 10 cm beyond the edge of the photograph on either side. The position of principal points of the first photograph and one of the two adjacent photographs is then traced on the Kodatrace. The radial directions to all the points appearing on the photograph are also drawn.

After completing this, the first photograph is removed and the second photograph is placed beneath the Kodatrace such that its base line and principal point coincides with the base line and principal point traced from the first photograph. The Kodatrace is firmly fixed with lead weights and the principal point base to the next photograph and all the radials of the second photograph are traced in blue ink. Similarly, the third photograph is then placed beneath the Kodatrace strip and the above exercise is repeated. The photographs on the other side of the starting photograph are likewise completed. In this way, minor control plots of all the strips are prepared.

4.2.9 Scaling and Combination

The minor control plots of different strips are on different scales. To bring all of them to the same scale, a projection is made on a thick paper on the scale of air survey section, to be made subsequently. Normally, in graphical method, the scale of survey is nearly the same as the mean scale of photographs. On the projected sheet which is usually gridded, all known control data is plotted. This is known as *plot sheet*.

Strips which contain two or more ground control points can be scaled down independently. If there are three or more strips, the strip which has a scale equal to mean photo-scale, is scaled first. Other strips are brought to this common scale through lateral control points.

The *scaling* is carried out by plotting the actual distance *AB* between the two ground control points, between which the scaling is to be done, on a straight line drawn on a separate sheet. On this line, the distance *A′* – *B′* (from the minor control plot) is plotted with *A* and *A′* coinciding as shown in Fig. 4.7. With a pair of bow compass, a semicircle is drawn taking *B′* as centre and distance BB′ as radius. The scaled position of any other point *C′* on minor control plot is obtained by coinciding *A′* with A and *C′* falling on the line *AB*. Draw an arc with *C′* as centre and perpendicular distance from *C′* to the tangent as radius. The arc intersects the line *AB* at *C*, which is the scaled position of point *C′*.

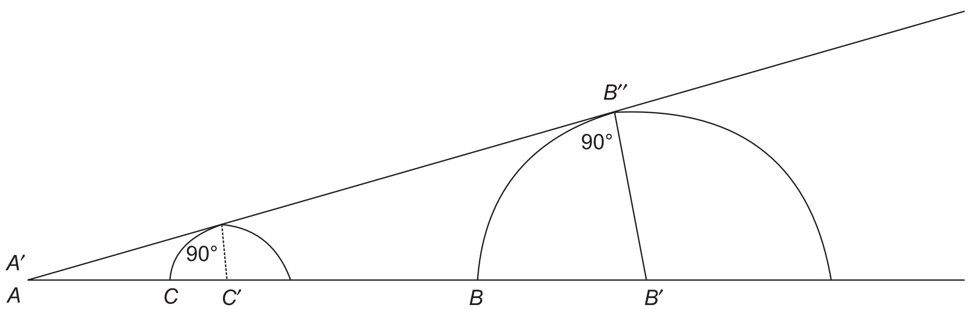

Fig. 4.7 *Scaling in Arundel method*

The ground control points used for scaling are mentioned in the heading thus: "Scaled between points *A* and *B*". After scaling all the points of minor control plot, these points are pricked through the plot sheet. The positions of principal points, minor control points and lateral control points of all the strips are likewise pricked on the plot sheet and adjusted so that all ground control points fall over their plotted positions and lateral control points give positions of least error. This process is known as combination i.e. bringing all the minor control plots on the same scale.

It may be possible to place all the strips in such a way that there are no discrepancies greater than the one that can be tolerated in the final map. However, quite often, it may be necessary to fit portions of strips together using intermediate lateral tie points. It may also be necessary to rescale some strip in two or more parts if scale errors have accumulated. If the discrepancies are still large, the operation is going to be tedious and is likely to give unsatisfactory results. Additional ground control points in strips also serve as a check. The difference in position from two adjacent strips should not normally exceed 3 mm. For better accuracy, the two points used for scaling should be farthest apart. In graphical triangulation, it is desirable that ground control points should exist for every 20 cm length of a strip.

4.2.10 Completion

The pricked positions of the points on the plot sheet are marked in distinctive colours and numbered as on the photograph. After pricking down all the points of all the strips, the accepted positions of principal points, minor control and lateral control points and their numbers are inked up on the plot sheet in distinctive colours for different strips.

4.3 MECHANICAL RADIAL TRIANGULATION

In mechanical radial triangulation, each photograph is represented by a template which should be of a stiff but smooth material. The radial centre is replaced by a hole and radials lines by slots, all of which are punched radial from the hole on the template by a slotting machine. While punching the centre of the hole, it should coincide with the radial centre and the axes of the slots must pass through the radial centre.

4.3.1 Slotted Template Triangulation

The slotted template method carries out minor control plotting, scaling and combination of minor control plots, mechanically and simultaneously, to fit ground control points. It is a block adjustment method as opposed to strip adjustment in graphical triangulation. It is particularly suitable for areas where ground control is sparse. It is a rapid and accurate method, provided proper care is taken at all stages. The only disadvantage of the slotted template method as compared to the graphical method is the additional cost both of instruments and material.

The steps in slotted template method are as follows:

(a) Preparation
(b) Marking and transfer of principal points
(c) Selection and transfer of minor control points
(d) Selection and transfer of lateral control points
(e) Preparation of templates
(f) Centre punching
(g) Slotting
(h) Assembly
(i) Inspection of assembly
(j) Completion

Steps (a) to (d) are carried out in the same way as in graphical radial triangulation as given in Sections 4.2.3 to 4.2.6. In mechanical radial triangulation, all minor control points are selected as far as possible so that they may be used as lateral control points between the adjoining strips.

4.3.2 Preparation of Templates

The templates should be slightly bigger in size than the photographs to permit scale enlargement, if necessary. The templates may be of transparent acetate or opaque impregnated hylam sheets of 1/64th inch thickness. Thick exposed X-ray films can also be used as a good substitute.

After all the points have been marked on the photographs, each photograph is firmly clipped on its template and all the points are pricked down on the template. The pricking should be done methodically to avoid any missing point, thus principal points first, then minor control points, followed by lateral control points and lastly ground control points. All the points pricked are circled in black or any other suitable colour using colour grease pencil, on the template. The pricks of minor, lateral and ground control points are numbered clear of the radial lines. The principal points are so numbered that it reads correctly when oriented towards the north. The pricks are numbered with lettering of 1/8th inch height and close to the point.

After all the templates of a strip have been pricked, radial lines, about 6 cm long, are drawn through all the points from the radial centre with a straight edge and a pricker. If the radial lines of two adjacent points clash, only one of them, usually the more reliable one is punched. If a slotting machine (Radial Sector – I or II) is available then this step is not required.

4.3.3 Centre Punching

After radial lining of templates, the central hole at the radial centre is punched. The pin point of the centre punch is placed on the principal point prick and the punch is pressed down vertically until the cutting edge of the punch is resting firmly on the template. The punch is then given a sharp blow with the hammer, just sufficient to cut the template cleanly. The centre punching of all the templates is completed first.

4.3.4 Slotting

After centre punching, the template is placed in the slotting machine – Zeiss Radial Sector - I/II (or any other machine available), with the centre hole on the centre stud of the machine. The template is swung around until the registering pin is over a prick of any minor or lateral control point. The lever arm is pulled slowly down until the pin touches the prick, then the slotting is accomplished by a sharp pull down. In this way all the radial slots of a template are cut (see Fig. 4.8). The slot is 4 mm in width and 5 cm in length; these are about 0.05 to 0.15 mm bigger than the diameter of the studs, to accommodate errors in transference of points and in using the principal point as radial centre as well as allowing free movement. All the slotted templates are examined for defects in cutting and a new template is cut if any one is found defective. The templates are then trimmed leaving about 2 cm beyond the outer edge of the radial slots. In Zeiss Radial Sector – I, the registering of slots is done with the help of an optical arrangement. It also permits enlargement or reduction up to two times of the photo-scale.

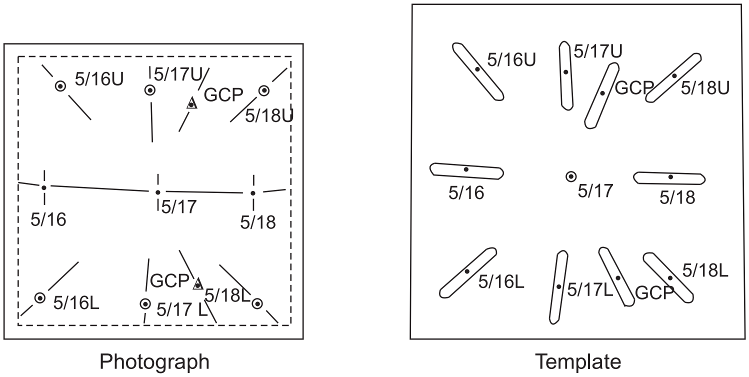

Fig. 4.8 *Slotted template*

4.3.5 Assembly

The slotted template assembly is usually carried out on a flat Masonite board kept over a flat smooth topped table. Rectangular grid is projected on the scale of assembly with lines 1000 m apart on medium and small scales, over thick Cartridge or Raglitho paper sheets. These sheets are pasted to form a big sheet, covering the whole of the assembly board. The sheet is then fixed firmly on the Masonite board, using cello tape. The gridded sheet should be seasoned before use. The ground control points are then plotted on the sheet.

After plotting, needles are pricked on the assembly board over all the ground controlled points and studs are put over the needles. Some identifying coloured tapes, triangular or circular in shape and about 2 cm in size, having central holes are used for GCPs. The bases of the studs for GCPs may be fixed to the board by a strong adhesive like durofix and the pins may be removed thereafter.

The assembly is started with the templates of the strip selected as starting strip, from a ground control point. The concerned radial slot of the first template is engaged on the GCP stud and metal studs are inserted in the central hole and other radial slots of the first template. The next template is fixed by first inserting the radial slot for the transferred principal point of first photo on the stud meant for it and then sliding it till the radial slots for minor or lateral control points enter the stud already there. More studs are inserted in the empty slots of the second templates. The third template is connected to it in the similar way. In this way template after template are connected till the next GCP is reached. There will be closing errors in scale as well as azimuth, which can be easily adjusted by moving the whole assembly in or out and by rotating it (see Fig. 4.9). When one strip is scaled down, the adjacent strip can be easily assembled because the LCPs provide the scale. If difficulty is experienced in fitting templates to LCPs or MCPs, slight bending of the first strip may help out; however, no force is to be applied.

Where a GCP falls too close to a principal point or base line to permit a separate stud, the assembly is made to cover the two or three adjacent control points. The two templates fixing the difficult control point are then moved forcibly so that that the intersection of the engraved radial line, or the point indicated by the procedure of proportional distance, lies over the plotted position of the GCP. The nearest principal point stud should then be nailed as a substitute control point. It is best to avoid selecting a control point near the principal point base (see Fig. 4.9).

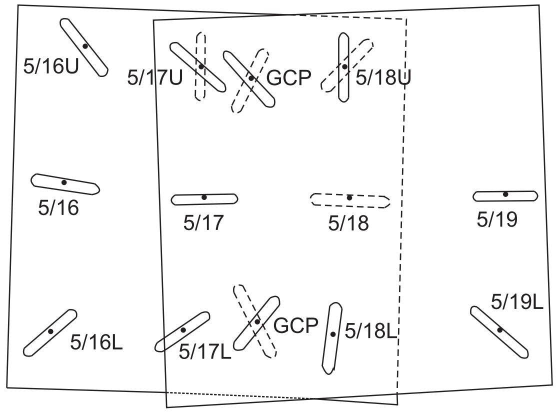

Fig. 4.9 *Assembly of slotted templates*

4.3.6 Inspection of Assembly

On completion of assembly, it should be inspected for ill fitting or buckling, etc. The majority of errors are due to mis-identification or wrong transfer of points or bad slot cutting. A doubtful template should be examined as follows:

(a) Check the identity of MCPs and their transference for three overlaps on either side.
(b) Check the identity of LCPs and their transference for three overlaps on either side, on both the strips.
(c) Check the transference of principal points for three overlaps.
(d) Check for correct slotting by placing the doubtful template over its photograph.
(e) If no errors are found complete the assembly without the faulty photograph and fit it last of all.
(f) If the above is not possible, check if the error is due to a faulty or mis-identified GCP, by releasing the assembly from its stud. Use another control if available nearby.

4.3.7 Completion

When the whole area has been satisfactorily assembled, the studs of all principal point, minor control and lateral control points are nailed down by a fine pin through the centre of the studs. As the templates are removed one by one, the pricked points on the plot sheet are identified by the numbers appearing on the template in pencil.

When the whole assembly is dismantled, the pricked positions of principal points, minor control and lateral control points and their numbers are inked up on the plot sheet in distinctive colours for different strips.

4.3.8 Accuracy

The ground control requirements for constructing a slotted template assembly depend on the number of photographs involved, on the permissible error in the map and position of principal points and minor control points. Troray (U.K.) has established an empirical equation for finding the density of GCPs required to properly controlling a slotted template assembly. This empirical equation is:

$E = k.\sqrt{t}/c$, where E is the arithmetic mean error in position of minor control and principal points in millimeters on the scale of combination; 't' is the number of templates involved in the assembly; 'c' is the number of GCPs used and 'k' is a constant. For computing '*c*', a cluster of points should be taken as 1. Tests indicate that this equation provides adequate accuracy, if the constant '*k*' is taken as 0.16.

4.3.9 Distribution of Control Points

The disposition of control points is also important, though no formula can be applied. Experimentally, the following lay out of control points has been found suitable.

1. Minimum control requires a point in each corner of the assembly.
2. Additional points can be:
   (a) In the centre.
   (b) In every 5^{th} or 6^{th} template in the top and bottom strip.
   (c) In the first and last template of intervening strip.

The survey should not be extended beyond the periphery of control points used for combination.

4.4 MAP COMPILATION BY GRAPHICAL METHOD

4.4.1 Map Compilation

Map compilation is a process where selected detail is plotted on the map, step by step. Complete new maps are normally compiled by graphical or Arundel method from aerial photographs. This method is convenient when the scale of compilation and the vertical aerial photographs are approximately the same. The method utilizes simple instruments like mirror stereoscope and ruler for compilation. The method is of great practical importance where rapid mapping is required. This method of air survey is generally suitable for terrain where height differences are less than $1/10^{th}$ of the flying height above ground. However, if lesser accuracy is acceptable, as is often the case for natural resources survey, then the method is used in terrain with greater relief variation as well. The Arundel method of air survey is carried out in the following steps:

(a) Preparation of air survey section
(b) Interpretation and chalking of details
(c) Framework of intersections
(d) Survey of detail or planimetry
(e) Height control for contouring
(f) Contouring on photographs
(g) Survey of contours on Air Survey Section
(h) Completion of Air Survey Section

4.4.2 Preparation of Air Survey Section

The grid or graticule, principal, minor, lateral and ground control points are traced from the plot sheet on to matt side of a sheet of Kodatrace in blue water proof ink to form the air survey section. On this section the plotting of all the GCPs is checked. All inking on the section is done in water proof ink, as other ink is likely to flake off. The heading of the air survey section and sheet number (if any) is written in black.

4.4.3 Interpretation and Chalking of Details

All photographs falling on the air survey section are examined under the stereoscope. The details, which will appear on the final map, are interpreted and chalked on alternate photographs in the following order:

(a) Temples, churches, mosques, towers, power and telegraph lines.
(b) Isolated huts and caves
(c) Graveyards
(d) Village blocks
(e) Communication in the following order: footpaths, pack tracks, roads and railways together with their cuttings and embankments.
(f) Pipe lines and wells
(g) Perennial water forms—irrigation canals, tanks and streams.
(h) Limits of cultivation
(i) Dry water course
(j) Isolated conspicuous trees
(k) Steep banks and broken ground which will appear on the final map in black.

The details which will appear on the final map according to the standard of generalization employed on the scale of publication will only be chalked up. In surveys for natural resources, considerable generalizations can be done. Many items of detail, which appear on a normal topographic map, are not required and can be conveniently omitted. The symbols given in Conventional Signs Table are recommended for use. Suitable colours could be used on the photographs and on the air survey section.

4.4.4 Framework of Intersections

On completion of interpretation, the intersections of photo-points about 2 cm apart on the scale of photograph are transferred to the air survey section. These auxiliary points are chosen at points of identifiable details, e.g. at change of slope, track junctions, stream junctions, cultivation corners, etc. These are stereoscopically transferred to adjacent photographs. The auxiliary points are intersected by radial lines drawn in blue pencil and their intersected positions on the air survey section are marked by small dots in vermillion (water proof ink). The density of this network depends on the difference in scale between photograph and air survey section, ruggedness of the terrain and the skill of the surveyor. Details lying on or near the principal point bases cannot be intersected and must be adjusted in proportion to the distance from the principal points (see Fig. 4.10).

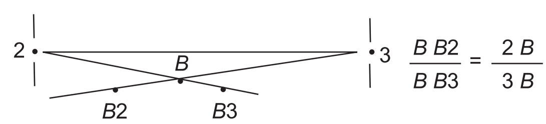

Fig. 4.10 *Intersection closer to base line*

4.4.5 Survey of Planimetry

Planimetry within each small triangle formed by the intersected points is surveyed in pencil to its correct position. The final scale adjustment is carried out by eye estimation and sliding the chalked photograph gradually. The planimetry traced in pencil on the air survey section is finally inked up in different prescribed colours. Ridge lines are then drawn in a non-photographic colour to assist in survey of contours.

4.4.6 Height Control for Contouring

About eight to ten height control points are provided on each stereo-pair of aerial photographs at important changes of slope and at hill tops and valleys either on the ground by plain-table and clinometer or aerial triangulation. The network of spot heights is augmented with the help of parallax bar observations. The height differences are calculated from the parallax differences thus measured. The height control points are then transferred to and marked on the alternate unchalked aerial photographs. A density of about 20 to 30 heights in an overlap will usually suffice.

4.4.7 Contouring on Photographs

After appropriate density of the height control network has been provided and the most important slope changes in the terrain are marked, the vertical aerial photographs are observed stereoscopically. The contours are surveyed by estimation along ridges, spurs and streams between the height control. The contours are chalked in brown pencil on those photographs on which other details were chalked.

In some cases extensive dead ground or dark shadows may prevent the correct interpretation of contours in small valleys. These areas should be contoured with form lines as best as possible.

Accurate contouring on air photographs can be carried out only by a person who has acute stereoscopic vision and has ample experience with the stereoscope. He should also be fully qualified in contouring of all types of terrain in ground survey.

4.4.8 Tracing of Contour

At this stage, the air survey section contains complete planimetry and all the alternate photographs have both details and contours chalked up on them. The survey of contour merely consists of adjusting the photographs under the section so that the details fit over a small area and the contours are traced directly on to the air survey section over this small area. After this the details in an adjacent area are fitted and the contours are traced and the process goes on. The contours are inked up on the section in burnt amber for thick and burnt sienna water proof ink for thin contours.

4.4.9 Completion of Air Survey Section

The air survey section is now complete except for names and information regarding vegetation. If this information has been collected earlier by ground verification of photographs, the names are entered in blue pencil at appropriate places and are later typed. The information regarding vegetation is also entered by comparison with photographs. The scattered trees, scrub or bushes are also drawn. The limits of extensive wooded areas are inked up in green mixed with black. Selected spot heights are entered on the section. Colour traces should be prepared for each air survey section as necessary to assist in subsequent fair drawing.

The border is then inked up. The information regarding title, sheet numbering, legend, scale, contour interval, index to sheets, administrative index, copyright legend and other relevant information are then lettered at appropriate places. Name of the air surveyor should be entered in bottom left hand corner of the air survey section.

The air survey section is then tested for accuracy by intersecting some detail at intervals. The contouring is checked by computing some fresh spot heights by parallax bar observations. Such spot heights should agree with surveyed contours within half the contour interval. After checking, the faint inking are all finally touched up and then the air survey section is varnished with a solution of Durofix and Amyle Acetate to prevent flaking off.

4.5 RADIAL LINE PLOTTER

The plotting of planimetric map is greatly speeded up by the use of plotting instruments called Radial Line Plotters, which solve the problem of radial line intersection continuously (Radial Line Plotters were/are manufactured by Kail in USA and Hilger and Watts in UK).

4.5.1 Parts of Instrument

A radial line plotter consists of the following parts:

(a) a mirror stereoscope for stereoscopic viewing of photographs,
(b) two photo-tables on which the photographs are mounted,
(c) a pair of transparent arms, with radial line mark, which passes above and below the photo-tables and rotate about the centre of photo-tables,
(d) a parallel bar which moves parallel to photo-base and the ends of which connect to the lower part of each radial arm by means of a pin fitted into a slot in the arm,
(e) a linkage connecting the parallel bar to a pencil chuck, and
(f) the pencil chuck which holds the pencil

4.5.2 Operating Principle

The operating principle of Radial Line Plotter is that of continuous radial intersections and is shown in Fig. 4.11. The overlapping pair of photographs is placed on the photo-tables and is oriented by making the common base lines on the two photographs coincide with each other when the photographs are viewed through the mirror stereoscope. The positions of the principal points of the photographs are fixed on the tables by pins, which also pass through the radial arms. Orientation takes place by rotating the photographs about these pins. A map sheet lying underneath the plotter and containing model control points, is used to fix the plotting scale. As the operator views the two photographs as one stereoscopic image, the radial lines etched on the radial arms appear to cross at a point which represents the continuous intersection point and its motion is conveyed to a pencil moving over the map sheet.

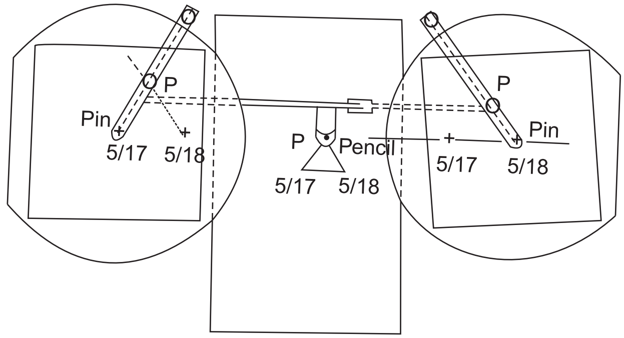

Fig. 4.11 *Principle of radial line plotter*

The scaling is performed with two ground control points, farthest apart, and is checked on two other points. Thus, it is desirable to have four ground control points per overlap for radial line plotters. When the scaling has been satisfactorily adjusted to fit the ground control points, the operator can trace the planimetric features. As the pencil is moved along a feature being surveyed, the apparent intersection of radial lines also moves and the feature is located in its correct map position by continuous intersection.

The three dimensional image seen through the stereoscope greatly enhances the operator's ability to interpret planimetric features, thus making the plotting operation more efficient. The scale range in radial line plotters varies from slightly larger to one-third of the photograph scale. Plotting is straight forward except for the area in the centre of the overlap where the intersection angle is too small to be decisive. The shaded area shown in Fig. 4.12 gives intersection of less than 30°; the circles are locii of intersection of 45°. In the Hilger and Watts Plotter, this difficulty is overcome by displacing the radial centers at fixed distance and intersecting from a false centre.

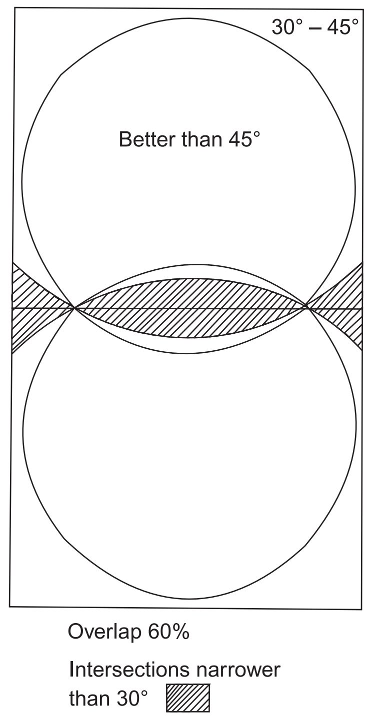

Fig. 4.12 *Narrow intersections in an overlap*

The assumption used in this plotter is that tilts are small, so that principal point can be taken as a good substitute for the plumb point. These instruments give a correct solution only when truly vertical or rectified photographs are used. They are more suitable for mapping at scales less than the scale of photography.

There is no provision for measuring or tracing contours. The instrument may be used for plotting the contour if it has been interpolated and penciled on one photograph of the pair.

4.6 ACCURACY OF RADIAL LINE METHOD

The accuracy of a radial line compilation depends upon the range and distribution of photo-tilts, variation in flying height and relief of the terrain. It also depends on the density and distribution of ground control points and their relationship to the pattern of strips and photographs used.

Some idea of the accuracy of an assembly can be had by the discrepancies between strips in graphical triangulation, or by the lack of buckling, etc. of the slotted template assembly and the ease of connecting on to additional control points. Of course, the pattern and density of control points used are equally significant for final accuracy.

4.6.1 Advantages

The advantages of radial line methods are as follows;

(a) It is economical and quicker than ground method, provided that the photographs are near vertical.

(b) It is useful for making maps of inaccessible territory.

(c) The method is simple and needs only inexpensive instruments like mirror stereoscope and ruler.

(d) The method is suitable for rapid revision of maps prepared by other methods.

4.6.2 Limitations

The limitations of radial line methods are given below:

(a) The method can only be applied with caution if the elevation differences are more than 10% of flying height. In such cases the accuracy does not come up to the standard, desired in topographic mapping.

(b) The scale of photography has to be kept larger than the scale of the final map.

(c) The method is slow as compared to photogrammetric plotting in restitution instruments.

4.6.3 Precautions

If it is known or discernible from the relative deviations of the two component photographs that tilts during exposure are large, it is best, particularly for mountainous country, to transform the photographs in to exactly true verticals by rectification beforehand. If no other means are available, the data for rectification is obtained by radial triangulation.

The dimensional changes in ordinary photographic paper due to humidity and temperature changes sometimes vitiate the accuracy of radial line method. To obtain the best results, the photographic prints for survey should be prepared on non-shrink, foil-mounted Agfa Correctostat Paper.

Whenever the radial line method is used, it should be remembered that the method is used solely as a matter of economy and expediency in relation to the material and instruments available and the final results to be achieved.

4.6.4 Digital Photogrammetry

The recent advances in Electronics and Computer Science have provided new approaches for solving problems of Photogrammetry. While the basic mathematics, optical theory and basic practices of Photogrammetry remain valid, new techniques and new equipments have been introduced to address the traditional problem of map making and geographic information extraction.

Digital Photogrammetry deals with topics like Scanning, Airborne and Satellite Global Positioning System (GPS), Storage and Compression of Data, Aerial Triangulation and Image Registration, Digital Elevation Model (DEM), and Digital Orthophotos. DEM is the digital cartographic representation of the elevation of the land (z value) at regularly spaced intervals in x and y directions (eastings and northings or longitude and latitude). Various types of DEM are produced on the pattern of topographic maps (7.5 minutes, 30 minutes and 1 degree, latitude and longitude). These are also classified as Level 1, 2 or 3, depending on their level of accuracy. Digital Terrain Model (DTM) is similar to DEM, but it incorporates significant topographic features, land marks and the change points which are irregularly placed. The DTM results are technically superior to DEM for many applications.

Digital Photogrammetry also includes feature extraction and object recognition to use in mapping and resource management. The technique incorporates the functionality of analytical stereoplotters and integrates numerous photogrammetric tasks into the computer based environment.

Some more techniques are being developed and used for more specific applications. These include Videography, Radargrammetry and Laser Imaging Direction and Ranging (LIDAR). The details on these topics are beyond the scope of this book and interested readers may consult relevant books, some of these are given at the end of this chapter.

Suggestions for Further Reading

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Frequently Asked Questions

1. What are different types of Radial Triangulation?
2. Describe different steps involved in Graphical Triangulation and Mechanical Triangulation.
3. Write about Scaling carried out in Graphic Triangulation.
4. Describe different steps involved in Map Compilation by Arundel Method.
5. What is the operating principle of radial line plotter?
6. Write about Map Compilation by radial line plotter.
7. What are the advantages, limitations and precautions to be taken in Radial Line Methods?
8. Write short notes on: Ground Control Point (GCP); Minor Control Point (MCP); Lateral Control Point (LCP); Accuracy and requirement of GCPs; Digital Photogrammetry.

5

AERIAL MOSAICS

5.1 INTRODUCTION

5.1.1 Definition

An aerial mosaic is an assemblage of aerial photographs, the edges of which have been cut and matched to form a continuous photographic representation of a portion of Earth's surface.

5.1.2 Mosaic and Map

A mosaic is similar to a planimetric map as these have an over-all scale and can be produced in quantity. A mosaic differs from a map as it is a perspective projection of the ground, as against the orthographic projection of the map. The mosaic suffers from non-uniformity of scales, whereas the map has a uniform scale. A mosaic shows actual photographic images of ground features, while these are portrayed by standard conventional symbols on the map.

To varying degree of accuracy, a mosaic is a map substitute. The size of errors depends on the amount of terrain relief, the exactness of photographic rectification and the accuracy and density of control points, on to which the photographs have been fitted, while mosaicing.

5.1.3 Types of Mosaic

Based on the method of compilation, the mosaics are classified in to the following types:

(a) Controlled mosaic – is a compilation of scaled and rectified photographs, which have been assembled to fit plotted control points.

(b) Semi-controlled mosaic – is a compilation of photographs, without using rectified photographs or utilizing control for positioning of each photograph. However, the scale and azimuth are within limits.

(c) Uncontrolled mosaic – is a compilation of photographs, without regard to any horizontal control positions. The photographs are oriented in position by matching corresponding images on adjacent photographs. The scale and azimuth are compromised in uncontrolled mosaic.

5.1.4 Uses of Mosaics

Mosaics are of great value for planning purposes. The study of geological features, flood control problems, irrigation projects and investigation of natural resources e.g. soils and forests are much simplified by the use of mosaics. For highway and railway locations and for alignment of pipe lines, transmission lines, etc., the mosaic permits selection of best possible locations, without extensive field surveys. Mosaics are also useful for urban planning.

5.1.5 Advantages of Mosaic

(a) A mosaic can be compiled more rapidly and economically than map.
(b) A mosaic shows wealth of details which a map can never equal.
(c) Certain terrain features can be more easily recognized and interpreted on a mosaic.
(d) No detail of a terrain is omitted on a mosaic whereas a map presents only selected items of the detail.
(e) A mosaic presents a vast area for study in a composite form, which is important for all planning processes.

5.1.6 Limitations of Mosaic

(a) The basic disadvantage of a mosaic for use as a map substitute, is the inaccuracy in the horizontal positions of details, because of relief, tilt and scale variations.
(b) The wealth of terrain details, at times, turns out to be a disadvantage, due to excessive details obscuring some of the important features.
(c) Lack of topographic information, e.g. terrain height or contours.
(d) Lack of names of places and features.

To minimize the effects of (c) and (d) above, the mosaics are annotated with the desired information, either directly on the mosaic or on a transparent overlay.

Mosaics of aerial photographs play an important role in all natural resources surveys. A photo-interpreter is seldom required to produce photo-mosaic by himself; this task is generally entrusted to an air survey or photogrammetric organization. This chapter is, however, intended to give sufficient background to appreciate the advantages and limitations of aerial mosaics and to be able to compile a simpler mosaic, if need be.

5.2 PLANNING FOR MOSAICS

When ordering for aerial photography with a view to mosaic compilation, a few factors need to be considered. These factors are: scale of mosaic, scale of photography, focal length of aerial camera to be used and requirement of ground control points. The intended use of the mosaic, the accuracy desired the nature of terrain and availability of time and funds govern consideration of these factors.

5.2.1 Scale of Mosaic

The scale of mosaic is decided by its intended use. These are given below:

(a) Small scale (1; 20,000 or smaller) mosaics – are used in geology, soil survey, forestry, flood control and other studies of extensive areas.

(b) Medium scale (1; 10,000 to 1: 20,000) mosaics – are used in town planning, preliminary location work for highways, railways, transmission lines, pipe lines, etc.

(c) Large scale (larger than 1: 10,000) mosaics – are used for detailed investigations of any of the above purposes. Generally, mosaics on 1: 5,000 scale are used.

5.2.2 Scale of Photography

The scale of photography is directly related to the scale of mosaic. In developed countries, where good photographic laboratories are available, the enlargement from aerial photography to mosaic can be extended up to four times i.e. the scale of photography may be ¼ th of the intended mosaic scale. Normally, no enlargement larger than two times should be planned. For precision work, where planimetric scale is of importance, the scale of aerial photography should be 1.5 times of the mosaic scale. For instance, the scale of aerial photography should not be smaller than 1: 30,000 scale for mosaic of 1: 20,000 scale.

5.2.3 Focal Length of Aerial Camera

The selection of focal length of the camera is related to flying height and relief displacement. When a camera having short focal length is used, the plane flies at a low altitude, which adversely affects the ease and cost of flying operations and the relief displacement is relatively large. When a camera having a long focal length is used, the flying height is increased and relief displacement of images is reduced. The variations in scales between successive photographs are reduced as the flying height is increased. The variation in flying height is also smaller when flying at higher altitudes.

Generally, focal lengths of 15 cm, 21 cm and 30 cm are used for photography for mosaic compilation. In rugged areas, where the scale of mosaic is small, 15 cm lens Wild RC 5(a) or RC 8 camera will be most suitable, whereas 30 cm lens Ross Eagle IX camera will meet the requirements of a mosaic of urban area. The 21 cm lens Wild RC 5 (a) camera is suitable for practically all types of mosaics.

When photography is taken to serve the dual purpose of preparation of topographic maps and compilation of mosaics, the requirement of photogrammetric mapping will govern the factors in flight planning.

5.2.4 Requirement of Ground Control

Ground control points are required for controlled and semi-controlled mosaics. First the density, distribution and accuracy of existing ground control points should be investigated. If the existing control points are not sufficient, extension of planimetric control by radial triangulation, using slotted template method should be considered. If the existing ground control points are not sufficient for slotted template assembly, some of the identifiable ground details of existing maps may be used as control points. If this is not possible, the existing ground control points should be supplemented by additional control provided by triangulation or traversing.

The use of existing topographical maps for control of mosaic compilation is possible when the published map is accurate and the scale of map is nearly equal to the scale of radial triangulation.

The provision of control points is the responsibility of the organization entrusted with the construction of mosaic. However, if the photo-interpreter is constructing his own mosaic, he should, as far as possible, obtain control from the existing largest scale map and extend it by radial triangulation, where necessary. The radial triangulation, as given in Section 4.1.3 of Chapter 4 should be followed.

5.2.5 Mounting Board

Several types of mounting boards, which have been treated to withstand moisture are used. A veneer of birch or maple that is smoothly sanded and periodically sealed with a resin is fairly satisfactory. Fir plywood is not satisfactory because the alternate boards of hard and soft wood may cause ridges to appear on the finished mosaic. Open-grained plywood like walnut, mahogany and oak are not recommended. The following brands of Indian plywood are found satisfactory: Aero, National, Rocket and Sitapur Plywood Products having thicknesses of 4 mm and 6 mm. A piece of masonite board 1/8 inch thick is a very satisfactory mounting board. The mounting board size varies from 5 feet by 3 feet or 8 feet by 4 feet. If contact size reproductions are required, the maximum sizes of film or bromide paper restrict the size of mosaic.

5.2.6 Adhesive

The most convenient adhesive to work with mounting photographs in mosaic construction is gum Arabic which comes in powdered form or in tear drop form. The powdered gum Arabic, though expensive, is easier to prepare in small batches. The adhesive is prepared in warm water in proportion of 5 ponds of gum to 1 gallon of water and by stirring the mixture all the time until it attains the consistency of strained honey. To prevent the mixture from becoming sour, 3 or 4 ounces of salicylic acid should be added to each gallon of adhesive. Ten ounces of glycerin, added to each gallon of adhesive, will prevent the mounted photographs from becoming brittle and curling at edges.

5.2.7 Photographic Paper

Generally, single weight glossy paper is used for uncontrolled mosaic. For higher quality, glossy photographic paper of double weight or waterproof type should be used for construction of mosaic, as differential expansion factor of photographic paper of single weight during exposure, drying and application of adhesive may be as much as 1% normal to the grain. For construction of controlled mosaic, it has been found expedient to use foil mounted correctostat bromide paper for alternate photographs. In making rectified prints, it is a good practice to keep the direction of the photographic paper grain constant.

5.3 MOSAIC COMPILATION

Compilation of controlled mosaic is an elaborate and precision technique and should preferably be carried out by organizations fully equipped to carry out rectification of photographs. The photo-interpreter may have to compile an uncontrolled mosaic as a matter of expediency. In this section the operational procedure for compilation of all types of mosaics will be described so that it may be consulted when assembly of mosaic is contemplated.

5.3.1 Controlled Mosaic

The controlled mosaic is the most accurate form of mosaic. The photographs are rectified and scaled before, in order to remove the errors due to tilt displacements and scale differences. For proper scaling of each photograph, sufficient control points are provided by radial triangulation, if these are not already available from existing maps. In a controlled mosaic, the scale of aerial photograph has already been chosen to restrict the errors due to relief displacement within tolerable limits.

Actual rectification process consists of placing the role of film negative in the negative carrier of the rectifier and the radial line plots at the compilation scale, on the projection table. When radial line plots are too large, then templates of alternate photographs are prepared on astrafoil sheets by tracing the grid lines and positions of control points on it. The settings of the rectifier are systematically altered according to their effects so that gradually the coincidence of the projected image of the control points which are marked on the film negative with their position on the plot is achieved. With experienced operators the time taken for rectification of each photograph is about 10–15 minutes. After the coincidence has been achieved, the plot on the projection table is replaced by bromide paper and exposed. In this way all the selected photographs are scaled and rectified.

After drying of the rectified prints, the control points are marked on the photographs by a circle in grease pencil. The control points consist of all principal points, conjugate principal points and at least four minor control points, on each photograph as obtained from the radial line plot.

The photographs are assembled in a loose assembly at least two strips at a time and the cut lines of each photograph are marked by grease pencil, by matching the edges.

While marking the cut lines, due consideration should be given to matching of tones and photographic details. When the cut line has been determined, a single edge razor blade is used to barely cut through the emulsion of the photograph. The photograph is then placed with the emulsion side down and the discarded portion is torn back towards the portion to be used. This process gives the edge of the photograph a feathered appearance. The technique of feathering the edges is important as it ensures smoothness of layers of prints less perceptible. Fine sand paper is then used to smoothen out this feather edge.

Before commencing mosaicing, the mosaic board is cleaned and the grid lines are projected on it. In addition to the photographs, the adhesive, razor blade, sand paper, a pail of water, two or three sponges and a squeegee made from 1/16 inch thick celluloid piece, whose edges and corners have been rounded, or a small rubber roller and some pins or needles are collected.

The first photograph to be mounted is placed at its position. The positions of its control points relative to their plotted positions are checked. The adhesive is spread in to the back of the print by hand and the print is then placed in position on the mounting board. A needle is pushed through the principal point and a second needle through another control point. The needle through principal point is centered on the mounting board position of the principal point; the other needle is centered on the corresponding control point on the mounting board. This operation positions and orients the photograph on the mounting board. Before the point is squeezed down, the coincidence of other control points may be checked virtually by flipping the edges of the photograph over the mounting board. A slight amount of rotation may be necessary to strike an average coincidence of all points. However, the position of the principal point should be held fixed. The photograph is then secured by means of the squeegee, working from the centre outwards. All air pockets and surplus adhesive must be removed by means of the squeegee. Adhesive is then wiped out from the surface of the print and the board by means of a damp sponge. After the adhesive has set, the second print is oriented on to the control and flipped over the first print to permit a visual selection of the cut line.

After cutting and feather edging the second print is placed in its position to fit its principal point and other control points. The adhesive is applied and the print is matched to the principal point and the other control points. The second print is squeezed in to place and the excess adhesive is wiped out from the face of the print and the board. The direction of squeezing is always towards the edge of the print, being mounted. In this way all other photographs are fitted in their positions.

Loose print edges sometimes occur and a stronger adhesive such as case-in-glue is used to make such edges adhere.

5.3.2 Semi-controlled Mosaic

When arrangements for rectification are not readily available, it is not possible to compile a controlled mosaic. Under such circumstances and for reasons of expediency, semi-controlled mosaics are prepared. For compiling a semi-controlled mosaic, the photographs are enlarged or reduced to the scale of mosaic compilation. If adequate ground or map control points are not available for scaling, control extension is carried out by radial triangulation. In very rare cases, when no control is available and there is urgent requirement of a mosaic, or where the accuracy requirements do not demand more precise control, an azimuth line or a series of azimuth lines may be used to afford simple control for semi-controlled mosaic.

The azimuth line is prepared in the following manner. The photographs are laid on the map table in proper sequence, taking care that the images of successive photographs match. As each photograph is placed, it is held in position along its edges by small weights. A straight edge is laid over the strip so as to pass through the centers of as many photographs as possible, and a fine line is drawn across the face of the top photograph. The photographs are then separated. In the common portion of first and second photographs, two points '*a*' and '*b*' are selected on first photograph which are transferred to the second photograph. A fine line is drawn across the face of this photograph and a new pair of points '*c*' and '*d*' are chosen on the line which also appear on the third photograph. The process is continued throughout the remaining part of the strip.

The azimuth line control is very useful in that it prevents the flying strip from swinging off line as the photographs are mounted. It also prevents errors, caused by miss-matches, from accumulating out towards the corners of the mosaic. This type of control is very easy to prepare.

Before assembly, all photographs are either scaled, if possible, or marked with azimuth line. Each photograph is then trimmed, featheredged as in the case of controlled mosaic and assembled in position, oriented either on the control point or on the azimuth line.

5.3.3 Uncontrolled Mosaic

Mosaics requiring less accuracy can be compiled by less rigid methods. In uncontrolled mosaic, an effort is made to bring the photographs to a common scale, if some ground control points are available in the area. If not, the uncontrolled mosaic is assembled in such a way that photographs match edge to edge. Each photograph is trimmed and featheredged before it is pasted on the mounting board. However, the circumstances under which the uncontrolled mosaics will be compiled should be rare. Sufficient ground control or map control data is available throughout the country to prepare, at least, semi-controlled mosaics.

5.4 ANNOTATION AND REPRODUCTION

5.4.1 Editing

After the assembly of all the photographs has been completed, the grease pencil marks are removed from the face of the print with a cleaning fluid, generally Benzol. While doing so, care has to be taken not to disturb the edges of the prints.

As a rule, this is followed by slight touching up of the mosaic to eliminate differences in tone and disturbing influences in the photographs e.g. trails of smoke, vehicles, reflection of water surfaces, etc. A black dye, which is diluted in water to produce the various shades of grey, is applied with a soft brush to obtain a balanced tone throughout the mosaic.

The mosaic is completed by mounting a white border along the four margins.

5.4.2 Annotation

Mosaics should contain sufficient information to fulfill the requirements of a map substitute. The grid lines are usually drawn in white on the face of the mosaic in case of controlled and semi-controlled mosaic. The title and authorship of the mosaic should be identified. A graphic scale as well as numerical scale is given in a controlled mosaic.

Body information i.e. names of various planimetric and cultural details are entered on the mosaic in ink, contrasting to the surface on which it is written. Care should be taken not to crowd a mosaic with too much of information.

Border information is usually placed on the white border material, grid values are entered within the border. The destination names and distances are also entered on this border.

5.4.3 Reproduction

After completion of the mosaic, photographic copies are made for general use and the master mosaic is preserved. Photographic copies are made with large size copy cameras. Usually, the negative is made on 1:1 scale and copy prints are made from the negative by contact printing. This ensures minimum loss of details. However, if scale change is required, the negative is prepared on the desired scale and copies are made by contact printing.

5.5 CHOICE OF METHODS

5.5.1 Problem

In the production of a mosaic, two different problems are encountered. The first is matching of the photographic images of two adjacent photographs and the next, to give the prints equal tone by taking good care that the density of the two adjacent photographs is equal. If the photo-interpreter does not contemplate reproduction of the mosaic for use as an annexure to his report, the tone matching condition becomes less important. Moreover, when the photo-interpreter is interested only in the broader view of the features of his interest, spread over a wide area as presented in a mosaic, slight miss-matching of edges should not bother him very much. In many cases, an error of 1 to 2 mm in the matching between adjacent photographs is acceptable.

5.5.2 Uncontrolled Mosaic

In cases where the miss-matching of edges and geometrical accuracy are not of fundamental importance, simple uncontrolled mosaics, made from a combination of contact prints, without any change of the scale, using only the image of the topography as the basis of matching, will be sufficient. In a mountainous area, matching of details, which suffers from relief displacement, will cause large deformations of the mosaic. The use of central part of all individual photographs, in stead of each second photograph, gives an improvement in such cases. Use of long focal length normal-angle lens reduces relief displacement. But short focal length, wide-angle lens is used for nearly all natural resources surveys because the advantages of lower flying height and better base-height ratio compensate in miss-matching in the mosaic. Thus it is evident that uncontrolled mosaics of reasonable quality can only be obtained in case of almost entirely flat terrain and its compilation is generally limited to such uses.

5.5.3 Semi-controlled Mosaic

If the terrain under study is not flat and higher accuracy is required, it will be desirable for the photo-interpreter to compile a semi-controlled mosaic. This implies that by some means or other, the relative positions of the principal points of adjacent photographs must be determined. In case the terrain is hilly or mountainous, the method of radial triangulation, either by Arudel or slotted template method, should be carried out. The resulting positions of principal points and six other minor control points afford a more reliable basis for matching of images. This has also the advantage that the relative positions of boundaries of geological structure, soil or forest types, will show only local discrepancies of a limited nature which the photo-interpreter, while interpreting features of his interest, can easily evaluate by taking into account the amount of relief displacement.

5.5.4 Controlled Mosaic

The fully controlled mosaic is compiled in case the accuracy requirements demand it and it is possible to rectify and scale the photographs. The data for rectification may be obtained from aerial triangulation observations, where topographical mapping is an integrated part of the project. In other cases, the rectification data may be obtained from horizon camera photograph or gyroscopic data (commonly used in Finland and France). Rectification data is also determined with the help of Multiplex (e.g. in Sweden). For reasonably flat terrain, a normal slotted template layout, adjusted between ground control points, will suffice.

By the above method, there will be nine points available on each photograph for rectification and matching of edges. In this way, the influence of difference in scale between different photographs and that of tip or tilt in optical axis of the camera is eliminated. The same control data are plotted on the mounting board so that each individual photograph can be fitted correctly in its position. On a controlled mosaic, superimposing of a coordinate grid system and entering of a graphic scale are fully justified.

5.5.5 Special Methods

It is obvious that even with this system, a good controlled mosaic with good matching between adjacent prints can never be made in a mountainous or hilly terrain. A slight improvement may be had by using only the central part of each photograph. For hilly and mountainous terrain, the only method acceptable at present, for controlled mosaics fulfilling normal map accuracy specifications, is the use of ortho-photographs, in which the influence of relief displacement in the photographic images has been eliminated. The facet method, employed commonly in France, corrects the relief displacement between four corner points of a polyhedron whose heights have been measured barometrically. This method requires a considerable amount of work in field, as well as, in the office.

Suggestions for Further Reading

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Frequently Asked Questions

1. Define Aerial Mosaics. How it differs from map?
2. What are different types of aerial mosaics? What are their advantages and limitations?
3. Describe compilation of Controlled Mosaic.
4. Describe compilation of Semi-controlled Mosaic.
5. Describe compilation of Uncontrolled Mosaic.
6. Write about the annotation, editing and reproduction of aerial mosaics.

PART II

REMOTE SENSING

6

BASIC CONCEPTS

6.1 INTRODUCTION

Remote sensing may be defined as acquisition of data about an object from a distance without having a physical contact with it. The formation of image on the retina of a human eye is a common example of Remote Sensing. The eye senses only visible part of electromagnetic radiation reflected from the object. The radiation collected on the retina is transmitted to the mind, which physiologically processes these signals to form a picture.

Though the human eye-mind system can be considered to be the most advanced Remote Sensing system, it gathers information from the outside world only through visible light which forms a very small part of the electromagnetic spectrum. If it is able to sense other ranges of the electromagnetic radiation (EMR) as well, it would be able to see much more.

In modern remote sensing, the information given out by the object over a wide range of the EM spectrum is captured by the sensors. Subsequently, this information is read and interpreted to know about the objects of interest in various fields of human activity.

6.1.1 Electromagnetic Spectrum

It has been observed that a stationary electric charge produces a static electric field and a stationary magnet produces a static magnetic field in the surrounding space. Now if the static charge is oscillated, it produces oscillations in the electric field which propagates as a transverse electric wave from the source outwards. It has been further observed that the oscillating electric charge not only produces a transverse electric wave but also simultaneously establishes an oscillating magnetic field, which propagates a transverse magnetic wave of the same frequency. Both the electric and magnetic waves propagate with the same velocity, equal to velocity of light, and have the same frequency and wavelength. Thus they can not be separated from each other and the resulting wave is called electromagnetic wave, which has electric and magnetic field vectors perpendicular to the direction of motion (Kirchhoff's rule).

Electromagnetic waves can be described in terms of their velocity, wavelength and frequency. All electromagnetic waves travel at the same speed C. In vacuum, C = 299,793 km/sec (1,86,000 miles/sec) or for practical purposes C = 3 x 10^8 m/sec. This is commonly spoken as *speed of light*, although light is only one form of electromagnetic energy. The wavelength (λ) of electromagnetic waves is the distance from any position in a cycle to the same position in the next cycle (Fig. 6.1). Different units of distances, commonly used in standard metric system, are given in Table 6.1.

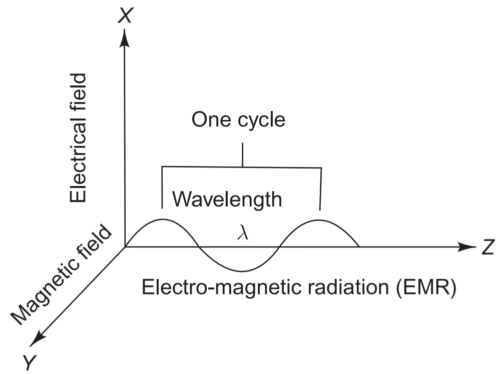

Fig. 6.1 *Electro-magnetic wave*

Table 6.1 Nomenclature of distances in metric system

Unit	*Symbol*	*Equivalent*	*Remarks*
Kilometer	km	1000 m = 10^3 m	
Meter	m	1.0 m = 10^0 m	Basic unit
Centimeter	cm	0.01 m = 10^{-2} m	
Millimeter	mm	0.001 m = 10^{-3} m	
Micrometer	μm	0.000001 = 10^{-6} m	Also called micron (μ)
Nanometer	nm	10^{-9} m	
Angstrom	Å	10^{-10} m	Common unit in X-ray technology

Frequency (*f*) is the number of wave crests passing a given point in a specified unit of time. It was formerly expressed as cycle per second. Now, Hertz is the unit for frequency of one cycle per second. The terms used to designate frequencies are given in Table 6.2. The relationship of velocity (C), wavelength (λ) and frequency (*f*) is shown by the expression $C = \lambda . f$

Table 6.2 Terms used to designate frequencies

Unit	*Symbol*	*Frequency*
Hertz	Hz	1 cycle/sec
Kilohertz	KHz	10^3 cycle/sec
Megahertz	MHz	10^6 cycle/sec
Gigahertz	GHz	10^9 cycle/sec

The oscillating motion is produced by the atoms and molecules of any object at temperatures above absolute zero. Thus the object emits electromagnetic radiation. Further, when objects receive radiation from natural sources like sun or an artificial source, a part of it is reflected back. Every object in nature has its unique patterns of reflected, emitted and absorbed radiation. The nature and quantity of EMR received from a body, upon detection, becomes a valuable source of data for interpreting important properties of the object.

The electromagnetic spectrum, divided into different radiation ranges on the basis of wavelength of radiation, is given in Table 6.3.

6.1.2 Black Body Radiation

Black body may be considered as a cavity having perfect reflecting inner surface, and the quantum oscillator placed within, which attains an equilibrium temperature, as the radiation is not able to escape and is totally confined within the cavity. This condition is expressed as the cavity electromagnetic radiation has attained thermal equilibrium with matter (oscillator). Now if we make a hole in the cavity and look at it, when theoretically its temperature is 0°K (–273° Celsius), it looks perfectly black, as no radiation is coming out of the cavity. It is for this reason the cavity is called black body and the cavity radiation is called the black body radiation. Thus the black body is a perfect absorber and perfect emitter of electromagnetic radiation. On the contrary, a white body is non-absorber, non-emitter and is a perfect reflector. In nature we come across neither a black body nor a white body. They are in between the two and may be called grey bodies in terms of electromagnetic radiation.

Table 6.3 Electromagnetic spectrum with its broad spectral regions

Frequency	*Spectral band*	*Wavelength*
10^{21} Hz	Cosmic rays	0.003 Å
10^{20} Hz	Gamma rays	0.03 Å
10^{16} Hz	X-rays	300 Å or 30 nm
10^{15} Hz	Ultraviolet	0.3 μm
	Visible	0.4-0.7 μm
10^{12} Hz	Infrared	0.7-1 mm (*f* for 0.3 mm)
10^{9} Hz = 1 GHz	Microwave	1 meter (*f* for 0.3 m)
10^{6} Hz = 1 MHz	Radio U HF V HF HF MF LF	0.3 km 10 km
	Audio (Sonar, etc.)	100 km
10^{3} Hz = 1 KHz	A.C. current	300 km

All matters, at temperatures above absolute zero (0°K or –273°C), continuously emit electromagnetic radiation. Thus terrestrial objects are also source of radiation, though it is different in magnitude and spectral composition than that of the sun. The energy radiated by any object is, among other things, a function of the surface temperature of the object. This property is expressed by Stefan-Boltzmann law, which states that

$$W = \sigma . T^4$$

Where W = Total radiance emittance from the surface of an object, Wm^{-2}

σ = Stefan-Boltzmann constant, 5.6697×10^{-8} Wm^{-2} T^{-4}

T = absolute temperature (°K) of the emitting object.

It is important to note that the total energy emitted from an object varies as T^4 and, therefore, increases very rapidly with the increase in temperature. Also it should be noted that this law is expressed for an energy source that behaves as a *black body*. As the total energy emitted by an object varies with temperature, the spectral distribution of the emitted energy also varies. Figure 6.2 shows energy distribution curves for black bodies at temperatures ranging from 200°K to 6000°K. The area under these curves equals the total radiant emittance (W°) and the curves illustrate graphically what the Stefan-Boltzmann law expresses mathematically. The higher the temperature of the radiator, the greater the total amount of radiation it emits.

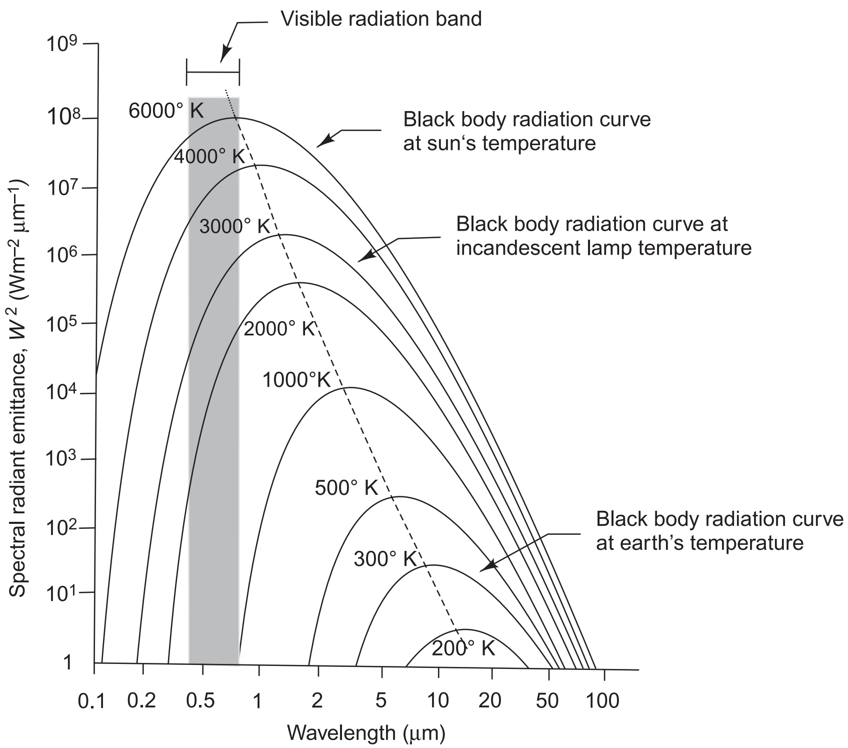

Fig. 6.2 *Spectral distribution of radiation from black body at various temperatures*

The curves also show that there is shift in the peak of the black body radiation curves towards shorter wavelengths, as temperature increases. The dominant wavelength or the wavelength at which the black body radiation curve reaches a maximum, is related to its temperature by Wein's displacement law as

$$\lambda_m = A/T \ \mu\text{m}$$

Where λ_m = wavelength of maximum spectral radiant emittance

A = 2898 μmK (Wein's constant)

T = Temperature °K

This phenomenon is observed when a metal body, such as an iron piece is heated. As the object becomes progressively hotter, it begins to glow and its colour changes successively to shorter wavelengths—from dull red to orange, to yellow and eventually to white.

The sun emits radiation in the same manner as a black body radiator whose temperature is about 6000°K. Sun is the strongest source of radiant energy. Earth intercepts about 1/50 million of the total output of solar energy. About 46% of the solar energy reaching the earth falls in the visible band of the spectrum (0.4–0.7 μm) and the maximum irradiance occurs at 0.47 μm wavelength. Our eyes and photographic films are sensitive to energy of this magnitude and wavelength.

The average surface temperature of the earth is 300°K (27°C),which is also called the *ambient temperature*. The energy radiated from the earth at this temperature is distributed as a broad low curve (see Fig. 6.2) with a maximum wavelength of 9.7 μm. This radiant energy level is very low in comparison to solar energy received. However, during night this is the dominant energy which can be used for remote sensing in middle infra-red (MIR) band.

6.2 INTERACTION OF EMR WITH ATMOSPHERE

The electromagnetic radiation coming from sun passes through the atmosphere before reaching the earth surface. It is absorbed, transmitted or scattered depending on the composition of the atmosphere.

6.2.1 Composition of Atmosphere

The constituents of the atmosphere can be divided into two groups viz. (i) pure gases and (ii) particulates. The pure gases comprise Nitrogen (78%), Oxygen (21%) and traces of Argon, Carbon dioxide (CO_2), water vapor and Ozone. The particulates in the atmosphere include particles of various sizes originating from smoke, dust and rock debris.

A significant factor which has to be taken into account in remote sensing is that the reflected and emitted radiations from the object has to pass through an intervening media with its scatter and absorption characteristics for different wavelength regions of EM spectrum depending upon its composition. Absorption and scattering together result in attenuation of the radiant flux. After attenuation by the atmosphere, almost all the radiation flux of solar radiation, which reaches the earth's surface, is of wavelength shorter than 3 μm, whereas the radiance emitted by the earth is principally in the broad wave band from 4 μm to 40 μm.

There is thus practically no overlap between the type of radiation reaching the Earth from the Sun and the radiation emitted by the objects of the Earth. The former is sometimes called shortwave radiation and the latter longwave radiation. The atmosphere not only absorbs a part of the solar radiation reaching the earth but also part of the longwave (Terrestrial) emitted radiation.

6.2.2 Absorption of EMR by Atmosphere

Radiation of wavelengths shorter than 0.3 μm is highly absorbed by the oxygen and nitrogen of the ionosphere and the ozone layer of the atmosphere. Further, less complete ozone absorption occurs in the region from 0.32–0.36 μm. Absorption at a minor level by ozone also occurs around 0.6 μm in the visible band and around 14.1 μm in the infrared bands (Fig. 6.3). Near complete absorption of radiation of wavelength shorter than 0.3 μm by the atmosphere is the reason why the Earth hardly receives any ultra-violet (UV) radiation from sun.

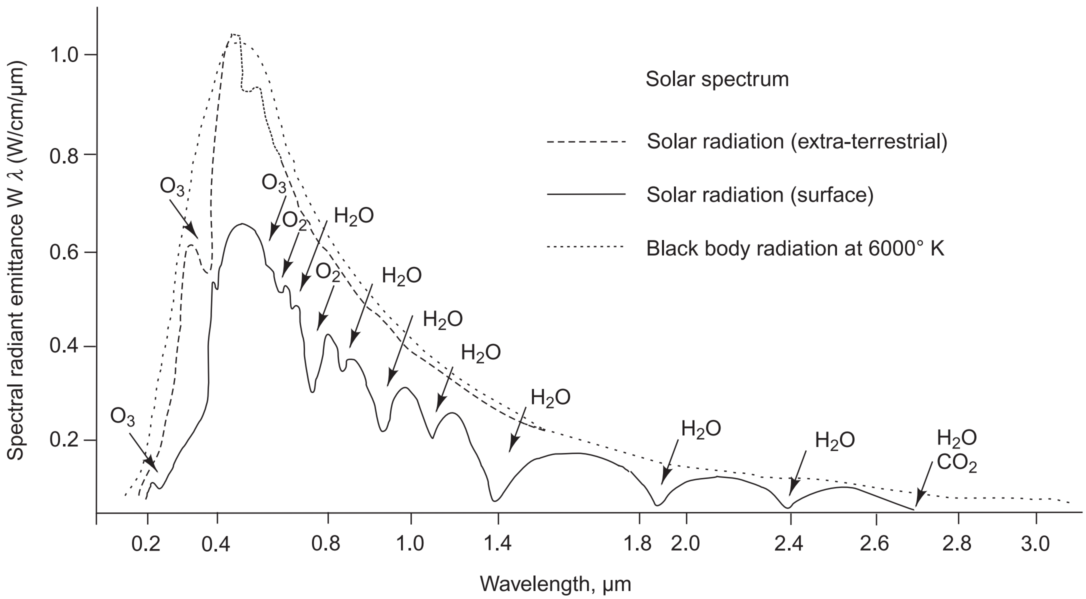

Fig. 6.3 *Absorption of EMR in the atmosphere*

The water vapor in the atmosphere absorbs the largest amount of solar radiation. The strongest water vapor absorption is around 0.6 μm (infrared band) where apparently 100% radiation may be absorbed if the atmosphere is moist. Water vapor also absorbs varying amounts of radiation between 0.7 to 0.8 μm and minor amounts of radiation below 0.7 μm.

CO_2 in the atmosphere is a week absorber of radiation at about 4 μm to 10 μm wavelength.

6.2.3 Atmospheric Windows

Spectral regions for which the atmosphere is transparent (absorption is minimum) are known as atmospheric windows. In the visible and infrared bands atmospheric windows exist in the following regions:

(a) VIS (Visible) – 0.4 to 0.7 μm
(b) NIR (Near Infrared) – 0.7 to 1.3 μm
(c) SWIR (Short Wave Infrared) – 1.1 to 1.3 μm
(d) MIR (Middle Infrared) – 3.0 to 5.5 μm
(e) TIR (Thermal Infrared) – 8.5 to 14 μm
(f) Microwave – 0.1 to 133 cm

Atmospheric absorption beyond 25 μm is so considerable that present day infrared techniques can be used in a limited manner beyond 25 μm. The atmosphere is again transparent in the microwave region beyond about 1 mm wavelength.

In the infrared region the 3 μm to 4.5 μm window has an advantage in that it is rather sharply defined. The advantage of 8.5 to 14 μm window is that it completely lies within the thermal emission spectrum of the Earth and hence can be conveniently used for remote sensing in the thermal region. In this window, however, there is an atmospheric absorption band around 9.5 μm but it is usually disregarded in all but satellite and high altitude rocket missions.

6.2.4 Atmospheric Scattering of EMR

The other serious effect of atmosphere after absorption is scattering of radiation by the atmospheric particles. Unlike vacuum in which nothing happens, the atmosphere may affect the frequency, the intensity, the spectral distribution and the direction of the radiation passing through. Scattering of EMR within the atmosphere has two adverse effects in Remote Sensing. (1) it reduces the image contrast (2) it changes the reflectance characteristics (spectral signatures) of ground objects as seen by the sensor.

The scattering by atmosphere depends upon the relative size of atmospheric particles and radiation wavelengths. Gas molecules are of the order of 10^{-4} μm in size and haze particles (water droplets) vary in size from 10^{-2} μm to 10^{2} μm. Essentially two types of scattering takes place: Elastic scattering in which the energy of radiation (velocity or wavelength) is not changed due to scattering and Inelastic scattering in which the energy of scattered radiation is changed (Compton scattering and Raman scattering). Inelastic scattering usually takes place when high energy photons are scattered by free electrons in the ionosphere or the loosely bound electrons of atoms and molecules in the atmosphere. It is less important for Remote Sensing.

Elastic scattering occurs in three different ways: (a) Rayleigh scattering (b) Mie scattering (c) Nonselective scattering. These depend on the size of scatterers and wavelength of radiation (λ) being scattered. The atmospheric scattering process is summarized in Table 6.4.

Table 6.4 Atmospheric scattering processes

Scattering process	*Wavelength*	*Particle size approx.*	*Kind of particles*
Rayleigh	λ^{-4}	<< 0.1 μm	Air molecules
Mie	λ^{0} to λ^{-4}	0.1 to 10 μm	Smoke, fumes, haze
Nonselective	λ^{0}	> 10 μm	Dust, fog, cloud

6.2.4.1 *Rayleigh Scattering*

It is largely due to gas molecules and other very small particles, many times smaller than the wavelength of radiation under consideration, such as visible light (0.4 – 0.7 μm) by pure gas molecules of size 10^{-4} μm, in a clean atmosphere. Rayleigh scattering is inversely proportional to the fourth power of the wavelength. The scattering is accomplished through absorption and re-emission of radiation by atoms and molecules. For a wavelength ratio of 1:2 between 0.4 μm (blue) and 0.8 μm (beyond red), the ratio of scattered light is 16:1. This is the reason for bluish appearance of clear sky.

6.2.4.2 *Mie Scattering*

This type of scattering takes place when there are essentially spherical particles present in the atmosphere with diameters approximately equal to the wavelength of radiation. For visible light, water vapor, dust and other particles, ranging from a few tenths of a micron to several microns in diameter, are the main scattering agents. The amount of Mie scatter is greater than the Rayleigh scatter and the wavelengths scattered are longer.

In water bodies colloidal particles usually less than 1 μm size are present which cause selective scattering of blue light, while the green and red components are transmitted downwards. Part of this blue scattered light reaches upwards and thus the colour of water appears bluish. This is known as Tyndall effect.

In a clear atmosphere, the combination of Rayleigh and Mie scattering processes cause selective scattering of light. Selective scattering of violet and blue light by the atmosphere causes the blue colour of the sky. When the sun is directly overhead at noon, the sky appears white because the light pass through minimum thickness of the atmosphere and little selective scattering occurs. At the sunrise and sunset, however, Sun's light passes tangentially through a much thicker column of atmosphere, in which the shorter wavelengths are so completely scattered that it hardly reaches the eye and hence the red colour of the sun. Selectively scattered light illuminates the shadows which are never completely dark but bluish in colour. This scattered illumination is called sky light. The shadows of moon photos (and the sky) are completely black because, due to lack of atmosphere on moon, there is no scattering of light.

6.2.4.3 *Non-selective Scattering*

This occurs in the other extreme case, when the particle size is very much larger than the wavelength. Non-selective scattering does not depend on the wavelength of radiation.

Whitish appearance of sky, under heavy haze conditions, is due to non-selective scattering. The effect of Rayleigh component of scattering can be eliminated by using minus blue filter. However, the effect of non-selective scattering due to heavy haze, when all wavelengths are scattered uniformly, cannot be eliminated by using any filter.

6.2.5 Effect of Scattering on Remote Sensing

The downward radiation, which illuminates the terrain, has two components: (1) Direct Sun light and (2) Diffused sky light originating due to atmospheric scattering. The relative importance of the two depends upon the solar zenith angle or the optical path length in the atmosphere. The sky light is bluer than the sun light. Similarly, the upcoming radiation from the object, which reaches the remote sensor, has also got two components: (1) The light which interacts with the Earth's terrain and is reflected upwards and (2) The component arising from the back scattering of radiation from atmospheric particles.

The most serious effect of scattering is contrast reduction. The downward component of scattered light (sky light) reduces the brightness difference and hence the contrast between the sun-lit and shaded areas on the ground is less. The upward component of the scattered radiation (sky radiance) inreases the irradiance reaching camera image plane thus reduces the image contrast.

In the infrared photos, the shadows are completely dark, as scattering is negligible in this region of EM spectrum. For the same reason, the effect of haze is less pronounced in thermal infrared region. Microwaves are completely immune to haze and can penetrate clouds, except in very disturbed atmospheric conditions like rain and storm.

6.3 INTERACTION OF EMR WITH EARTH'S SURFACE

The radiation from sun when incident upon the earth is reflected, scattered, absorbed and emitted or transmitted into the surface. The incident EMR on interaction with the surface experiences change in magnitude, direction, wavelength, polarization and phase. These changes, when detected by a remote sensor and analyzed provide useful information about the object of interest. The remotely sensed data constrains both spatial information (size, shape and orientation of the object) and spectral information (spectral signature).

6.3.1 Reflection

Besides characteristic properties of the object, the factors influencing reflection are: surface smoothness, orientation of the object lying in the path of EM radiation and polarization and wavelength of incident radiation. If the object has smaller surface irregularities than the wavelength of impinging radiation, it will act as a mirror. This reflection is termed as specular reflection.

In the visible spectrum, however, the wavelengths being too short, most surfaces reflect diffusedly (diffused reflection), regardless of the angle at which the radiation strikes the terrain object. Some of this diffused reflected energy returns towards the source. Longer wavelengths (microwave) create more specular reflection and the reflected energy is generally directed away from the source. The reflected radiation is most important for remote sensing because many systems are based on this energy.

6.3.2 Spectral Reflectance

Spectral reflectance is the ratio of reflected energy to incident energy as a function of wavelength. Various earth surface materials have different spectral reflectance characteristics. The spectral reflectance is responsible for the colour or grey tone in photographic image of an object. A tree appears green because it reflects more of green wavelength of the spectrum and absorbs other radiation impinging on it.

A graph of the spectral reflectance of an object as a function of wavelength is designated as the spectral reflectance curve. The configuration of the spectral reflectance curve give an insight into the spectral characteristics of the object and has strong bearing on the choice of wavelength region(s) in which remote sensing data are acquired for a particular application. Figure 6.4 illustrates this in regard to deciduous and coniferous forests. The two forest types are clearly separable in infrared region, while in visible band their identification from each other is not so obvious. Figure 6.5 gives typical reflectance curves for vegetation, soil, and water.

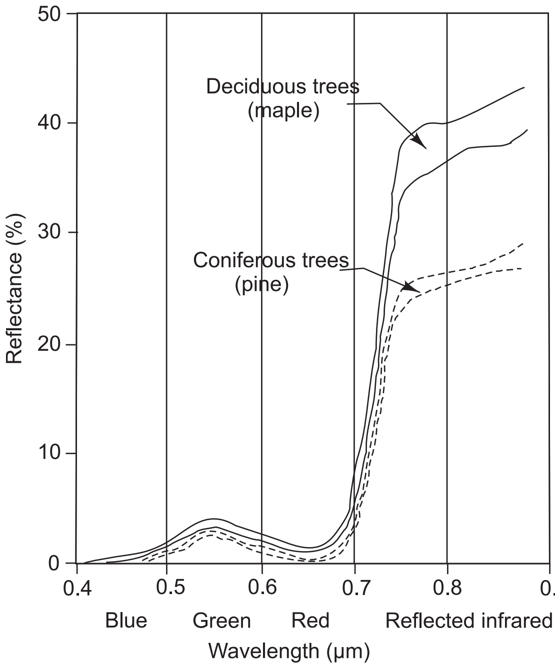

Fig. 6.4 *Spectral reflectance curves for desiduous and coniferous forest types*

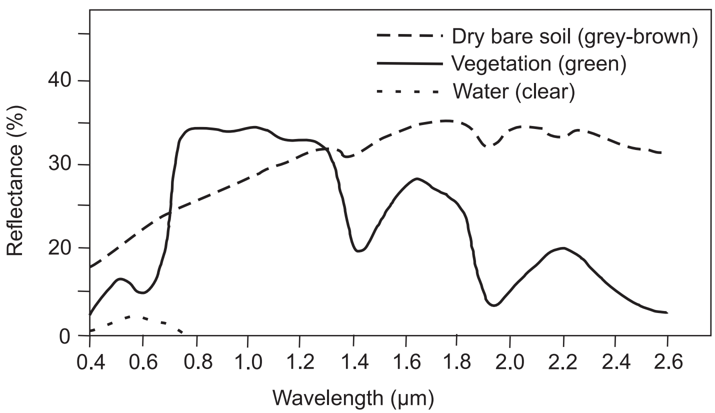

Fig. 6.5 *Spectral reflectance curves for vegetation, soil and water*

The value of spectral reflectance of objects measured in different well-defined wavelength intervals, comprise the *spectral signature* of the objects or features by which they can be distinguished. Figure 6.6 illustrates the idea of spectral signature.

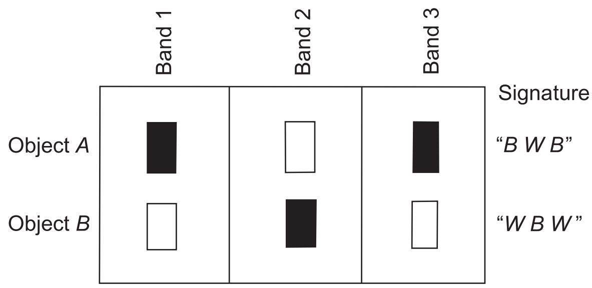

Fig. 6.6 *Spectral signature*

For obtaining necessary ground truth for interpretation of multispectral imagery, the spectral characteristics of various natural objects have been measured/recorded by instruments called spectro-photometers or spectro-radiometers. The spectro-photometer measures the absolute spectral reflectance characteristics of samples in laboratory while spectro-radiometers are field instruments which measure the radiance.

6.3.3 Absorption

Some of the energy striking the surface may enter the target as a refracted wave front, while part of it may be absorbed. The ability of a surface to absorb radiation (absoptance) depends upon its composition and thickness.

Absorptance is also wavelength dependant and as a result, a target may behave differently when exposed to radiation of different wavelengths. For example, an object or medium may be highly absorptive in the visible band yet transparent in the infrared region (semi-conductors). On contrary, it may be transparent in visible and opaque in infrared region (glass). Clearly, some knowledge of the absorptance of target is often desirable in choosing the best remote sensing means to solve specific problem and in interpreting correctly the data acquired.

The net effect of absorption of radiation by most substances, including the atmosphere and terrain surface, is that a greater part of absorbed energy is converted to heat energy, thereby raising the temperature of the substance. This heat energy may enable the target of radiation to become a secondary source of radiation source due to emission of some of the absorbed energy.

A target may be smooth or rough, opaque or transparent, good or bad absorber depending upon the wavelength of incident energy and the relation between reflection, absorption and transmission varying across the EM spectrum. Further, the angle of incidence, if low, causes the portion of reflected energy to exceed the combined absorbed and transmitted energy, and if high, may allow some of the energy to enter the target, provided its detailed surface characteristics permit.

6.3.4 Spectral Regions Useful for Remote Sensing

From the absorption characteristics of the atmosphere, it is obvious that the entire EM spectrum is not useful for remote sensing applications. The important wavelength regions for remote sensing are the atmospheric windows, given in Section 6.2.3 above, for which the atmosphere, in general, acts as a transparent medium (Fig. 6.7). These spectral regions include Reflective optical region (0.3 to 01.3 μm); Reflective/Emissive region (MIR 3 to 5.5 μm), Emissive region (TIR 8 to 14 μm) and Microwave region (1 mm to 133 cm).

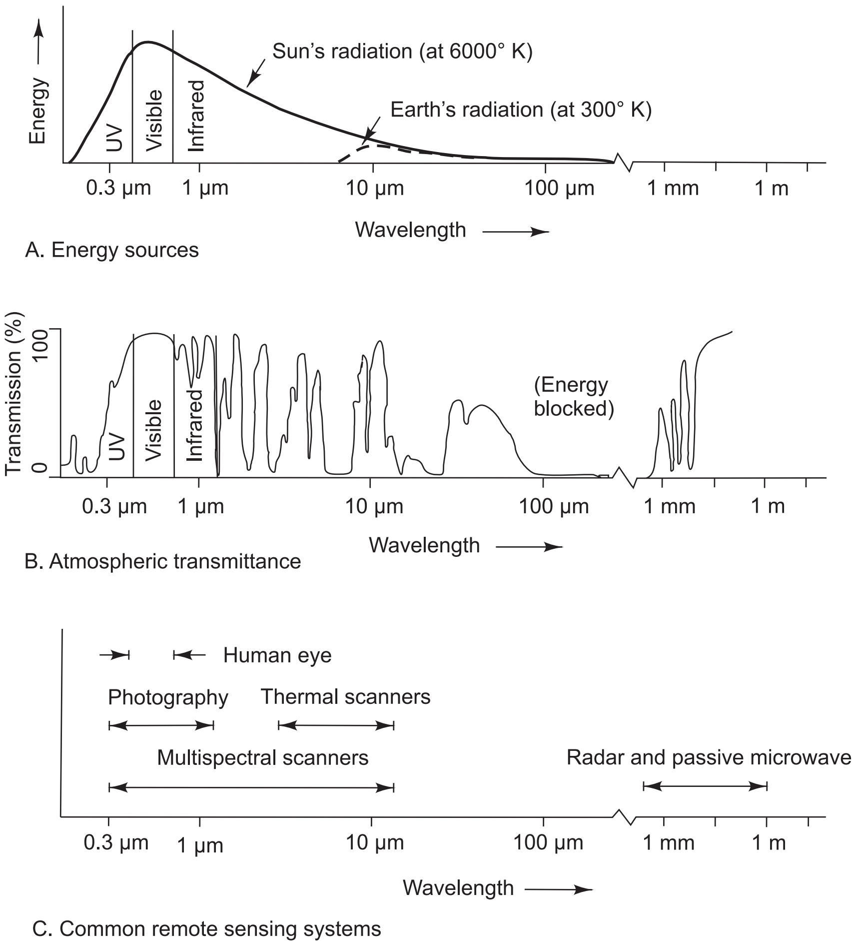

Fig. 6.7 *Atmospheric windows and common remote sensing systems*

The wavelengths that are of great interest to remote sensing are the optical wavelengths, which can be reflected and refracted with solid materials like mirrors or lenses. The most important and widely used wavelengths are of the reflective region, as the energy sensed in these wavelengths is primarily the radiation originating from the sun and reflected by objects on the earth.

In the emissive region, the wavelengths corresponding to the atmospheric window between 8 and 14 μm is known as thermal band, as the energy available in this band for remote sensing is due to thermal emission by terrain objects. Both reflection and self emission are important for the middle IR band from 3 μm to 5.5 μm.

The energy from sunlight, scattered by terrain objects in microwave region, is too less. Emitted thermal radiation beyond 1 mm wavelength, though small, can be measured by radiometers. Remote sensing can be accomplished in this region effectively by providing artificial source of energy.

Suggestions for Further Reading

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Frequently Asked Questions

1. Write short notes on: Electromagnetic Spectrum; Black body radiation; Stefan-Boltzmann law; Wein's Displacement law; Absorption of EMR with Atmosphere.
2. Define: Atmospheric Windows; Spectral Reflectance; Spectral Signature; Spectral regions useful for Remote Sensing.
3. What are different types of atmospheric scattering? What is its effect on Remote Sensing?
4. Describe interactions of EMR with earth surface.

7

DATA ACQUISITION SYSTEM

In remote sensing, the data about an object is acquired by sensor; a device which detects radiation received from the object and transforms the same into recordable information. The sensor is mounted on a suitable platform. These components constitute the data acquisition system and will be dealt in more details below.

7.1 SENSORS

There is no single sensor which can detect the signals from the entire range of EM spectrum. Each sensor can only gather information from a certain band of the spectrum. At the outset, two broad categories of sensors can be identified as non-imaging and imaging sensor systems.

Non-imaging sensor system includes sounders and altimeters for measuring heights and topographic profiles. Spectrometer, spectro-radiometer, scatterometer, etc. also fall in this category.

7.1.1 Imaging Sensors

Imaging sensor system is further subdivided into two types: (1) Photographic system, and (2) Scanner (non-photographic) system. Figure 7.1 shows schematically the different types of imaging sensor systems. The photographic systems operate in the visible and optical infrared parts of the EM spectrum (0.38 to 1.1 μm). However, the system is rarely used for wavelengths larger than 0.9 μm because of the problem of making thermo-stable photographic emulsion of sufficiently finer grain size. The temperature of camera body fogs the emulsion because of thermal radiation emanating out of it.

The scanner or non-photographic sensors can operate over a wide range of the spectrum; from X-ray to radio wavelengths.

7.1.2 Active and Passive Sensors

The sensors are also classified on the basis of whether they operate on the radiation received from a source which is not a part of the sensing system or from a source built in as a part of sensing system. The sensors like lens system is an example of passive sensor as it operates on the reflected part of the radiation received from the Sun. Radar is an active sensor as it transmits its own radiation and senses radiations returned by the object. There are passive sensors which measure radiation emitted by objects viz. microwave radiometers.

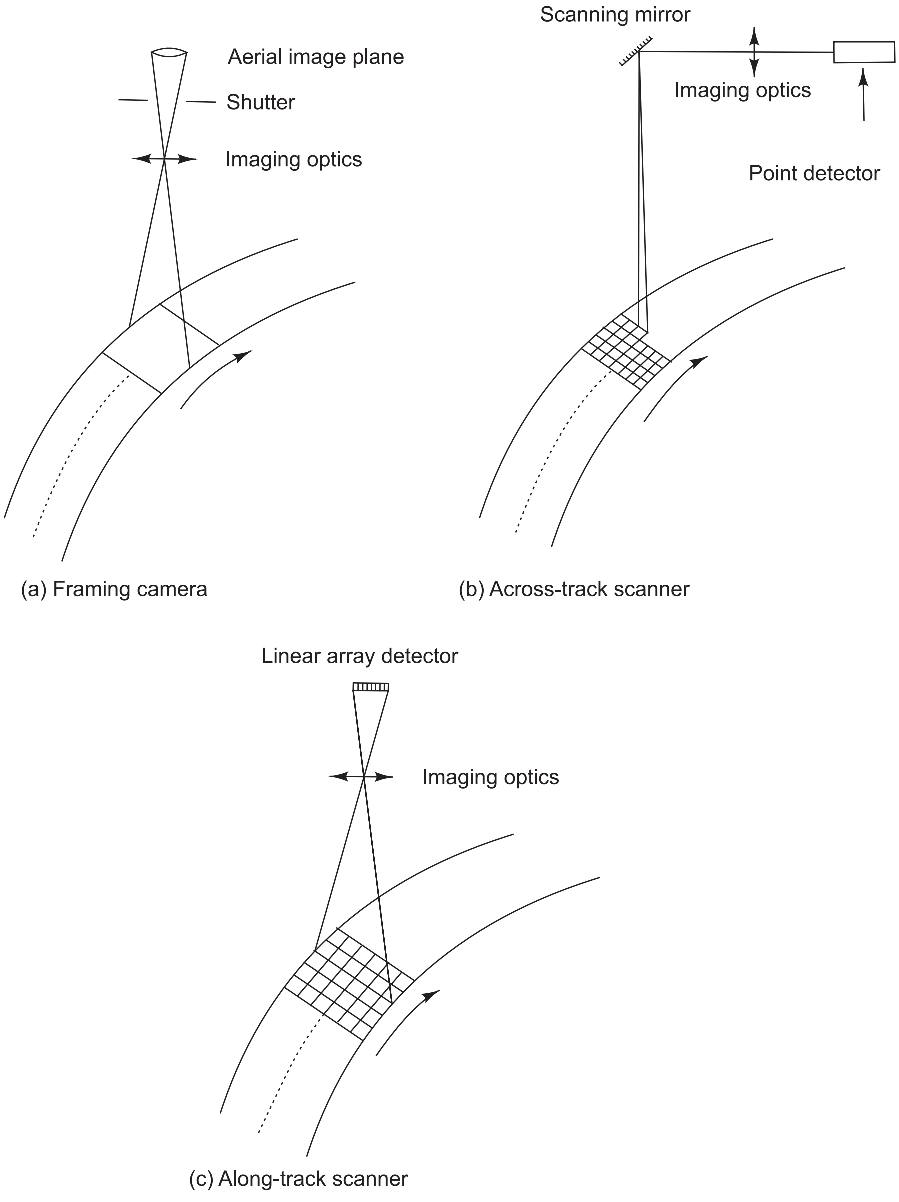

Fig. 7.1 *Different types of imaging systems*

7.1.3 Sensor Materials

Different sensor materials are used for the construction of detectors in different wavelengths of EM spectrum. In general there are two types of electromagnetic signal detectors: optical film detectors and opto-electronic detectors.

Sensor materials in the film detectors are silver chloride or silver bromide grains. Usually black and white, true colour, B and W infra-red and false colour films are in use. B and W (panchromatic) and true colour films are sensitive to visible band of EM spectrum (0.4 to 0.7 μm). However, the emulsions of panchromatic films can be made sensitive to near infrared region up to 0.9 μm through spectral sensitizing procedures. Similarly false colour films are having an additional layer sensitive to near IR (0.7 to 0.9 μm). More details are available in chapter on Aerial Films.

Opto-electronic detectors are classified into two types on the basis of physical procedures by which the radiant energy is converted to electrical outputs. These are: (i) thermal detectors (sensitive to change in temperature) and (ii) quantum detectors (sensitive to change in incident photo flux).

Typical thermal detectors are thermocouple/thermopile and thermister bolometer. Change in voltage takes place due to change in temperature in thermocouples and thermopiles, between thermo-electric junctions. Change in resistance takes place due to change in temperature of the sensor material in thermister bolometer. Thermister bolometers usually use carbon or germanium resistors having a resistance change of 4% per degree. Thermal detectors are slow, have low sensitivity and their response is independent of the wavelength of the EMR.

Quantum detectors are of three types, namely,

(i) Photo-emissive detectors (photocells and photomultipliers use alkali metal surface coatings such as cesium, silver-oxygen-cesium composite)

(ii) Photo-conductive detectors (photosensitive semiconductors whose conductivity increases with incident photon flux), and

(iii) Photo-voltaic detectors (here modification takes place in the electrical properties of a semiconductor p-n junction, such as backward bias current on being irradiated with light).

In the wavelength region < 1 mm, quantum detectors like photo-multipliers and Silicon-photodiodes are found quite efficient and do not need cooling devices. However, for satellite platforms the photomultipliers are found less suitable because of its accompanying high voltage power supplies, thereby substantially increasing the payload. In 1 to 3 μm wavelength region, Germanium (Ge)-photodiode, Ge-photo-conductor, Indium-Antimony photodiode, Indium-Arsenic photodiode and Mercury-Cadmium-Tellurium photodiode can be used for sensor material. However, these sensors are to be kept cooled as their electrical characteristics change with increase in their temperature. In thermal wavelength region (10 to 14 μm), Mercury-Cadmium-Tellurium photoconductors and Lead-Tin-Tellurium photodiodes can be used as sensor materials with effective cooling system. Microwave antenna is used as sensor in microwave region of EMR.

A list of the sensors along with materials, which operate on different regions of EM spectrum and the form in which the information is collected is given in Table 7.1.

Table 7.1 Sensors and materials used in different wavelengths

Sl. No.	*Sensors and materials used*	*Spectral region*	*Wavelength*	*Form of data collection*
1	Ionization detectors	Cosmic rays	0.00003 to 0.03 Å	Digital
2	Scintillation counters, x-ray spectrometers (using sodium iodide crystal detectors)	Gamma rays	0.03 to 0.3 Å	Digital
3	Scintillation counters	X-rays	0.3 to 100 Å	Digital
4	Scanners with photomultipliers	Ultraviolet	100 Å to 0.3 μm	Imaging
5	Image orthicons and camera with filtered infrared film 2900 Å	Near ultraviolet	0.3 to 0.4 μm	Image on B and W or colour film or magnetic tape data from scanners
6	Solid state detectors in scanners or lens system using conventional B and W and colour film	Visible spectrum	0.4 to 0.7 μm	-do-
7	-do- (using aerographic BandW film or Infra-red Ektachrom colour film)	Optical IR	0.6 to 0.9 μm	-do-
8	Solid state detectors in scanners and IR radiometers (using Indium Antimonoide crystals to detect temperature difference)	Thermal IR	0.7 to 800 μm	Film in an imaging system or tape analog signal
9	Radiometer response in radar, r.f. receivers in scanners and radiometers	Microwave including radar	1 mm to 100 cm	Oscilloscope or tape analog signal

Summing up, it maybe mentioned that photographic cameras can be employed in visible and optical IR region to good advantage, which incidentally provide a central perspective. Beyond visible range, in thermal infrared region, thermal scanners are employed as sensors from airborne or space borne platform. In multispectral scanners, the received radiation from 0.3 to 14 μm, is dispersed in to various bands and sensed by detectors suitable for these bands. In microwave region, microwave radiometers are used in the passive system to detect the emitted radiation, while radars are used in active sensor system.

7.2 PLATFORMS

The success of many applications of remote sensing is considerably improved by taking a *multiple view* approach to data collection. This may involve *Multi-stage* sensing, wherein data about a site are collected from multiple altitudes. It may involve *Multispectral* sensing, whereby data are acquired simultaneously in several spectral bands; or it may entail *Multitemporal* sensing, where data about a site are collected on more than one occasion.

In multistage approach, data from satellite may be analyzed in conjunction with data obtained from high altitude and ground observation (Fig. 7.2). Each successive data source may provide more detailed information over smaller geographical areas. Information extracted at any lower level of observation may then be extrapolated to higher level of observation.

Essentially three types of platforms are used for mounting the sensors for data collection. These are:

1. Ground observation platform
2. Airborne observation platform, and
3. Space-borne observation platform

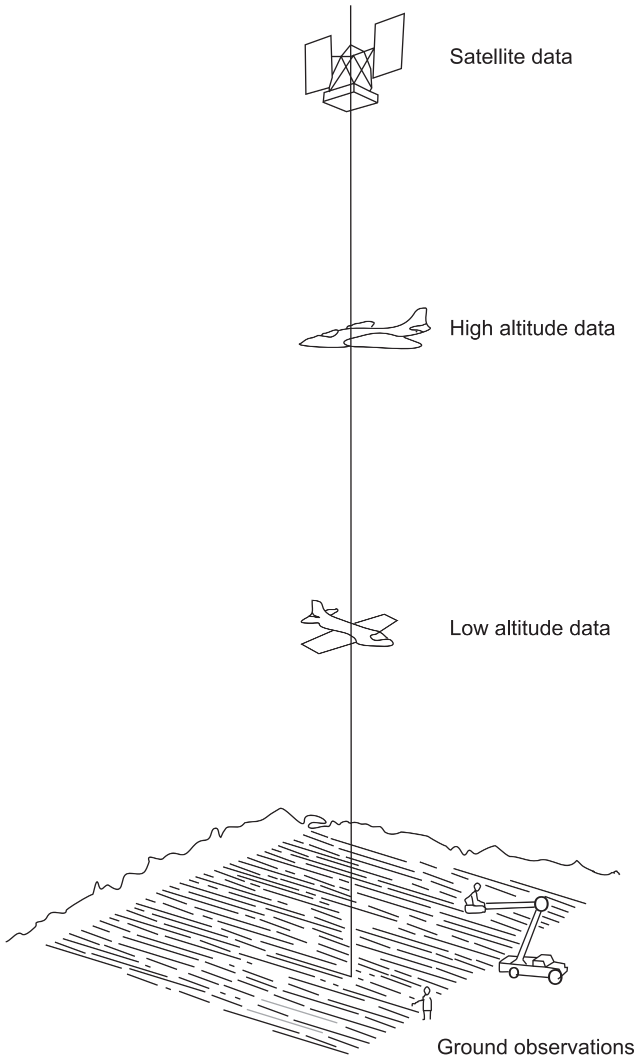

Fig. 7.2 *Multistage remote sensing concept*

7.2.1 Ground Observation Platform

These are necessary to develop scientific understanding of signal-object and signal-sensor interactions. Important ground observation platforms include, hand held platform, cherry picker, towers and portable masts. Portable hand held photographic cameras and spectro-radiometers are used for laboratory and ground truth collection. In cherry pickers automatic recording sensors can be placed at heights of above 10 m from the ground. Towers can be raised for placing the sensors at higher level for observation. Portable masts mounted on vehicles can be moved from place to place, to support camera and other sensors for testing and collection of reflection data from field sites.

7.2.2 Airborne Observation Platform

Important airborne observation platform include balloon, drones (short sky spy), aircraft, high altitude aircraft and high altitude sounding rockets. Balloons are used for remote sensing observations (aerial photography) and nature conservation studies. They can go up to an altitude of 30 km. The sensor system is brought back to earth by tearing the carrying balloon through remote control.

Drone is a remotely piloted vehicle which looks like a miniature aircraft. It is capable of a climb rate of 4 m/s with an operating altitude of 0.5 km, a forward speed of 100 km/s. The drone sensors can provide information to maintain the drone at the altitude demanded by the ground control or by programmed navigation system. Drone's payload includes equipment of photography, infrared detection, radar observation and TV surveillance.

Special aircraft carrying large format cameras on vibration-less platforms have been used to acquire aerial photographs. While low altitude aerial photography results in large scale images providing detailed information of the terrain, the high altitude smaller scale images cover more area providing regional view. NASA acquired aerial photographs covering US areas from U-2 and RB-57 reconnaissance aircrafts at an attitude of 18 km, on 1:120,000 scale.

High altitude sounding rockets are useful in assessing the reliability of the remote sensing techniques. Synoptic imagery can be obtained from such rockets covering areas of about 50,000 km per frame. Once the desired scanning work is over from a stable altitude, the payload and the spent motor are returned to the ground gently by parachute, enabling the recovery of the data/photographic records.

7.2.3 Space-borne Observation Platform

Essentially, these are satellite platforms, which are of two types: manned and unmanned satellite platforms. Manned satellite platforms are used as the last step, for rigorous testing of the sensors on board so that they can be finally incorporated in the unmanned satellites. Some of the manned satellite programme of NASA include Mercury (1962-63), Gemini (1964-65), Apollo (1968-72), Skylab (1973-74), Space shuttle (1981onwards) and International Space Station (2000 onwards). Unmanned remote sensing satellites include Landsat series (NASA), Spot series (France) and IRS series (ISRO) and others.

The important remote sensing data acquisition systems, operating in different regions of EM spectrum, are grouped in three broad categories, namely multispectral remote sensing, remote sensing in thermal IR region and remote sensing in microwave region. These are dealt in more details in the following chapters.

Suggestions for Further Reading

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Frequently Asked Questions

1. Write short notes on: Sensors; Imaging Sensor; Active and Passive Sensors.
2. What are different types of Platforms?
3. Give examples of Space borne Platforms.

8

MULTISPECTRAL REMOTE SENSING

Normal aerial cameras can take pictures in B and W, colour, B and W infrared or false colour, by using suitable films. In this system, the sensing is done in visible and optical IR parts of the EM spectrum, by a single sensing unit and the data recorded is cumulative information from the entire band. However, if data in different sub-regions of this band can be obtained separately for comparative study, more useful information can be extracted. This is achieved in Multispectral photography and Multispectral scanning.

8.1 MULTISPECTRAL PHOTOGRAPHY

Multispectral cameras with lens system (central projection) were developed to take simultaneous multiple photographs of the terrain; each photograph recording a different spectral band in visible and optical IR portion of the EM spectrum. Either a multi-camera array or a multi-lens camera can be used for the purpose. Multi-lens camera is more commonly used, which uses number of lens cones, fitted in one camera body. With suitable filters, a number of pictures are simultaneously taken in different bands with a single shutter operation. The shutter consists of separate slits, each functioning as the shutter of one lens focal plane combination. Using this technique, 9 lens, 6 lens and 4 lens cameras were built. The images are normally recorded on suitable B and W films and obtained as B and W positive transparencies for use. When these transparencies are illuminated through a second set of spectral filters, an artificially produced additive colour version, which can be changed by changing the filter and intensity combination, is obtained. This system was proved to be very promising as a good substitute for normal colour and false colour photography.

Since an unusually small portion of the visible spectrum enters each lens of the multiband unit, the camera sensitivity is relatively low and hence shutter speed of the order of $1/60^{th}$ of a second is commonly used. Because of slow speed of the shutter, the motion of aircraft would result in blurred photography, if the camera system does not include an image motion compensating arrangement. Compensation, in some cameras (viz. Itek), is achieved by moving the film continuously during the period of exposure, at a rate proportional to the velocity of the aircraft. Description of some important cameras is given below.

8.1.1 Hasselblad Camera

This multiband camera was on board of Apollo-9 flight mission of NASA in March, 1969, to obtain first multiband pictures of earth from space. It has an assembly of four Hasselblad cameras with filters in the green, yellow, red and deep red regions of EM spectrum. Hasselblad camera with infrared ektachrom film was also used to obtain first historical aerial photographs of coconut plantation of Kerala in India in late nineteen sixties, which resulted in discovering coconut wilt disease, opening up possibilities of remote sensing applications in various fields.

8.1.2 Itek Multiband Camera

Initially this camera had a nine lens assembly. Subsequent use of this camera as a research tool lead the investigators and designers to select bands which are significant for remote sensing. It has now become common to use a four band camera, operating in blue, green, red and optical infrared regions. The spectral band covered in this camera and the films used are given in Table 8.1.

Table 8.1 Itek multiband camera

Sl. No.	*Film*	*Mean wavelength of sensitivity (in μm)*	*Band phase in μm*
1	Panatomic-x (Panchromatic) 58 B (B and W)	0.525 (green)	0.46 – 0.61
2	Panatomic-x (Panchromatic) 25 A (B and W)	0.645 (red)	0.58 – 0.7
3	Infrared Aerographic 89 B (B and W)	0.8	0.7 – 0.9
4	Infrared Ektachrom 15 (colour)	Green, red and IR	0.51 – 0.9

8.1.3 Skylab Cameras

Observations of earth were made from Skylab during 1973-74 from an altitude of 435 km. A six band multispectral photography was included as one of the experiments under the Earth Resources Experiment Package (EREP). Another experiment used a three band Earth Terrain Camera (ETC). The bandwidth and resolutions of the cameras are given in Tables 8.2 and 8.3.

Table 8.2 Skylab multispectral camera

Designed bandwidth (μm)	*Film*	*Ground resolution (m)*
0.5 to 0.6	PAN – X B and W (S0-022)	30 - 53
0.6 to 0.7	PAN – X B and W (S0-022)	28 – 47
0.7 to 0.8	IR B and W (EK-2424)	68 – 119
0.8 to 0.9	IR B and W (EK-2424)	68 – 119
0.5 to 0.88	IR Colour (EK-2443)	57 – 98
0.4 to 0.7	HI-RES Colour (S0-356)	25 - 40

Approximate scale of 9″ × 9″ frame is 1: 700,000

Table 8.3 Skylab earth terrain camera

Type of film	*Description*	*Designed bandwidth*	*Resolution (line per mm)*	*Ground resolution (m)*
S0-242	Aerial colour, high resolution	0.4 to 0.7	100	10–15
EK-3414	High definition aerial (B and W)	0.5 to 0.7	114	10–15
EK-3443	Aprochrome IR, colour	0.5 to 0.88	31	20–30

Approximate scale of 9″ × 9″ frame is 1: 470,000

8.1.4 Large Format Camera (LFC)

This high performance photographic film camera was used for the first time in space shuttle flight mission in October, 1984 (Fig. 8.1). The LFC has an achromatic lens (in the wavelength of 0.4 to 0.9 μm) of focal length 305 mm. It has a format of 230 × 460 mm and exposure range of 3 to 24 ms. The camera is flown with the long dimension of its format along flight direction in order to obtain necessary stereo-coverage. The magazine capacity of the LFC is 1200 m of film for 2400 frames.

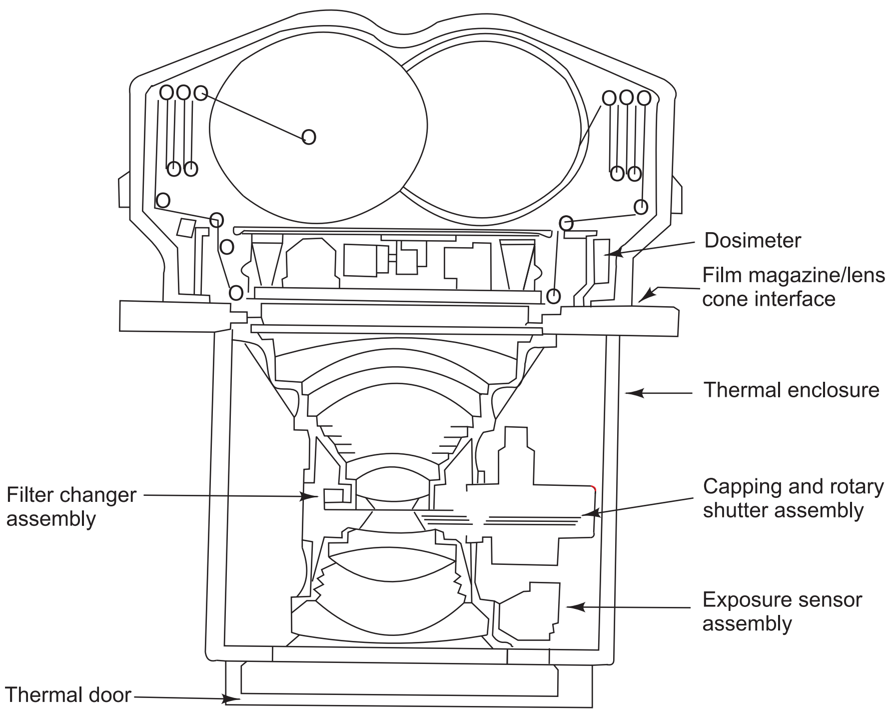

Fig. 8.1 *Schematic diagram of the large format camera (LFC) (after Panda 2005)*

8.1.5 I²S Multispectral Camera

This camera was developed by International Imaging System. It records four pictures simultaneously on a single 23 cm × 23 cm black and white negative film. Focal length of the camera is 150 mm. Individual pictures are 8.9 cm × 8.9 cm size. The positive transparencies (chips) can be fed to the I²S Additive Colour Viewer to obtain a composite colour view of the terrain, using suitable intensities of light through different filters. By changing the filters, any desired colour composite including false colour can be obtained using two or more bands.

8.1.6 Return Beam Vidicon (RBV)

RBV is an electron imager, works like a television camera and takes pictures frame by frame (Fig. 8.2). On exposure, its optical system focuses an image on a photo-conducting plate, retained as varying charge distribution, just like a camera frames the image on a photo-chemical film. The charged pixels are scanned by a fine beam of electron from an electron gun line by line. A part of the beam returns back carrying image describing signals to the detectors. The strength of these feeble signals is increased in an electron multiplier and final signals are digitized and recorded as the image output. These electronically processed data are amenable to rapid transmission from sensor platform to ground receiving station. Being a framing device, the RBV collects a full frame data practically instantaneously. Alternately, the image may be recorded on a magnetic tape for replay at a later time when the sensor platform is within the range of a ground station (Fig. 8.2).

Landsat-1 and Landsat-2 satellites carried three RBVs with spectral filters to record green (0.475 – 0.575 μm), red (0.580 – 0.68 μm) and optical IR (0.698 – 0.830 μm) images of the same area on the ground. Landsat-3 carried two RBVs operating in panchromatic band (0.505 – 0.750 μm) to obtain better resolution (24 m) compared to its MSS ground resolution (79 m). Successive pairs of RBV had forward overlap of 17 km. The two RBVs had a side lap of 15 km (Fig. 8.3).

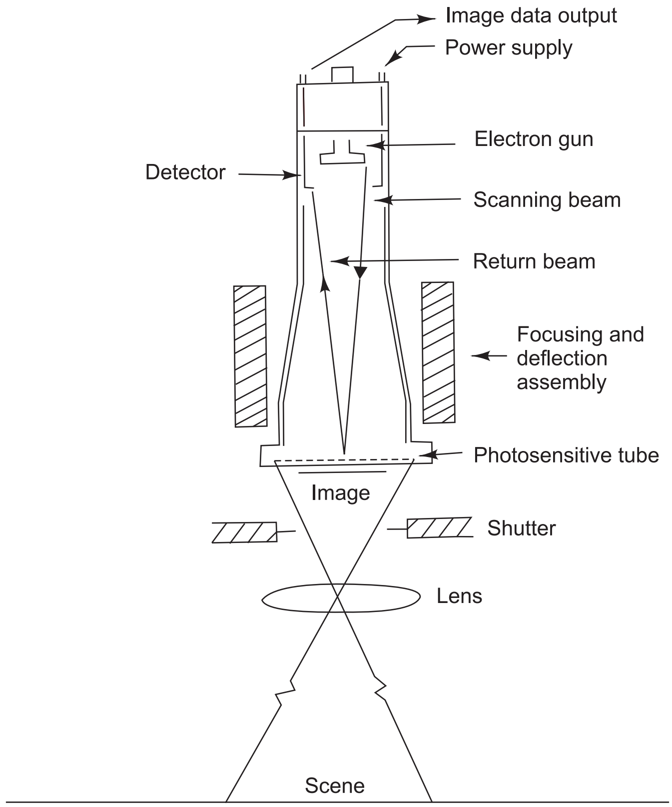

Fig. 8.2 *Schematic diagram of return beam vidicon (RBV)*

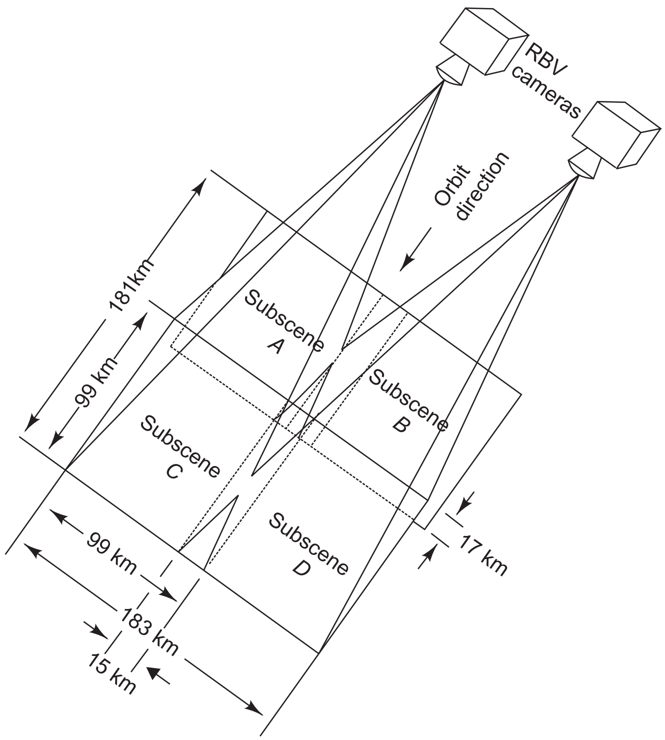

Fig. 8.3 *Assembly of two RBV cameras having sidelap in their swaths*

8.2 MULTISPECTRAL SCANNING

Unlike the photography, multispectral scanning is based on entirely different principle. As it does not use a photographic emulsion as recording medium, it can be operated on large number of bands, ranging from x-ray to radio wavelengths, by detecting radiation through sensors. Further it has additional advantage in that the data can be transmitted to a ground station, where it can be readily used to either obtain an image or processes through computers to get desired output products.

8.2.1 Scanner

A multispectral scanner (MSS) is essentially a radiometer which measures radiation in more than one waveband. It consists of: (i) an optical head with scanning mechanism, (ii) a radiation diffracting element to split the received radiation into a number of discrete spectral bands, (iii) set of detectors with associated amplifier electronics, and (iv) recording setup to store the data (Fig. 8.4). Multispectral scanning is accomplished across or along the scanning track. Also, there is possibility of side looking. These are elaborated in the following sections.

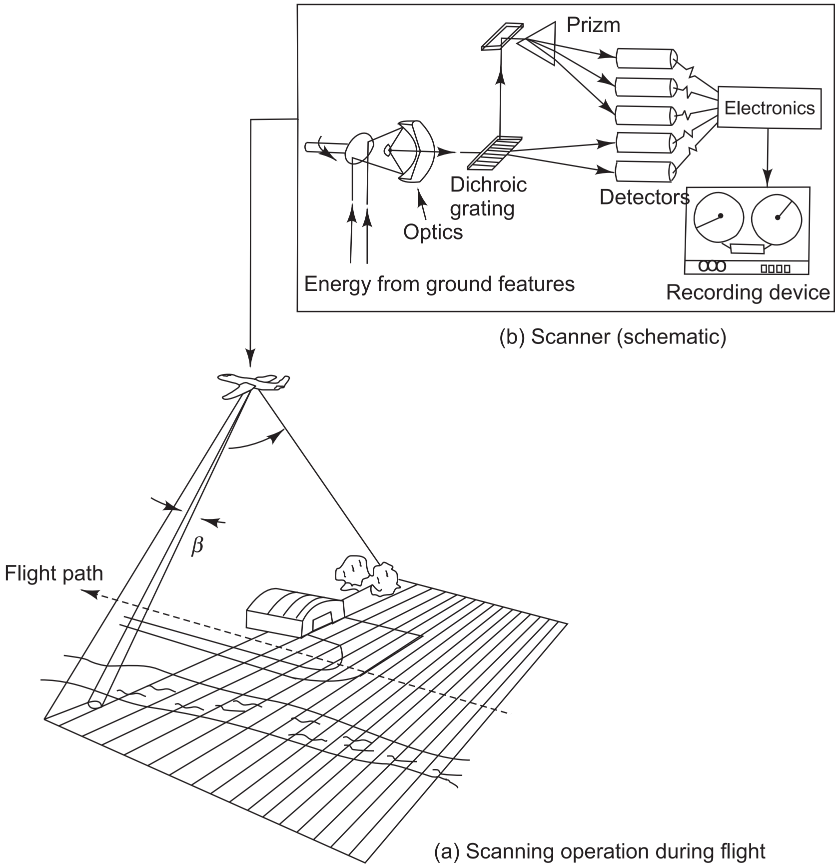

Fig. 8.4 *Operation of a multispectral scanner system*

8.2.2 Across Track Scanner

This type of Multispectral Scanner (MSS) is used in Landsat series of satellites. The scanning system employs a single detector per band of the multispectral signal received from the ground. It has an electronic motor, having a solid metal cylinder attached to its axel. The free end of the cylinder is cut at 45º to its axis of rotation and highly polished to act as a scanning mirror (Fig. 8.5). The rotating mirror scans the ground line by line, perpendicular to the direction of flight of the platform on which it is installed. The field of view (FOV) is restricted by an aperture so that the mirror receives signals in almost nadir view from the ground. On completion of one rotation, the mirror begins to scan another line on the ground. The forward motion of the platform serves to advance the scan pattern. The scan rate is so adjusted with respect to velocity of the platform that succeeding scan lines are just adjacent or barely overlapping at the nadir.

The incoming radiation received by scanning mirror is reflected to the optical head and is focused on to a diffracting element such as prism, monochromator/spectroscope or grating, which splits the radiation into different spectral bands. These spectral radiation components are allowed to fall on a set of radiation detectors sensitive to respective bands. Filtered photomultiplier (up to 0.4 μm in ultraviolet region), photomultiplier tube (between 0.4 to 0.8 μm), silicon photodiodes (from 0.8 to 1.1 μm), Indium antimonide (for 3 to 5 μm) and cadmium-mercury-telluride (for 8 to 12 μm) have been used as detectors.

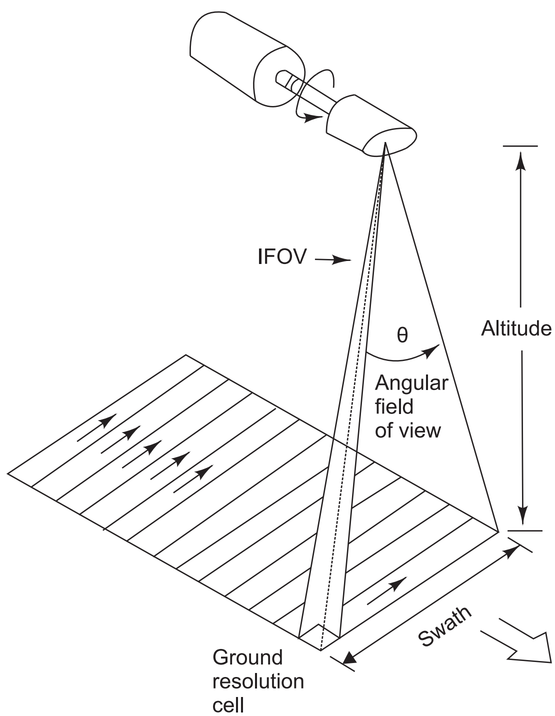

Fig. 8.5 *Schematic diagram of across-track scanner*

The optical head along with the detector can be considered to be a spectral radiometer, whose narrow field of view is being directed to the ground by the scanning mirror. The detectors produce electrical signals, which are proportional to the amount of radiation received by them from each ground resolution cell (GRC), corresponding to instantaneous field of view (IFOV), as the scanning proceeds. The signals are amplified, processed and recorded on different tracks of a magnetic tape. This data is transmitted to the ground receiving station. It can be processed on a computer to obtain a visible record or display as visual image on a TV screen. Since the swath line, along which scanning is done, is perpendicular to the track (flight direction), the scanner is called across track scanner.

The dwell time of the scanner is computed by the formula

Dwell time = Scan rate per scan line/Number of GRC per line;

The spatial resolution of the scanner

= Ground resolution cell

= IFOV × Altitude of the sensor

MSS of 9 to 24 channels have been built by Bendix Aerospace of USA. Skylab has used a 13-channel MSS. The bandwidth and other details are given in Table 8.4.

Modular multiband scanner (M^2S) of NRSA, India, is an airborne scanner having 11 bands; 10 of these in 0.4 to 1.01 μm region and one in 8 to 10 μm. The IFOV is 2.5 milliradians which gives a resolution of about 25 feet at an altitude of 10,000 feet.

8.2.3 Along Track Scanner

This is also called Push Broom Scanner because the array of detectors is analogous to bristles of a push broom, sweeping the floor. In this type of scanning, the scan direction is along the track (flight direction) of the sensor (Fig. 8.6 a, b). There are as many (generally 24) silicon photodiodes detectors as there are GRCs (corresponding to IFOV), accommodated within the restricted IFOV of the sensor optics. Each photodiode is coupled with a tiny charge storage cell, forming a charge-coupled device (CCD). The CCDs are arranged in a linear array, hence the system is also called linear imaging self scanning (LISS) system. The system has been used in Indian remote sensing satellite (IRS) and French satellite SPOT.

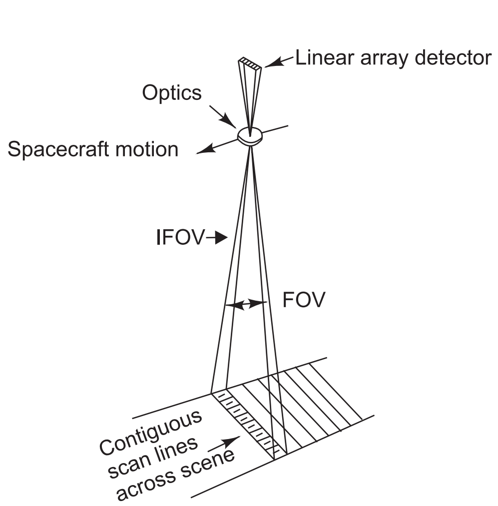

Fig. 8.6(a) *Schematic diagram of along-track scanner*

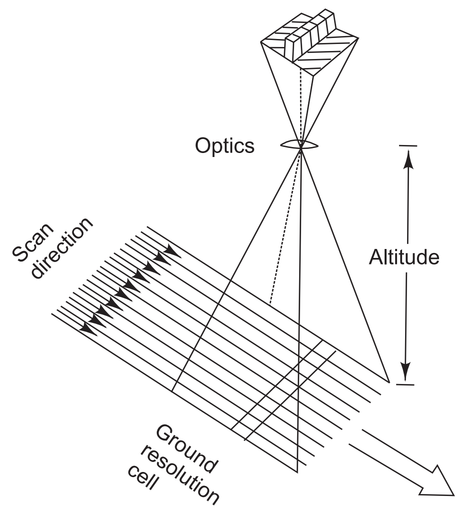

Fig. 8.6(b) *Along-track scan lines corresponding to each detector*

Table 8.4 Skylab MSS

Sl. No.	*Bandwidth μm*	*Atmospheric transmission percentage*	*Pixel per scan line*
1	0.41 to 0.46	45	1240
2	0.46 to 0.51	45	1240
3	0.52 to 0.56	55	2480
4	0.56 to 0.61	55	2480
5	0.62 to 0.67	60	2480
6	0.68 to 0.76	65	2480
7	0.78 to 0.88	70	2480
8	0.98 to 1.08	80	1240
9	1.09 to 1.19	50	1240

(*Contd.*)

Sl. No.	*Bandwidth μm*	*Atmospheric transmission percentage*	*Pixel per scan line*
10	1.20 to 1.30	80	1240
11	1.55 to 1.75	70	2480
12	2.10 to 2.35	70	2480
13	10.20 to 12.50	90	2480

For multispectral scanning, the along track scanner accommodates one line of detector array for each spectral band. However, IRS satellites use separate camera for every spectral band, each with a characteristic filter and a linear array of CCD detectors.

The spatial resolution of scanner = ground resolution cell

= IFOV x altitude of the scanner.

The dwell time for along track MSS is given by:

Dwell time = GRC dimension/velocity of sensor platform.

It is found that the dwell time of along track scanner is far greater than the dwell time of across track scanner. This results in higher signal intensity from the GRCs, which lead to minimize the IFOV, thus providing better spatial resolution. Decrease in detector size also results in narrowing down the spectral band width, there by increasing spectral resolution.

8.2.4 Side Looking Scanner

The aforementioned scanners always receive signals in the nadir view. However, there is provision in SPOT and IRS satellites to steer the cameras to look off-nadir at the required scene (on payment basis), some days before or after the normal nadir viewing (Fig. 8.7).

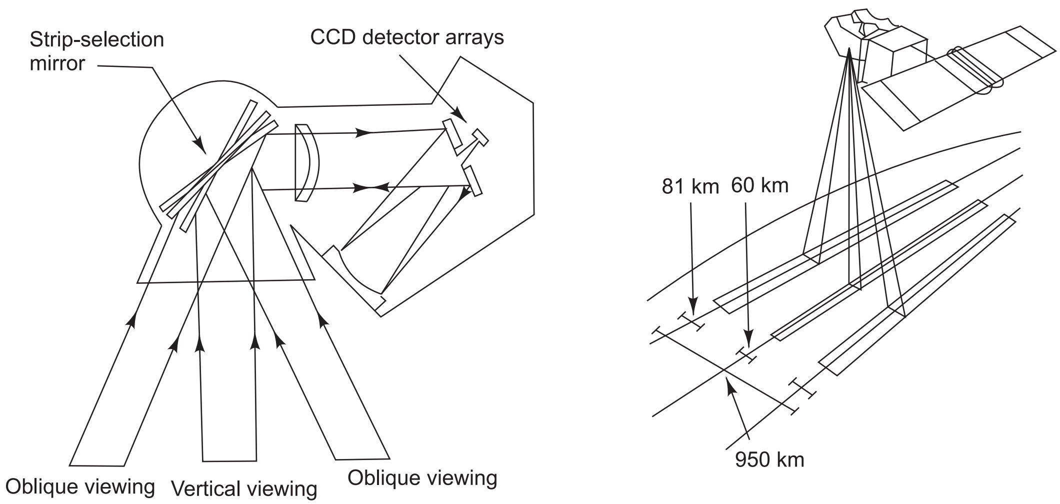

Fig. 8.7 *Schematic diagram showing oblique view*

8.2.5 Characteristics of Scanner Data

Unlike the conventional camera system, the scanner views only a small area at a particular instant of time. The narrow field of view directed to the ground is controlled by the entrance slit of the diffracting element and this is known as instantaneous field of view (IFOV). The area of the ground, which falls within IFOV, is known as ground resolution cell (GRC). The area on the film, which corresponds to GRC, is known as picture element or 'pixel'. At a particular instant of time, the output signal of the scanner depends on the net amount of radiation emanating from all objects within the GRC. Hence, finer details, which fall within the GRC, cannot be resolved or detected.

The size of GRC depends on the IFOV, the flying height and also on the scan angle. The size of the GRC changes with the angle of view of the scanner. The square ground patch at nadir (GRC at nadir) becomes distorted (becomes trapezoidal) off nadir. This problem is, however, not there in along track scanner.

8.2.6 Relief Displacement

In the central perspective of camera-lens system, the photograph has a nadir point and the relief displacement is radial to from this point in all directions. The scanner records only a narrow strip of image at a time, hence each scan line can be considered to have a nadir point.

The imagery, which is in the form of a continuous strip, therefore has nadir line, coinciding with the flight path of the platform. The relief displacement will be normal to this nadir line. A tower, which falls on the nadir line, will appear as a point. However, if it falls off the nadir line, it will be recorded as a line perpendicular to the direction of flight. Relief displace is not there in push broom scanner images.

8.2.7 Scan Distortion

The dimension of the instantaneous area viewed by a scanner goes on changing with changing of angle from the nadir. But, in the photographic reproduction of scanner data, the instantaneous area scanned is represented by a spot on the film having a constant size regardless of scan angle. This difference normally results in a gradual change of scale (reduction of scale) away from the nadir in the scan direction. The scale at a scan angle of 60° is only one fourth of that at the nadir. Further, if the scan lines are just contiguous at nadir, increase in width of scan line off nadir results in overlap of information. This distortion of line scan imagery can, however, be rectified by suitably processing the scanner data prior to photographic reproduction. In uncorrected scanner imagery, straight objects off nadir appear curved. Images from push broom scanner are free from this distortion as well.

8.2.8 Other Distortions

Other distortions of line scan imagery are due to flying height and velocity variations, viz. crab, tilt, etc., of the platform. However, these distortions are less in the case of space borne platforms as they are more stable due to lack of atmosphere at these heights.

Suggestions for Further Reading

Americal Society of Photogrammetry and Remote Sensing: *Manual of Remote Sensing V.I and II*, R.N. Colwell (Ed.). Falls Church, Virginia, 1983.

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Frequently Asked Questions

1. What are different types of multiband cameras used in satellite remote sensing?
2. Describe Return Beam Vidicon (RBV) System.
3. What are different types of Multispectral Scanners (MSS)?
4. Describe briefly the characteristics of scanner data.

9

REMOTE SENSING IN THERMAL INFRARED REGION

The reflective infrared region ranges from 0.7 to 1.2 μm and includes the optical *IR* band of 0.7 to 0.9 μm that can be detected by an *IR* sensitive film in a camera-lens system. The medium *IR* (1.2 to 8 μm) includes both reflected and emitted IR. The IR radiation of 8 to 14 μm region is absorbed by glass lenses and can not be detected by photographic film, as the emulsion is not sensitive to this wavelength region. Hence, to make use of this radiation for remote sensing, special opto-mechanical scanners with detectors sensitive to this wavelength region are used. The thermal *IR* energy is obtained in two atmospheric window regions of 3 to 5.5 μm and 9 to 14 μm. The *IR* radiation beyond 14 μm is not utilized for remote sensing, as this radiation is absorbed by the Earth's atmosphere.

9.1 EMISSIVITY

Thermal infrared energy is emitted by all materials at temperatures above absolute zero (0°K or –273°C), both during day and night. Emissivity is defined as the ratio of radiation emitted by an object to the radiation incident upon it.

Emissivity = *R* emitted/*R* incident, or

= *R* emitted by object/*R* emitted by black body at the same temperature, as the blackbody is a perfect absorber and re-emitter. For perfect black body Emissivity = 1.

Thermal infrared remote sensing refers to the detection of remote objects by recording the thermal emission of objects. The energy emitted in the thermal region depends on the emissivity characteristics of the objects in this region. The emissivity is wavelength dependent. Emissivity of most substances falls within the narrow range of 0.81 to 0.96. Table 9.1 gives emissivity of some of the terrestrial materials in 8 to 14 μm wavelength.

Table 9.1 Emissivity of some terrestrial materials in 8-14 μm band

Material	*Emissivity*	*Material*	*Emissivity*
Sea water	0.98	Cactus	0.96
Sweet water	0.97	Granite rock (rough)	0.89
Distilled water	0.96	Basalt rock (rough)	0.94
Snow	0.85	Quartz sand (large grains)	0.91
Ice	0.96	Quartz sand (small grains)	0.93
Corn canopy	0.94	Soil (dry)	0.92
Cotton canopy	0.96	Soil (wet)	0.95
Tobacco canopy	0.97	Soil (loam)	0.97
Sugarcane canopy	0.99	Clay	0.98
Meadow grass (dry)	0.88	Brick	0.93
Meadow grass (green)	0.95	Concrete	0.92
Green tree (deciduous)	0.96	Asphalt paving	0.96
Green tree (coniferous)	0.97	Polished metal surfaces	0.06

The final product of thermal mapping system is a map showing apparent surface temperatures. The system is sensitive not only to change in surface temperature but also change in emissivity of the scanned surface. Common surface materials like rock, soil, vegetation, etc. have emissivity values between 0.75 and 0.95 and hence, the surface temperature differences resulting from the changes in emissivity alone are quite small, as compared to the temperature differences produced by other factors. Therefore, interpretation of only the most subtle anomalies requires the consideration of emissivity.

9.1.1 Thermal Inertia

This is a measure of thermal response of a material to temperature changes. In general, the higher the density of a material, higher is its thermal inertia. Materials such as sandstone and basalt have higher thermal inertia and hence cooler in day time and warmer at night. Materials having low thermal inertia, such as shale, volcanic cinders are warmer in day time and cooler at night.

The thermal inertia of water is similar to that of soils and rock but during day, water bodies have cooler surface temperatures than soil and rocks and this position gets reversed during night. The reason of this phenomenon is that convection currents maintain a relatively uniform temperature at the surface of water bodies. Vegetation is cooler during the day and warmer during night time, compared to adjacent soils. In view of these changes in the surface temperatures of terrestrial objects during the day and night, the time of acquisition of thermal IR imagery should be kept in mind for proper interpretation.

Night time imagery is preferred for most geological applications, because the thermal effects of differential solar heating and shadowing are greatly reduced. In day time images, topography is typically the dominant expression because of these differential solar effects. As the radiant temperatures are relatively constant in the pre-dawn hours, thermal imagery obtained during such hours is preferable.

9.2 THERMAL INFRARED SENSORS

The thermal infrared sensors are of two types: (i) Infrared radiometers and (ii) Thermal scanners. These are described below.

9.2.1 Infrared Radiometers

These are non-imaging, non-scanning devices used to record the absolute measurement of thermal radiation flux. They measure radiant temperature using detectors sensitive to 8-14 μm wavelength. The temperature sensitivity of the instrument is typically 0.2°C. These measurements are useful for collecting ground truth. The radiometer looks at one element (cell) in a scene and, as it is calibrated to some known temperature, it can give data which permit quantitative estimation of apparent and, in some cases, actual temperatures. Temperature fluctuations up to 0.01°C can be measured with radiometers.

9.2.2 Thermal Scanners

In order to obtain satisfactory temperature resolution and aerial coverage, it is necessary to adopt a scanning system for remote sensing in thermal infrared region. The thermal scanners are passive, imaging and opto-mechanical type. As in multispectral scanners, the radiation is received by a scanning mirror. This radiation is focused onto a detector sensitive to thermal radiation. The detector output is amplified and recorded on a magnetic tape or used to drive a cathode ray tube (CRT) or a light source for recording directly on a film (Fig. 9.1). The important difference of this image from that of an aerial photograph, is that the aerial photograph records reflected light while the IR imagery records emitted radiation, which is a product of emissivity and surface temperature. Thus, warmer objects will appear brighter than cooler objects, even though the objects are the same.

The detectors used in thermal scanner are of Indium antimonide or gold/copper doped Germanium which is sensitive to thermal radiation. These detectors have to be protected from unwanted thermal radiation from the surroundings, such as the scanner body, etc., which affect this radiation by virtue of their temperature. The detector, therefore, is very small, not bigger than a pin head, which is kept cool in liquid nitrogen (for radiation between 3 and 6 μm) or in liquid helium (for radiation between 8 to 14 μm). The detectors have a dynamic range, but the recording film imposes a limitation on this range. The use of magnetic tape is less restrictive on this point.

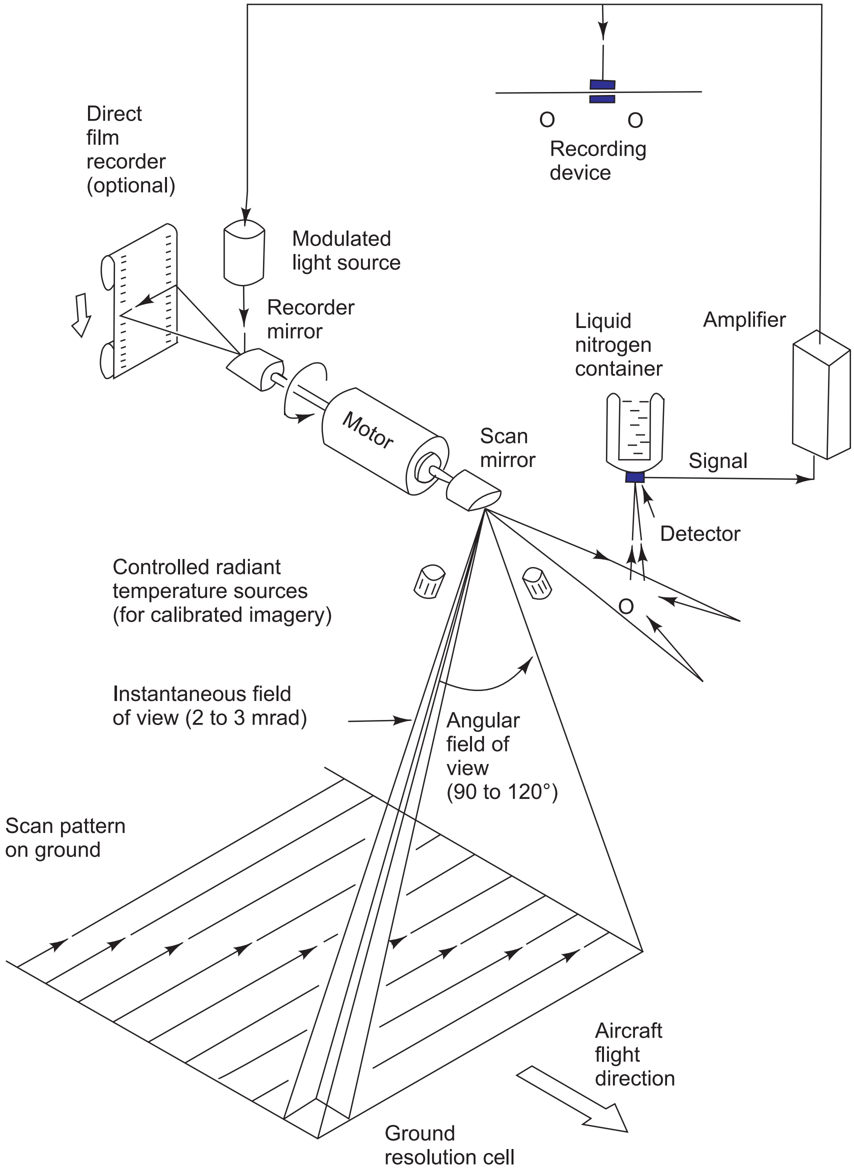

Fig. 9.1 *Diagram of thermal IR scanner*

The resolution of the scanner depends on the size of the detector surface and flying height. It is about 2-3 meters for a flying of 1000 m. An altitude of 2000 m is considered best for conducting thermal IR surveys. The thermal resolution varies from 0.1° C to 0.25° C for ground surfaces and is 0.01° C for water surfaces. In the atmospheric window of 8 to 14 μm, the maximum spectral distribution of materials occurs at normal temperatures. Cadmium-Mercury-Telluride detectors have maximum sensitivity in this region. Hence, this region of wavelength is particularly suited for measurements of emissivity coefficients of surface materials.

9.3 CHARACTERISTICS OF THERMAL IMAGES

The characteristics of thermal imagery, which includes distortions and irregularities, are discussed below.

9.3.1 Scanner Distortion

The scanner system produces a typical geometric distortion on the image. Because of the altitude of the platform, the ground resolution cell of the detector is larger at either end of the scan line than at nadir (Fig. 9.2). The scanning mirror rotates at a constant angular rate, but the imagery is recorded at a constant linear rate, so that each GRC is recorded equally in size, causing compression towards the edges of the image. This compression results in geometric distortion, shown diagrammatically in Fig. 9.2(b). The real situation is shown in Fig. 9.2(a). The 'S' shaped curvature of straight roads, trending diagonally across the fight path is a typical expression of scanner distortion. Image recorded on magnetic tape may be played back onto film with an electronic correction to produce rectilinear images, free from distortion. It is, however, impossible to remove image distortions completely and in consequence, thermal imagery is rarely used as a tool for precision mapping.

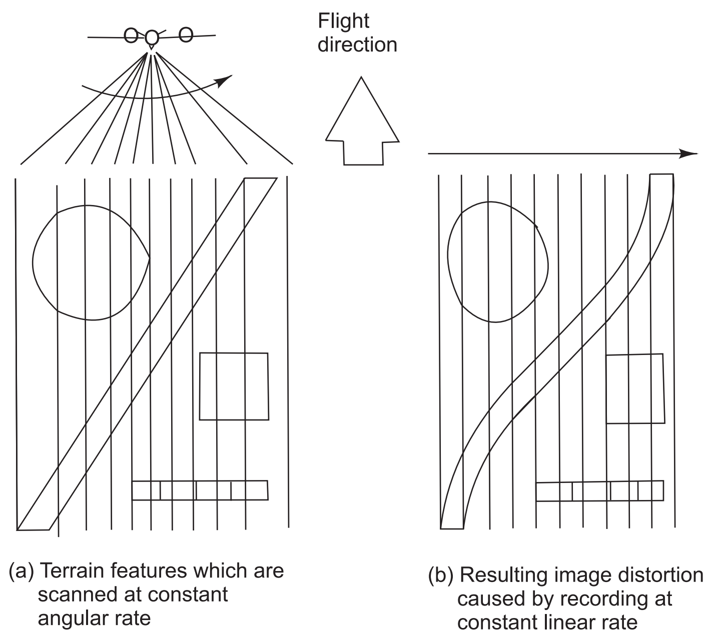

Fig. 9.2 *Distortion characteristics of images*

9.3.2 Thermal Image Irregularity

In addition to the normal scanner distortions, image irregularities may result due to random variation in aircraft parameters, weather effects, electronic noise and processing defects. A heavy cloud overcast layer reduces thermal contrast between terrestrial objects, because of radiation of energy between the terrain and cloud layer. Rain and showers produce strokes parallel to scan lines. Surface winds produce characteristic pattern of smears and strokes on images. Faulty developing may produce developer strokes. All these factors have to be kept in mind while interpreting thermal imagery.

9.3.3 Film Density and Temperature Range

The density changes on a film are linear over a relatively narrow range of temperature. Above and below this narrow range, large temperature differences produce only slight density differences. Hence a thermal mapping system, using film as recording medium, does not measure absolute surface temperatures but measures temperature differences of a few degrees, over a limited temperature range, as distinguishable tonal differences. However, in case of scanner produced thermal image, this aspect need not be considered, as the film is not directly exposed to thermal radiation.

9.4 APPLICATIONS

Thermal imagery has wide applications in geology. Denser rocks such as Basalt and Sandstone have higher thermal inertia, as such these show warm signature in night time thermal IR images. Faults may be marked by cooler anomalies caused by evaporative cooling of moisture trapped along the fault zones. Folds may be indicated by thermal patterns caused by outcrops of different rock types. Surfaces of active volcanic terrains may give warning for impending volcanic eruption. Thermal scanners can detect warm subterranean lava channels, which are not visible on the surface.

Thermal imagery can be effectively used in hydrology for locating thermal springs, cool and warm water zones in oceans, shallow water zones and even atmospheric temperature differences. They can indicate cool underground springs that discharge into warm water channels. Diffusion pattern of hot industrial effluents that pollute water can be mapped by thermal imagery.

Leaf temperature can be remotely measured by using 3–5 μm band. This knowledge is useful for assessing plant health, age, relative water supply received by the plants, etc. Sick plants, which have temperatures of 5° to 15°F more than healthy plants, can be spotted easily. Thermal images have been used to identify crop species, soil types and for detecting crop diseases and relative moisture content in various soil types.

Forest fires of 1 foot across, underneath forest canopy can be detected by thermal IR imagery from an altitude of 20,000 feet.

Military applications of thermal IR imagery in studying unusual concentration of troops, weaponry, military vehicles, jungle trails, etc. are well known.

Suggestions for Further Reading

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Frequently Asked Questions

1. Write short notes on: Emissivity; Thermal Inertia; Infrared Radiometer.
2. Describe different types of Thermal Infrared Sensors.
3. Describe the characteristics of Thermal Images.
4. What are the applications of Thermal Imagery?

10

REMOTE SENSING IN MICROWAVE REGION

Microwave region of EM spectrum encompasses the wavelengths ranging from 1 mm to 1 M. Beyond 1 mm wavelength of EMR, which is an arbitrary boundary between Infrared and Microwave regions, there is no atmospheric attenuation for wavelengths longer than 18 mm; although there are atmospheric windows between 1 mm and 18 mm wavelength. Remote sensing in Microwave region can be of passive or active type.

10.1 PASSIVE SYSTEM

In passive microwave remote sensing, the emitted energy, in part from below the surface of the object, is measured. Therefore, it is possible to know about the moisture content at depth of several centimeters in solid materials and a few meters in loose materials. Radiant energy in microwave region has also the capability of penetrating cloud covers. Ice has smaller dielectric constant in the microwave frequencies, as compared to water. Thus, this property is utilized to distinguish between iceberg and open water.

The intensities of naturally emitted microwave radiation are much lower compared to those of thermal infrared. The low intensities of microwave region result in poorer temperature resolution. However, longer wavelengths have advantage of passing through cloud cover.

In the passive system, a microwave radiometer is used as the sensor. It operates in the region of 1 mm to 100 mm wavelength. Typical frequencies which are employed in microwave radiometry are (i) 19 GHz, (ii) 33-38 GHz and (iii) 94 GHz, as these frequencies are less affected by attenuation due to water vapor present in the atmosphere. A microwave radiometer consists of a directional aerial, a receiver and a detector. The spatial resolution obtained by microwave radiometer depends on the aerial size and the altitude of platform. The spatial resolution capability is low (of the order of 1 km) and the temperature resolution is of the order of 1° to 1.5°C. It has found application in snow mapping, soil moisture mapping and similar fields.

10.2 ACTIVE SYSTEM

In order to achieve better resolution in the imagery of microwave region, an active system is employed. RADAR (Radio detection and ranging) system, which operates in microwave wavelength region of 1mm to 1m, is an active system as it has its own source of energy (klystron, magnetron, radio antenna) to illuminate the target. The energy returned from the terrain (called the radar return) is detected by the system and recorded as imagery. Being an active system, the light conditions of the terrain is irrelevant to the system. Hence it can be operated with the same results during day and night. Due to long wavelengths of EMR used, it has penetration capability through cloud cover and vegetation.

Plan Position Indicator (PPI) Radar was developed during World War II for navigation and target location. This radar, however, is not used for mapping now. SLAR, (side looking airborne radar) developed during 1950s, provide photo like images of the terrain and are very much used for mapping purposes.

10.2.1 SLAR System

The system essentially consists of a radio frequency generator and amplifier, a timer switch, a transmit-receive switch, an antenna, a receiver, a cathode ray tube (CRT) and a camera (Fig. 10.1). The antenna is a long, rectangular in shape and is mounted on the body of an aircraft, parallel to its longitudinal axis. The antenna emits fan shaped, essentially plane polarized pulses of electromagnetic energy in a direction normal to the antenna's longitudinal axis. The pulse travels along this plane until it intercepts a narrow strip on the ground, sideways below the aircraft.

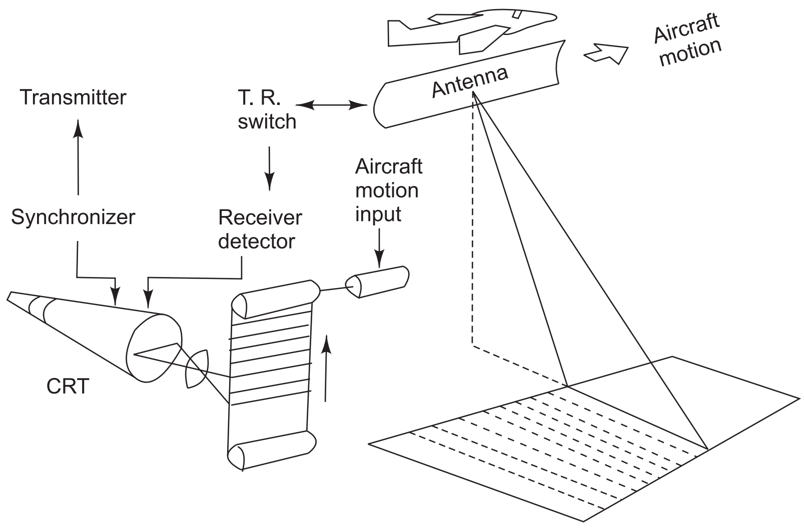

Fig. 10.1 *Diagram of SLAR system*

The energy which is not absorbed by the target surface is reflected back. If the terrain surface is flat and smooth, specular reflection takes place. If the surface is rough, diffused reflection occurs and a part of energy is returned to the antenna. Depending on the distance of the terrain feature from the antenna, reflections arrive sooner or later at the antenna. The radiation received by the antenna is transformed by the receiver into an electrical analog signal. This signal modulates the intensity of a flying spot of a CRT. The CRT screen is imaged sharply on a photographic film in such a way that one scan line on the ground is covered by one swoop of the flying spot, as in the case of a TV system. By moving the photographic film at a speed proportional to the speed of the aircraft, a continuous strip map of the terrain is formed.

10.2.2 Frequency Range of SLAR

Different radar wavelengths and corresponding frequencies used in SLAR system are given in Table 10.1.

Table 10.1 Bands used in SLAR system

Band	*Wavelength (cm)*	*Frequency (GHz)*
Ka (0.86 cm)	0.8 to 1.1	40.0 to 26.5
K	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X (3 and 3.2 cm)	2.4 to 3.8	12.5 to 8.0
C	3.8 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L (25 cm)	15.0 to 30.0	2.0 to 1.0
P	30.0 to 100.0	1.0 to 0.3

The figures in brackets indicate wavelengths commonly used in imaging.

Most of the available images have been acquired in Ka or X bands and a few in L–band.

10.2.3 Resolution in Radar Imagery

In case of radar imagery the special resolution achieved is in terms of range resolution and azimuth resolution. The range resolution is the resolution obtained along the length of the narrow strip of ground "illuminated" by the radar fan beam or resolution across the flight path of the aircraft. The azimuth resolution is the resolution obtained along the flight path of the aircraft. These are dealt in greater details below:

10.2.3.1 Range Resolution

The spatial resolution in range direction is determined by duration or length (in time unit) of the pulse of transmitted energy and is theoretically equal to half of the pulse length (Fig. 10.2) and therefore, shorter the pulse length, better the resolution. The range resolution is also dependent on the depression angle (angle between the horizontal plane and the line connecting the target and the antenna). Range resolution is given by the formula:

Range resolution = $\tau \,.\, c/2 \,.\, \cos \gamma$,

where

τ = pulse length (in time unit)

c = speed of EMR (3×10^8 m/sec)

γ = depression angle.

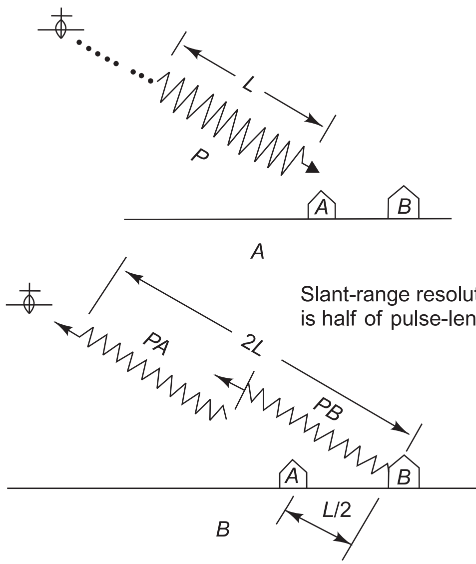

Fig. 10.2 *Effect of pulse length on range resolution*

For a depression angle of 50° and pulse length of 0.1 microsecond, the range resolution, the range resolution is 23 m. Hence, objects separated by more than 23 m in the range direction would be resolved. At a depression angle of 35°, range resolution would be 18 m. Thus, the resolution is better for objects situated far away in the range direction (in contrast to the oblique aerial photographs). The resolution in range direction is independent of aircraft distance from the object, for a given beam depression angle (Fig. 10.3).

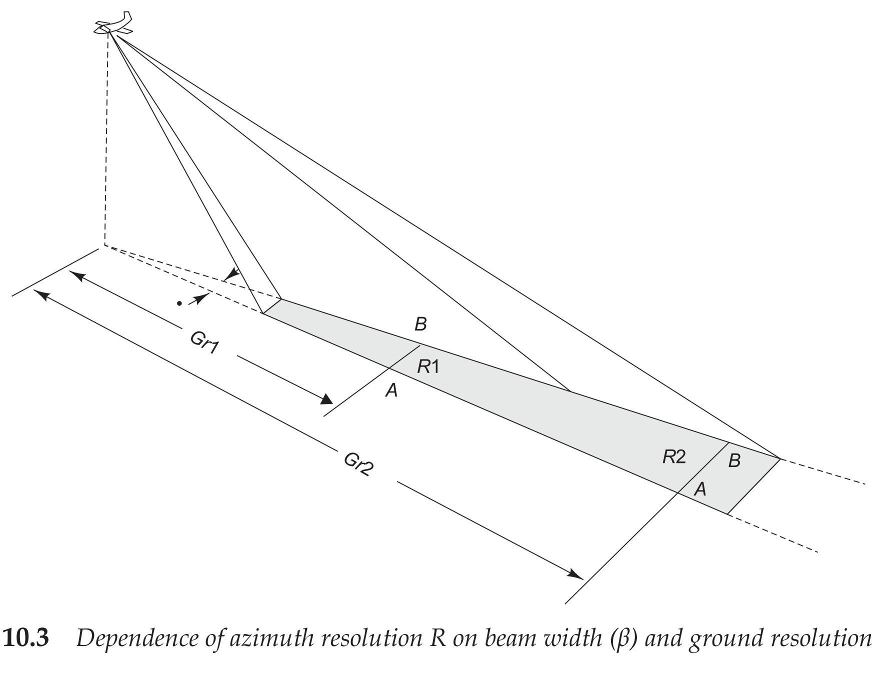

Fig. 10.3 *Dependence of azimuth resolution R on beam width (β) and ground resolution (Gr)*

10.2.3.2 Azimuth Resolution

Azimuth resolution is determined by width of the terrain strip 'illuminated' by the radar fan beam. In order to be distinguished separately (resolved), a distance greater than the beam width must separate targets in the azimuth direction on the ground. As the beam width is narrower in the near range, the azimuth resolution is better in the near range (Fig. 10.3).

As azimuth resolution depends on the width of the beam, which in turn depends on the wavelength of radiation used and the length of the antenna. Azimuth resolution is given by the formula:

$$\text{Azimuth resolution} = 0.7 \,.\, S \,.\, \lambda/D,$$

where S = slant range

λ = wavelength, and

D = antenna length

For a slant range of 8 km, wavelength of 0.86 cm and antenna length of 490 cm, the azimuth resolution would be 9.8 m in the near range. For a slant range of 20 km, azimuth resolution would be 24.6 m.

Most of the SLAR systems are designed to have about 10 m of azimuth and range resolutions. The resolution can be improved by using a longer antenna and shorter wavelength. But there is a limit to the maximum length of an antenna that can be carried outside an aircraft and shorter wavelengths will not have enough power to penetrate a moist atmosphere or clouds because much of the energy will be scattered.

10.2.4 Real and Synthetic Aperture Radars

Real aperture radar (RAR) uses an antenna of maximum practical length to produce a narrow beam width in the azimuth direction. While, synthetic aperture radar (SAR) employs a relatively small antenna that transmits a broad beam but mathematically synthesizes a very long antenna, which is achieved by using change of phase (Doppler shift) of the received signal. It would produce a very narrow beam (Fig. 10.4), thereby achieving improved resolution. The beam width is uniform after processing the signal, in case of synthetic aperture radar, which results in the resolution being same in the azimuth direction, for all objects from near range to far range (constant azimuth resolution). Processing of synthetic aperture radar signals have given azimuth resolutions up to 100 times better than those obtained with real aperture radars. Thus the area of ground resolution cell may be computed by the following formula:

The ground resolution cell of SAR data = Range resolution x Azimuth resolution

An improvement of synthetic aperture radar is focused synthetic aperture radar in which the resolution is independent of all parameters except the physical aperture and is equal to half the physical aperture size. It is, however, necessary that the aperture should be very much larger than the wavelength used. In view of the higher resolution, the data required to be handled by SAR is enormous and it is very expensive due to its complexity.

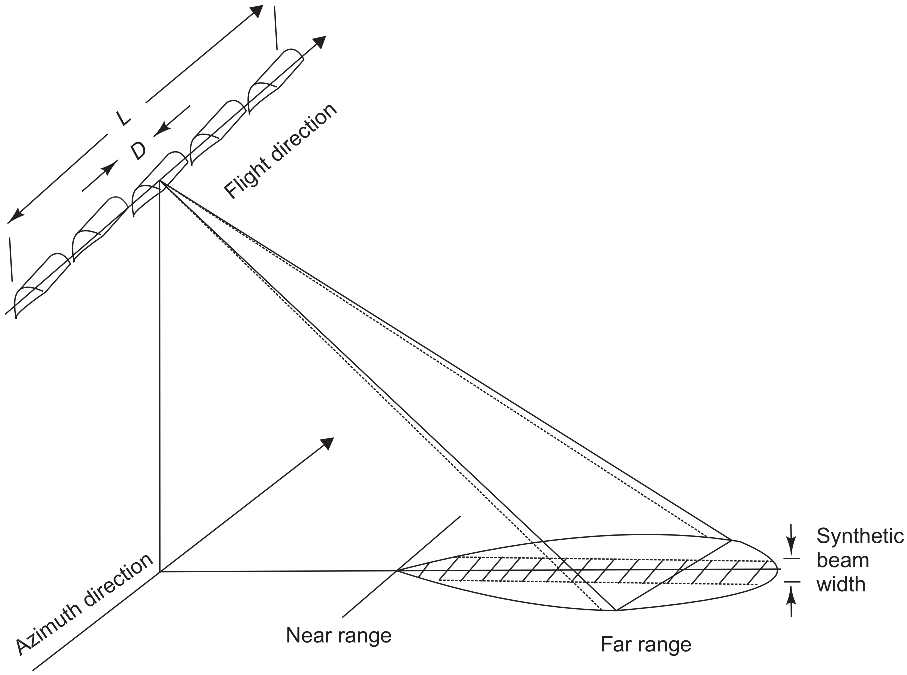

Fig. 10.4 *Synthetic aperture radar (SAR)*

Recording of radar data is done either on a strip of film or on tape. Due to the enormous amount of data involved, the recording is preferred on film. With the advent of high density storage devices (tapes, CD, DVD, Hard Disc in terrabyte capacity) and micro-computer digital processing, the data storage in high density storage device is coming in vogue. The advantage of stored data is in accommodation of a larger dynamic range than in the image.

10.2.5 Radar Return and Image Signatures

The energy reflected from the terrain objects to the radar is called radar return. It consists of mainly scattered energy from the ground objects. If the radar returns are stronger, the resulting image is brighter. The following parameters strongly affect the radar return.

(b) System parameters

- (i) Polarization
- (ii) Depression angle
- (iii) Wavelength

(c) Terrain parameters

- (i) Dielectric constant of surface material
- (ii) Surface roughness

10.2.5.1 Polarization

In normal SLAR, the antenna transmits and receives horizontally polarized (HH) energy. However, systems, where vertically polarized (VV) energy is transmitted and received, are also used. Not withstanding the polarization of transmitted energy, the reflected energy contains both horizontal and vertical components. A radar system containing two antennas to receive like polarized (HH or VV) and crossed polarized (HV or VH) returns allows simultaneous acquisition of two displays. A comparison of like and cross polarized returns may reveal differences leading to terrain identification. Water and trees appear the same in like and cross polarized images while swamps appear brighter in like polarized and darker in cross polarized images. Reverse is the case for grassland, which appear darker in like polarized and brighter in cross polarized images.

10.2.5.2 Depression Angle

Rough surfaces reduce diffused scattering of relatively uniform intensity, irrespective of depression angle. Smooth surfaces give a stronger return at depression angle near vertical but little or no return at lower depression angles.

10.2.5.3 Wavelength

The strength of radar return is determined by relationship of surface roughness to radar wavelength and to depression angle. It follows the Rayleigh criteria i.e. longer the wavelength, stronger the specular reflection from the object of an average roughness. Thus, loss or no energy returns to radar antenna. Reverse is the case for shorter wavelengths. However, considering the atmospheric attenuation, the longer wavelengths are less affected by it. The longer wavelengths have some penetration capability in the ground. In light of these criteria, a balance has to be achieved in selecting radar wavelength for the type of surveys required and atmospheric conditions (cloud, etc.) prevailing over the terrain.

10.2.5.4 Dielectric Constant

The electrical properties of matter influence the interaction of EMR. At radar wavelengths, the dielectric constant of materials, which is a complex function of permissivity and conductivity of the medium, influences the interaction pattern of EMR to a considerable extent. Dry rocks and soils have a dielectric constant 3 and 8 and water has a value of 80. The depth of penetration of radar waves below the surface varies inversely with the dielectric constant of the material and directly with the radar wavelength. An increase in dielectric constant increases the reflectivity of the surface.

10.2.5.5 Surface Roughness

Surface roughness of the terrain strongly influences the strength of radar returns. Surface roughness is distinct from topographic relief, which is measured in meters to hundreds of meters and is due to landforms and related features. Surface roughness is due to textural features such as leaves and twigs of vegetation and sand, gravel and cobble particles assembled on the rock surface. The average surface roughness within a ground resolution cell (of 10 × 10 m, for a typical SLAR system) determines the intensity of energy return from the cell.

The surfaces may be grouped in the following three categories:

(a) A smooth surface which reflects all the incident radar energy (specular reflection).

(b) A rough surface which diffusely scatters the incident energy at all angles, and

(c) Surfaces of intermediate roughness which reflect a portion of the incident energy and diffusely scatter the rest of it.

10.3 SATELLITE RADAR SYSTEMS

The developments of synthetic aperture radar lead to acquire radar images from space-borne observation platforms. Seasat and Shuttle programmes of NASA, Earth Resources Satellite (ERS) of European Agency, Radarsat of Canada, ERS of Japan and RISAT of ISRO are examples of satellite radar systems. Some of these are briefly described below.

10.3.1 Seasat

Seasat, an unmanned satellite, was launched by NASA in June 1978 for studying oceanic phenomenon. It remained operational only till Oct'78, due to major on-board electrical failure. However, during its short life, Seasat collected valuable data about global oceanic surface topography, through digital elevation models, using data from Seasat altimeter. It also acquired data about average global winds derived from Seasat scatterometer. Characteristics of SAR system of Seasat are given in Table 10.2.

Table 10.2 Characteristics of Seasat SAR system

Characteristics	*Values*
Orbit inclination	108°
Wavelength	L-band (23.5 cm)
Spatial resolution	25 m
Latitude coverage	72° N – 72o S
Altitude	790 km
Image swath	100 km
Depression angle	67° – 73° (Average 70°)
Smoothness criterion	H < 1.0 cm
Roughness criterion	h > 5.7 cm
Polarization	HH

10.3.2 Shuttle Imaging Radar

A manned space shuttle mission, Shuttle Imaging Radar (SIR-A) was launched by NASA in November, 1981 (Figs 10.5 and 10.6). The image data were recorded as holographic film.

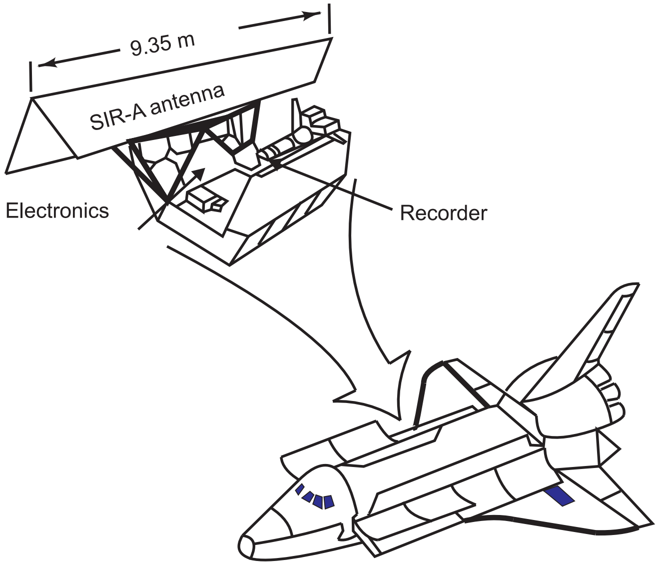

Fig. 10.5 *Diagram of Shuttle Imaging Radar (SIR-A)*
(The SAR Antenna was compactly placed inside the shuttle cargo bay) (after Panda 2005)

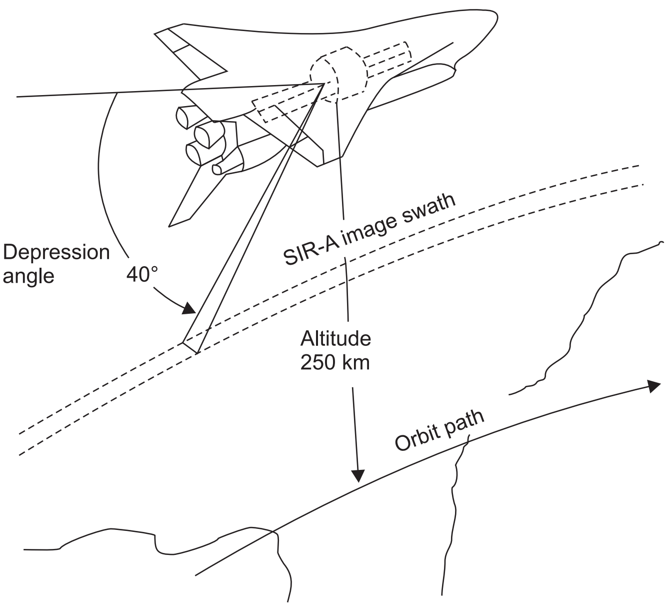

Fig. 10.6 *SAR antenna of shuttle (operates in inverted position)*

Subsequently, the data is processed in lab to get image showing terrain features. Next in the series, SIR-B was launched in October, 1984. It was essentially the same, except that SIR-B has and additional device for changing the depression angle of the radar antenna. The synthetic aperture radar antenna of SIR–A/SIR–B was compactly placed inside the shuttle cargo bay (Fig. 10.5). Characteristics of SIR–A and SIR–B systems are given in Table 10.3.

Table 10.3 Characteristics of SIR–A and SIR–B systems

Characteristics	*Values for SIR–A*	*Values for SIR–B*
Orbit inclination	38°	57°
Wavelength	L–band (23.5 cm)	L–band (23.5 cm)
Spatial resolution	38 m	25 m
Latitude coverage	50° N–35° S	58° N–58° S
Altitude	250 km	225 km
Image swath	50 km	40 km
Depression angle	37°–43° (Av. 40°)	30°–75° (Av. 52°) variable
Smoothness criterion	$h < 1.5$ cm	$h < 1.2$ cm
Roughness criterion	$h > 8.3$ cm	$h > 6.8$ cm
Polarization	HH	HH

10.3.3 Radar Imaging Satellite (RISAT)

ISRO Launched RISAT-2 on 20th April, 2009 in a circular sun synchronous orbit of 586 km height. It is a multimode SAR payload, operating in various modes to provide images with coarse fine and high spatial resolutions. It functions in C-band and has resolutions of 3 to 50 m in different modes. It has swaths of 10 to 240 km in various modes.

10.4 RADAR IMAGE CHARACTERISTICS

The characteristics of radar imagery are described under following subheads.

10.4.1 Relief Displacement

The relative position of target is determined by arrival of return signals, which are directly proportional to the travel time of the signal. This causes displacement of topographic points above or below mean terrain level. The slopes facing look direction show top of the object displaced towards flight line, resulting in fore-shortening (Fig. 10.7).

For vertical or near vertical objects, the top reflect radar pulse energy in advance of its base, resulting in displacement of the top towards the near range direction. This is called lay over.

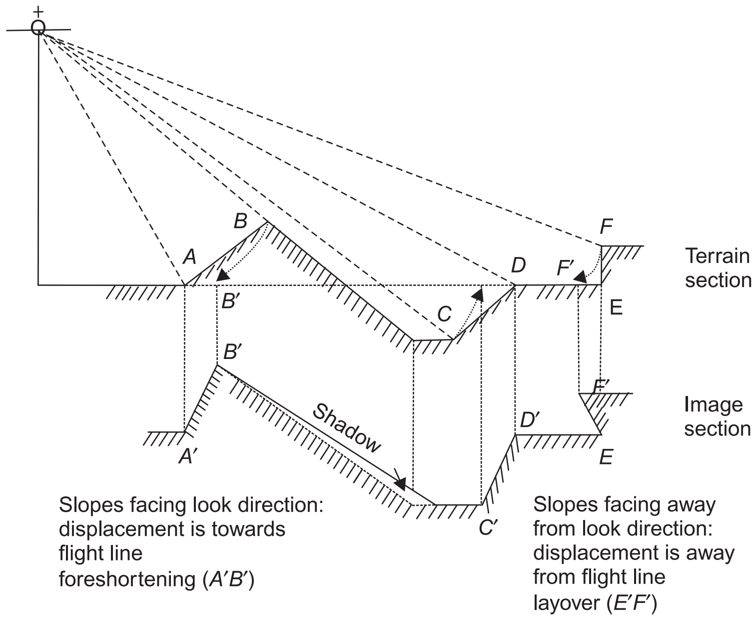

Fig. 10.7 *RADAR relief displacement*

10.4.2 Shadows

Terrain slopes inclined towards antenna will show strong reflection, while terrain slopes away from the flight line, show no reflection at all and consequently appear as shadows. Shadows increase in length as angle of incidence increases from near to far range (Fig. 10.8). The radar shadows are area of no information.

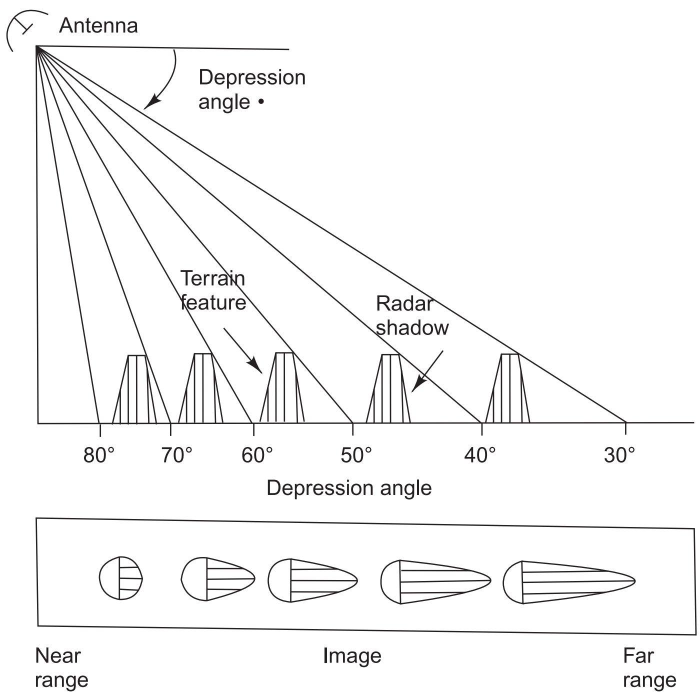

Fig. 10.8 *Shadows in radar imagery at different depression angles*

10.4.3 Effect of Aircraft Motion

SLAR antennas have stabilization systems to compensate for normal aircraft roll, etc. But strong turbulence and aircraft maneuvers may exceed the limit and may result in image distortion.

10.4.4 Look Direction

The relationship between radar look direction and the direction of faults and fractures determines whether these linear features are enhanced or subdued on the image. When the linear features are normal to the look direction, the shadows are more pronounced. When these are parallel to the look direction, they are subdued.

10.4.5 Stereo-imagery

Radar flight lines may be so spaced to give overlapping images, which, when viewed under stereoscope, would give three dimensional view of the terrain, though it is not similar to what is obtained from central perspective projection of aerial photographs.

10.5 RADAR IMAGE INTERPRETATION

The imagery should be oriented in such a way that the radar shadows fall forward the observer. The radar imagery is interpreted in a similar way as the aerial photographs using tone, texture, pattern, shape and other interpretation criteria.

In radar imagery, tone depends on the position and elevation of the reflecting surface, the nature of the reflecting material, its moisture content and vegetation cover on it. Essentially more so than on aerial photograph. A radar image registers the topographic relief and micro-relief in shades of black and white. A surface that slopes towards the flight line will radiate much more energy in the direction of the antenna, than will a similar surface facing the opposite direction. Consequently the first will show lighter tones whereas the second appears darker or complete shadow. Horizontal surface of equal material and moisture content will tend to show intermediate tone. Some materials cause stronger reflections than others, thus metal fences and posts will stand out clearly. Little is known about the relative strengths of reflection from different rock types.

Strong and bright signals are also indicative of prominent cultural features or man-made features. Weaker signals denoted by dark grey tones commonly indicate the presence of water and hydrologic features.

Texture in the radar images depends on the subtle changes in the relative interaction of the following components: Terrain roughness (as defined above), shadow effects of the micro relief, the dielectric constant of the surface material, and the covering vegetation. Texture may be designated by such terms as: coarse or fine, smooth or rough, even or uneven, speckled or mottled, granular, linear and blocky. Particle size and micro relief may affect both tone and texture. Surfaces composed of particles, or with constituent elements of the micro relief having a diameter less than half the wavelength will act as specular reflectors. Such surfaces that act as true specular reflectors are unruffled water and smooth ice. However, flat areas of fine grained materials, e.g. very fine sand, may approach specular reflection and show dark, or very dark tones. Surfaces composed of material or with component of micro-relief, exceeding half the wavelength in diameter, will act as diffuse reflectors. Thus irregular, blocky rock surfaces and rock or boulder strewn terrain will show light or medium tones and exhibit a rough, uneven appearance.

Dry soils have a low dielectric constant. With higher moisture content, the dielectric constant increases and reflections become stronger. Therefore, soils will exhibit lighter tones as they contain more moisture. Covering vegetation increases diffused reflection and cause lighter tones. The effect is not so pronounced in dry vegetation, but becomes particularly strong in lush, moisture rich vegetation. Grassland vegetation gives uniform returns and an even texture. Trees will cause a speckled appearance. Some surface materials have the ability to depolarize the return signals more than others. Change in silt composition or lithology may sometimes be enhanced by tonal contrasts presented in two different images, one presenting the component which has the electric vector polarized in the same direction as the transmitted energy (HH or VV), while the other is polarize perpendicularly with respect to the outgoing signal (HV or VH).

10.5.1 Advantages and Limitations

1. Being an active system, it can be operated any time of day or night with same output tonal uniformity. This leads to easier flight planning also.
2. Penetration capability through clouds results in imagery with same tonal quality under cloud and cloud free conditions.
3. Because of low resolutions, the vegetation cover is suppressed in radar imagery. This together with the enhancement of topographic features due to shadow effect (due to oblique illumination) resulting in emphasis of stream courses and water bodies, make it very suitable for topographic reconnaissance and drainage basin measurements.
4. In the radar imagery, it is possible to detect unconsolidated aquifers such as flood plains, alluvial fans and buried stream channels.
5. Oblique illumination enhances lineaments due to shadow effect and hence they can be easily recognized.
6. Valuable for monitoring sea-ice conditions at higher latitudes during periods of winter darkness.
7. Image strips, covering a long belt, can be conveniently joined to form mosaics.
8. Radar images have too small a scale and are of too restricted resolution for detailed or semi-detailed interpretation. However, this situation is getting improved with better resolution and better computing power.
9. Precision for cartographic purposes is not attained due to relief displacement and other inherent errors (radar-grammetric instruments are coming up fast).
10. For acquiring radar images, an elaborate and costly system is required.

For exploratory and reconnaissance types of surveys SLAR images will be of great help, essentially in areas where due to permanent haze or cloud cover, high altitude photography can not be obtained. SLAR might be more suitable than conventional aerial photographs or other remote sensing systems in these situations. For example, in order to obtain images for flood damage assessment at night or, during or just after severe storm, when an overcast sky might interfere with normal aerial photograph acquisition, SLAR system may prove very effective.

Presently SLAR and SAR (Synthetic Aperture Radar) data and imagery have been fruitfully utilized in the domain of geological mapping. These are particularly useful in areas that are under thick vegetation cover and are under cloud cover over a long part of the year. It has been very effectively used for depicting micro relief and thus deciphering neotectonic activities.

Suggestions for Further Reading

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Frequently Asked Questions

1. Write short notes on: Range Resolution; Azimuth Resolution; Synthetic Aperture Radar (SAR); Depression Angle; Dielectric Constant; Radar shadows.
2. Describe passive and active sensor systems used in Microwave Remote Sensing.
3. Describe in detail the SLAR system.
4. Describe about the Radar Returns and Image Signatures.
5. What are different types of Satellite Radar Systems?
6. Describe the characteristics of Radar Imagery.
7. What precautions would you take while interpreting Radar imagery?
8. What are the advantages and limitations of Radar Imagery?

11

SATELLITE REMOTE SENSING

11.1 INTRODUCTION

Remote sensing from space received its first impetus through rockets. As early as 1891, a patent was granted to Ludwig Rahrmann of Germany for a "New or improved Apparatus for obtaining Bird's eye photographic views". The apparatus was a rocket propelled camera system that was received back using parachutes. By 1907, another German, Alfred Maul, had added the concept of gyro-stabilization to the rocket-camera system.

Space remote sensing began in right earnest during the post war period of 1946 to 1950, when small cameras were carried aboard the captured V-2 rockets of Germany, that were fired from White Sands Proving Ground in New Mexico. Over the succeeding years, numerous flights, involving photography, were made by rockets, ballistic missiles, satellites and manned spacecrafts. The photographs, produced during early space flights, were generally of inferior quality; nevertheless they demonstrated the potential value of remote sensing from space.

In many respects, the initial efforts aimed at imaging the earth's surface from space were incidental outgrowth of meteorological satellites viz. TIROS (Television Infra Red Observation Satellite), ESSA (Environmental Survey Satellite), ATS (Application Technology Satellite) and Nimbus. The existing future of remote sensing from space became more apparent during the manned space programme of 1960s through Mercury, Gemini and Apollo when large number of high quality colour photographs were taken for earth resources applications and value of remote sensing was well recognized.

In further manned satellite series, Skylab was lunched in 1973 and its astronauts took over 35,000 images of the earth with the earth resources experiment package (EREP) on board. The EREP included a six-camera multispectral array, a long focal length Earth Terrain Camera (ETC), a 13 channel multi-spectral scanner and two microwave systems. The EREP experiments were the first to demonstrate the complementary nature of photography and electronic imaging from space. Another early (1975) space station experiment, having remote sensing component, was joint US–USSR Apollo-Soyuz Test Project (ASTP). For various reasons, the overall quality of most of the images from ASTP was disappointing.

11.2 LANDSAT

NASA initiated a programme in 1967 about the Earth Resources Technology Satellite (ERTS) series which were later, renamed as Landsat series of satellites. ERTS represented the first unmanned satellite specifically designed to acquire data about earth resources on a systematic, repetitive, medium resolution and multispectral basis. ERTS-1 (subsequently renamed as Landsat-1), was launched on July 23, 1972, in a sun synchronous, near circular, polar orbit at altitudes of 910 to 932 km. The period of one revolution was 103.2 minutes and being sun synchronous, it crossed the longitude at the same local time between 9.30 and 10.00 AM. Typical orbit paths for a single day are shown in Fig. 11.1. Each day, the path shifts westwards by 160 km at the equator so that after every 18 days, the paths are repeated. This results in repetitive coverage of the same area at this interval. This is known as 'temporal resolution'. Landsat-2 satellite was put 9 days out of phase with L-1; as such the temporal resolution became 9 days using both the satellites. The major components of Landsat are illustrated in Fig. 11.2.

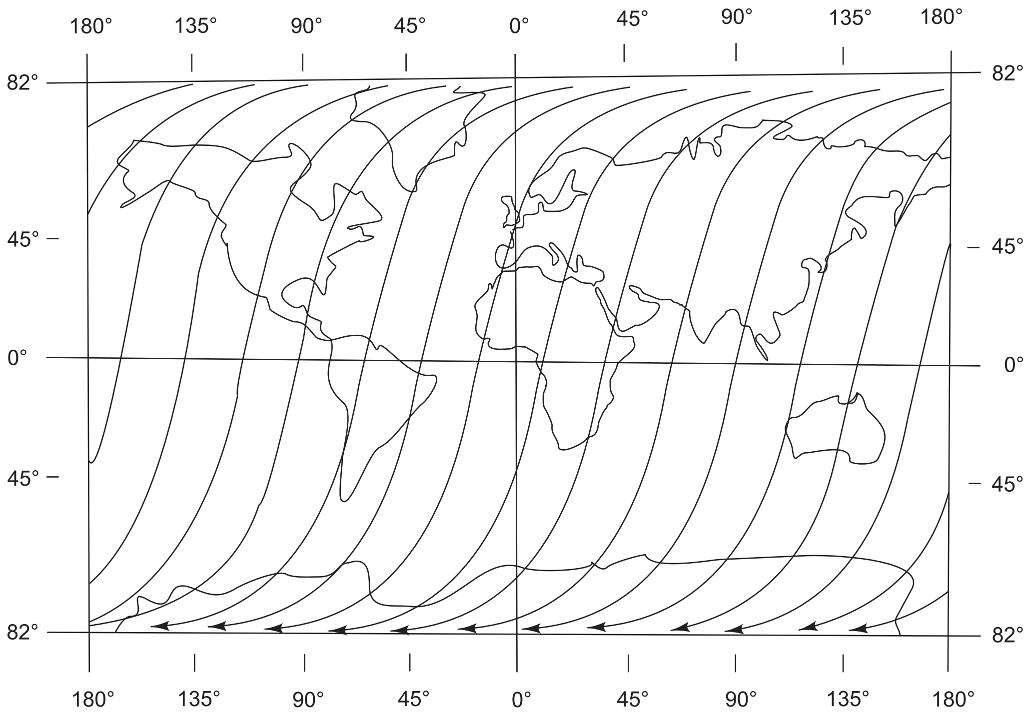

Fig. 11.1 *Daytime Landsat orbit paths (The paths repeat every 18 days)*

Imagery of Landsat-1 was obtained between 82° N and 82° S latitudes. The lateral adjoining areas covered in successive orbital revolutions provide about 10% lateral overlap at the equator, which progressively increases up to 50% at 60^o latitude. Although there is no forward overlap at the time of imaging by the satellite, the processing methods provide 10% overlap between successive images.

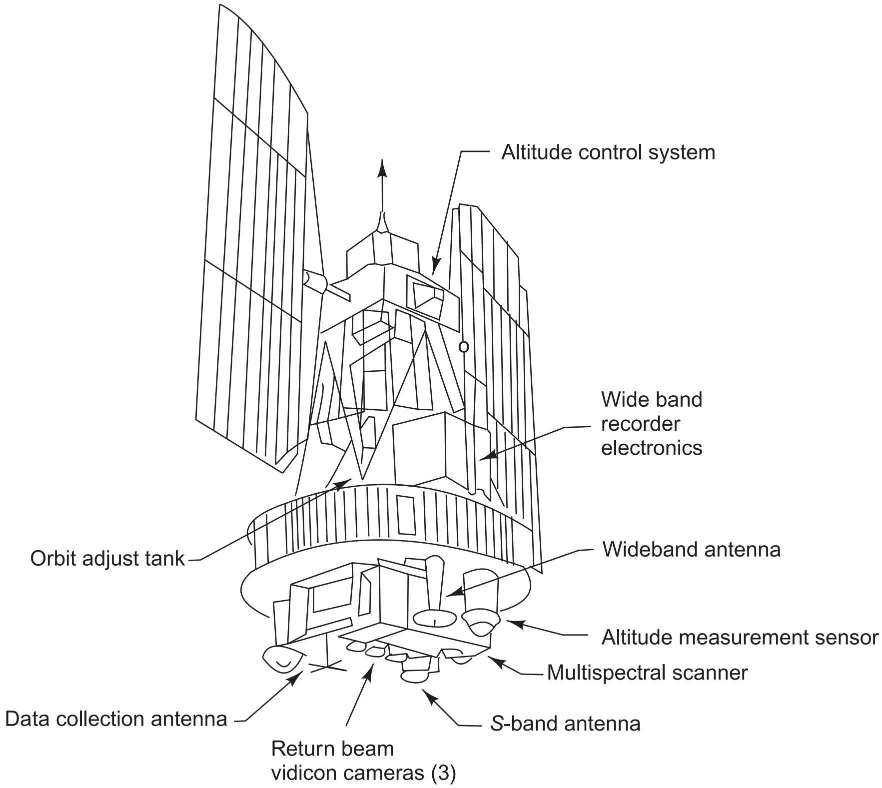

Fig. 11.2 *Diagram of Landsat-1 and 2*

The EMR reflected from the terrain is separated into four wavelengths or spectral bands, as shown in Fig. 11.3. There are six detectors for each spectral band, thus for each swoop of the mirror, six scan lines are simultaneously generated for each of the spectral bands. The energy sensed by the detectors is converted into an electrical signal for recording and transmission as image data. A blue image is not acquired, because it would be severely degraded by the effects of atmospheric scattering. When Landsat is within radio range of one of the earth receiving stations, the image data are transmitted directly to the station. When it is out of range, a limited number of scenes are stored on magnetic tape for transmission to the receiving station when it comes within the radio range.

Landsat-1 was followed by Landsat-2 and 3, which were launched in 1975 and 1978 respectively, having identical parameters.

11.2.1 Landsat Sensor Systems

Initially Landsat satellites were provided with the following two multispectral imaging systems:

(i) Return Beam Vidicon (RBV) system
(ii) Multispectral Scanner System (MSS)

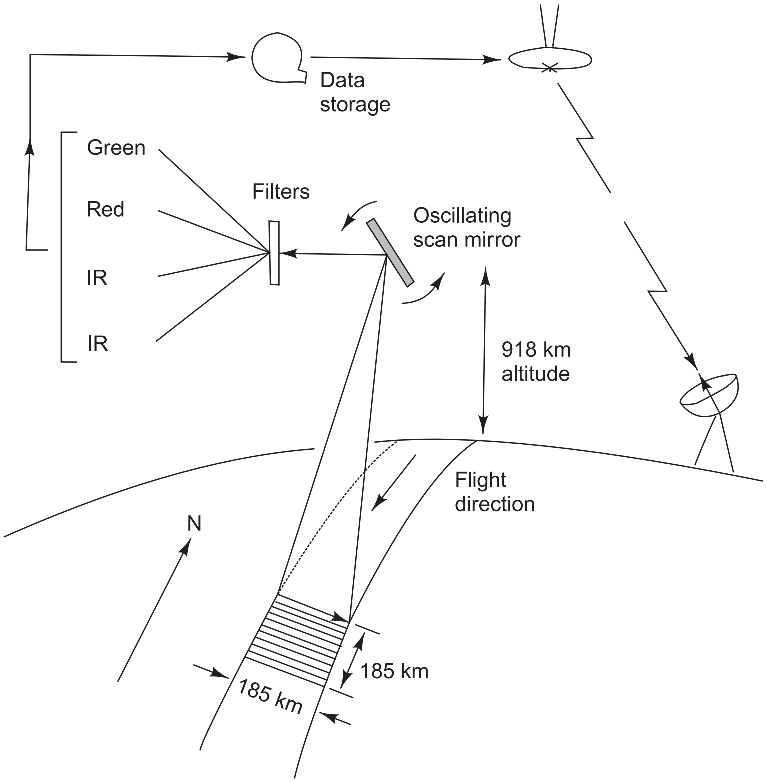

Fig. 11.3 *Landsat multispectral scanner and data transmission*

Besides these, the Landsat had a non-imaging system called Data Collection System (DCS) that relays data from sensor on satellite to receiving stations on earth.

11.2.1.1 Return Beam Vidicon (RBV)

It consisted of three cameras for three bands each provided with a 50 mm RBV with a useful image area of 25 × 25 mm on the tube face. The vidicon camera obtains a very high resolution picture through an optical system which is focused on a photoconductive target of the vidicon, resulting in a charged pattern on its surface, which is a replica of the image. This pattern is scanned by the electron beam and an analog television signal is created, which is further processed and transmitted to ground receiving station, where it can be recorded on a tape or converted to photo-image.

Each of the three vidicon cameras receive radiation in specific band, detected through proper filter system. The three bands used in Landsat-1 RBV system have been designated as band 1, 2 and 3 with following wavelength ranges:

Band 1 Blue green from 0.475 to 0.575 μm wavelength

Band 2 Red from 0.580 to 0.680 μm wavelength

Band 3 Near IR from 0.690 to 0.830 μm wavelength

The camera lens of this system has a focal length of 126 mm and exposure interval between successive exposures is 25 seconds. The exposure time varies from 4 to 16 milliseconds, depending upon scene brightness. The active video readout time is 3.5 seconds per photo and the terrain area covered per frame is 105 × 105 km. The RBV system aboard Landsat-1, however, went out of order after a few days of launch.

Landsat-2 was provided with a similar 3 band RBV in the wavelength range of 0.475 to 0.83 μm. Landsat-3 had 2 RBV systems in the spectral region of 0.5 to 0.75 μm wavelengths, covering an area of 98 × 98 km per scene. It is, however, generally felt that the quality of RBV images are not superior to those of MSS.

11.2.1.2 Multispectral Scanner System (MSS)

The Landsat MSS scans the terrain scene in several spectral bands simultaneously through a single optical system. The image is formed by sequential scanning across the orbital path of the satellite by a scanner mirror having an oscillation range of 2.89° from its normal position, which gives a 185 km across the track swath of earth's surface. The along track width of the swath is 6 scan lines, each of which are about 78 m, giving a total width of 474 meters. The image formed is focused on a screen of 4 × 6 matrix of optical fibers and light impinging on each glass fiber is routed to an individual detector through an optical filter appropriate to the spectral band being recorded. The instantaneous field of view (IFOV) of each detector is 0.07 milliradians, corresponding to 79 × 79 m of ground resolution cell (GRC). The data of six scan lines from four spectral bands is received as video signal in 24 channels. These signals transmitted to ground receiving stations (3 in USA and 1 in Canada) in real time or stored on a magnetic tape and transmitted later when the satellite comes within the range of ground receiving stations. In 1979, a ground receiving station was set up at Shadnagar, near Hyderabad (India).

The particulars of the four spectral bands of Landsat-1, designated as MSS band 4, 5, 6 and 7 are given in Table 11.1. Landsat-2 had identical MSS channels; while an additional thermal band (10.4 to 12.6 μm) was added to the Landsat-3. Unfortunately, the thermal channel of Landsat-3 developed operational trouble, shortly after launch. Landsat 4, 5 and Landsat-TM (Thematic Mapper) and Landsat-ETM (Extended Thematic Mapper) were launched subsequently in this series.

Table 11.1 Details of Landsat-1 MSS bands

Band No.	*Colour*	*Wavelength (μm)*	*Detector used*
4	Green	0.5 – 0.6	Photomultiplier tube
5	Red	0.6 – 0.7	Photomultiplier tube
6	Infrared	0.7 – 0.8	Photomultiplier tube
7	Infrared	0.8 – 1.1	Silicon photo diode

A single Landsat scene consists of 2340 scan lines, each consisting of 3240 pixels. Each pixel records the energy received from GRC of 79 × 79 m. The reflectance data, first obtained in analog form on board the Landsat, is converted to digital form on computer compatible tape (CCT) by sampling at 57 m interval along the scan lines with the result that each pixel covered a ground area of 79 × 57 m. The grey scale values (reflectance values) are recorded in the form of matrix of numbers (digital number DN), using 0 to 127 scale for bands 4, 5 and 6, and 0 to 63 scale for band 7. Characteristics of Landsat series of satellites are given in Table 11.2.

Table 11.2 Characteristics of different Landsat satellites

Satellite	*Altitude (km)*	*Orbits/ day*	*Repetivity (days)*	*Ground resolution*	*Radiometric resolution*
Landsat-1, 2, 3	918	14	18	79 m	128 MSS 4,5,6 64 MSS 7
Landsat-4, 5	705	14.5	16	30 m TM 120 m TM 6	256 TM
Landsat-6	705	14.5	16	15 m (Pan) 30 m Extended TM	Did not function
Landsat-7	705	14.5	16	15 m (Pan) 30 m Extended TM	

The position of a pixel element is determined by the rectangular coordinates with the origin at the upper left corner. The brightness has a numerical value from zero for black and highest number for white. Thus any pixel can be designated by three coordinates x and y representing the position and z representing the brightness level. The image gets digitized in this manner in the digitizing system and this can be fed into computers for extracting information in various ways. The principal advantage of digital data is its versatility, repeatability and preservation of original data precision. By reversing the process of digitization, the digital data can be converted into hard copy images. The hard copy image products by Landsat are of 70 × 70 mm format on 1:3.369 million scale. These images can be enlarged for various applications.

11.2.2 Image Characteristics

During playback of the data tape to produce an image, the scan lines are successively offset to the west to compensate for earth's rotation during 28 seconds required to scan the terrain. This accounts for parallelogram shape of the images.

The satellite had RBV camera and multispectral scanner. The latter has four bands 4, 5, 6, and 7 in green, red and two near infrared bands. The resolution of Landsat-1 was 79 × 79 m, which was improved to 30 × 30 m in Landsat-TM. The Thematic Mapper has 7 band MSS with one band (Band No. 6) in thermal IR region.

11.2.3 Image Annotation

Individual Landsat image has an annotation strip with useful information. The annotation strip of an image covering southern part of California, USA, is explained in Table 11.3.

Table 11.3 Explanation of annotation strip

12 Oct 72	Date image was acquired
C N 34-33/*W* 118-24	Geographic Central point of the image in degrees and minutes
N N 34-31/*W* 118-19	Nadir of the space craft
MSS	Multispectral scanner image
4, 5, 6 or 7	MSS spectral band
D or *R*	Direct or recorded
Sun EL 39	Sun elevation, in degrees above horizon
Az 148	Sun azimuth, in degrees clockwise from north
190	Spacecraft heading, in degrees
1225	Orbit revolution number
G, *A* or *N*	*G* = Gladstone, California, *A* = Alaska *N* = Network test and training facility at Goddard Space Facility Center
1090 – 18012	The unique identification number composed as follows: 1or 5 Landsat-1 (5 denotes Landsat-1 for days greater than 999 days since launch; 090 days since launch (this was 21 Oct, 1972) expandable to 4 digits to accommodate days higher than 999; 18 Hour at time of observation, GMT 01 minutes 2 tens of seconds

11.3 IRS AND OTHER SATELLITES

India launched its first satellite Aryabhatta on 19th April 1975 that quickly followed by Bhaskara, the satellite for earth observation (SEO), which was launched on 7th June 1979. Bhaskara-2 was launched on 20th November 81.

The launch of the first operational Indian Remote Sensing Satellite, IRS I-A on March 17, 1988, ushered in a new era in the country’s resources survey and management. The second satellite in the series IRS I-B identical to IRS I-A was launched on August 29, 1991. The payload on board IRS satellites included advanced imaging sensors, Linear Imaging Self Scanner (LISS-I with a resolution of 72.5 m and LISS-IIA and LISS-IIB both with a resolution of 36.25 m). These operate in four spectral bands in the range of 0.45 - 0.86 µm. The satellite had a repetitive coverage of 22 days.

The second generation IRS satellites, namely IRS1-C and 1-D launched on Dec 28, 1995 and Sept 29, 1997 respectively, incorporate an improved camera (LISS-III) operating in three spectral bands in visible and near infrared regions with a ground resolution of 23.5 m and a middle infrared region with a ground resolution of 7.5 m. It has also a camera (PAN) in Panchromatic band with resolution of 5.8 m. Also on board is Wide Field Sensor (WiFS) with a ground resolution of 188.3 m. IRS-P3 with Modular Opto-electronic Scanner (MOS) was launched on March 21, 1996. Oceansat-1 (IRS-P4) having Ocean Color Monitor (OCM) and Multi-frequency Scanning Microwave Radiometer (MSMR) was launched on May 26, 1999. Resourcesat-1 (IRS-P6) with AWiFs was launched on Oct 17, 2003.

Cartosat-1 (IRS-P5) having PAN resolution of 2.5 m was launched on May 5, 2005. The next in the series, Cartosat-2 having a PAN resolution of 1 m (equal to Ikonos of NASA, launched in 1999), was launched on 10th Jan'07. Cartosat-2A, having similar resolution was launched on 28th April'08. Risat-2, having different modes of SAR sensor with resolutions of 3 to 50 m, was launched on 20th April, 2009. Important milestones of Indian Space Programme are given in Annexure-1, at the end of this chapter.

The Indian Remote sensing Satellites used advanced charged couple device (CCD) technique, which has an array of 24 detectors scanning the ground like a push broom, instead of scanning across track. It improved quality of satellite pictures. The satellite data is available from NRSC Data Centre (NDC), Hyderabad, India in different formats, which include raw, radiometrically corrected, Georeferenced data in digital format and Standard, Geocoded data in both photographic and digital formats.

Launched in 1984, the French satellite SPOT (Satellite Probatoir pour la Observation de la Terre) was a precursor to IRS using CCD technology. It has a resolution of 20 meters. Details of some of these satellites are given in Table 11.4. QuickBird satellite, launched by USA on October, 18, 2001 from California, has resolution of 61 cm at nadir. American Satellite GeoEye-1, launched in 2008, had a resolution of 41 cm; while GeoEye-2, scheduled for launch in 2011-12, is expected to have a resolution of 25 cm.

11.3.1 Data Acquisition and Dissemination

Initially the EROS (Earth Resources Observation System) Data Center, Sioux Falls, USA had prepared Landsat index maps of the word, giving path-rows and listing as per central point of the images for their procurement. 'Browse files' are also available to examine band 5 images copied as microfilm, to enable users to assess image quality before placing order.

United States of America had promoted the establishment of Earth Stations all over the word to acquire, process and distribute Landsat data from mid-seventies. National Remote Sensing Agency (now NRSC), Under Department of Space, Government of India has Earth Receiving Station at Shadnagar, near Hyderabad to acquire, process and market remote sensing data products of Landsat, IRS, SPOT, ERS and NOAA series of satellites, including TIROS-N. These data products cater to the needs of Indian Sub-continent, South-East Asian, West Asian and African countries.

Table 11.4 Characteristics of some of the Remote Sensing satellites

Satellite	*Altitude (km)*	*Orbits/ day*	*Repetivity (days)*	*Ground resolution*	*Radiometric resolution*
SPOT 1, 2	832	13.8	26	20 m in MSS 10 m in PAN	256
IRS-1A, 1B	904	14	22	72.5 m LISS-I 36.25 m LISS-II	128 LISS-I 128 LISS-II
IRS-1C	817	14.2	24	5.8 m PAN 188 m WiFS	64 128
IRS-P3	817		24	188 m WiFS 580-1000 m MOS	128
IRS-1D	780	14.3	25	5.8 m PAN 23.5 m LISS-III 70.5 m LISS-III MIR 188 m WiFS	64 128 128 128
Resourcesat-1 (P-6)	817	14.2	24 5 5	23.5 m in LISS-III 5.8 m in LISS-IV 56 m in AWiFS	128 – 7 (bits) 10 (bits) 10 (bits)
Cartosat-1 (IRS-P5)	618		126 5 (revisit)	2.5 m in PAN (stereo)	10 (bits)
Cartosat-2, 2A	630		4/5 (revisit)	1 m in PAN (stereo)	10 (bits)
Risat-1 and 2	586			3- 50 m in SAR diff. modes	10 (bits)

Earth Observation Satellite (EOSAT) Company was formed in 1985 by merging several units to takeover the Landsat 4, 5 and 7 operations (Landsat 6 was aborted). EOSAT has wide linkage with several ground stations and an extensive distribution network. NRSC on behalf of DOS, Government of India and its corporate arm—Antrix Corporation, entered into a series of agreements with EOSAT for reception of IRS 1B, IC and 1D data by EOSAT Earth Station at Norma, USA and subsequent processing and marketing the data products.

ANNEXURE-1

Milestones of Indian Space Programme*

1962: Indian National Committee for Space Research (INCOSPAR) formed and it worked on establishing Thumba Equitorial Rocket Launching Station (TERLS) with the cooperation of USSR, USA and France.

1963: First sounding rocket launched from TERLS on November 21, 1963.

1965: Space Science and Technology Centre (SSTC) established in Thumba.

1967: Satellite Telecommunication Earth Station set up at Ahmedabad.

1968: TERLS dedicated to the United Nations on February 2, 1968. This International Range, under aegis of UN, is available to international scientific community.

1969: Indian Space Research Organisation (ISRO) formed on August 15, 1969.

1972: Government of India constituted Space Commission and set up Department of Space. ISRO brought under DOS on June 1, 1972.

1975: ISRO becomes Government Organisation on April 1, 1975. First Indian Satellite, Aryabhatta was launched on April 19, 1975.

1975-76: Satellite Instructional Television Experiment (SITE) was conducted from August 1, 1975 for one year with the help of borrowed Satellite ATS-6 of NASA, USA.

!977: Satellite Telecommunication Experiments Project (STEP) carried out with the help of Symphony satellite of France and West Germany, borrowed for two years.

1979: Bhaskara-I, an experimental satellite for earth observations, was launched on June 7, 1979. First Experimental Launch of SLV-3 with Rohini technology payload on board, was on August 10, 1979. The satellite could not be placed in the orbit.

1980: Second Experimental Launch of SLV-3 was on July 18, 1980, which successfully placed the Rohini Satellite in orbit.

1981: First Developmental Launch of SLV-3 RS-D1 paced successfully in orbit on May 31, 1981. Ariane Passenger Payload Experiment (APPLE), an experimental geo-stationary communication satellite was launched from Kourou, French Guyana with Ariane rocket on June 19, 1981. Bhaskara-II was launched on November 20, 1981.

1982: INSAT-1A was launched on April 10, 1982 from USA. It was deactivated on September 6, 1982.

1983: Second Developmental Launch of SLV-3 RS-D2 placed in orbit on April 17, 1983. INSAT-1B launched on August 30, 1983.

1984: Indo-Soviet manned space mission (April, 1984; Sq. Leader Rakesh Sharma participated).

1987: First Developmental Launch of ASLV with SROSS-1 satellite on board (March 24, 1987). The satellite could not be placed in orbit.

1988: Launch of first operational Indian Remote Sensing Satellite IRS-1A on March 17, 1988. INSAT-1C was launched on July 22, 1988. It was abandoned in November, 1989. Second Developmental Launch of ASLV with SROSS-2 satellite failed.

1990: INSAT-1D was launched on June 12, 1990.

1991: Launch of IRS-1B on August 29, 1991.

1992: Third developmental launch of ASLV with SROSS-C on board, on May 20, 1992. Satellite placed in orbit. INSAT-2A, the first satellite of indigenously built second generation satellite, was launched on July 10, 1992.

1993: INSAT-2B launched on July 23, 1993. First developmental launch of PSLV with IRS-1E on board, was on September 20, 1993. Satellite could not be placed in the orbit.

1994: Fourth developmental launch of ASLV with SROSS-C2 on board, on May 4, 1994. Satellite was placed in the orbit. Second developmental launch of PSLV with IRS-P2 on board, was on October 15, 1994. The satellite was successfully placed in polar sun-synchronous orbit.

1995: INSAT-2C was launched on December 7, 1995. Operational Indian Remote Sensing Satellite IRS-1C was launched on December 28, 1995.

1996: Third developmental launch of PSLV with IRS-P3 on board, on March 21, 1996. The satellite was placed in the orbit.

1997: INSAT-2D was launched on June 4, 1997. It became inoperable on October 4, 1997. An in-orbit satellite ARABSAT-1C, since renamed as INSAT-2DT, was acquired in November, 1997 to partly augment the INSAT system. First operational launch of PSLV with IRS-1D on board was on September 29, 1997. The satellite was successfully placed in the orbit.

1999: INSAT-2E, the last satellite in INSAT-2 series, was launched by Ariane from Kourou, French Guyana on April 3, 1999. IRS-P4 (OCEANSAT-1) was launched by Polar Satellite Launch Vehicle, PSLV-C2, along with Korean KITSAT-3 and German DLR-TUBSAT, from Sri Harikota Aeronautical Range (SHAR) on May 26, 1999.

2000: INSAT-3B, the first satellite in the third generation INSAT-3 series, was launched from French Guyana on March 22, 2000.

2001: Successful launch of Geosynchronous Satellite Launch Vehicle (GSLV), on April 18, 2001. Successful launch of PSLV-C3 was on October 22, 2001, placing India's TES, Belgium's PROBA and German BIRD, into polar sun-synchronous orbit.

2002: Successful launch of INSAT-3C from French Guyana on January 24, 2002. Launch of KALPANA-1 by ISRO's PSLV from Satish Dhawan Space Centre (SDSC)-SHAR on September 12, 2002.

2003: Successful launch of INSAT-3A from French Guyana on April 10, 2003. Successful launch of second developmental test flight of GSLV-D2 with GSAT-2 on board from SDSC-SHAR was on May 8, 2003. Launch of INSAT-3E from French Guyana on September 28, 2003. Successful launch of IRS-P6 (RESOURCESAT-1) by PSLV-C5 from SDSC-SHAR was on October 17, 2003.

2004: Maiden operational flight of GSLV (GSLV-F01) launched EDUSAT from SDSC-SHAR on September 20, 2004.

2005: Cartosat-1 (IRS-P5) having PAN resolution of 2.5 m, along with HAMSAT was launched by PSLV-C6 from SDSC-SHAR on May 5, 2005. Successful launch of INSAT-4A by Ariane from Kourou French Guyana, was on December 22, 2005.

2006: Second operational launch of GSLV (GSLV- F02) with INSAT-4C on board was on July 10, 2006. The satellite could not be placed in orbit.

2007: PSLV-C7 successfully launches four satellites – CARTOSAT-2, having PAN resolution of 1 m, Space Capsule Recovery Experiment (SRE-1), Indonesian LAPAN-TUBSAT and Argentina's PEHUENSAT-1, on Jauary 10, 2007. Successful recovery of SRE-1, after maneuvering it to re-enter the earth's atmosphere and descend over the Bay of Bengal, about 140 km east of Sriharikota on January 22, 2007.

2008: PSLV-C10 sucessfully launches TECSAR satellite under a commercial contract with Antrix Corporation on January 21, 2008. PSLV-C9 successfully launches CARTOSAT-2A, IMS-1 and eight foreign nano-satellites from SDSC-SHAR on April 28, 2008. PSLV-C11 successfully launches **CHANDRAYAAN-1** from SDSC-SHAR on October 22, 2008. Indian Tricolour placed on Moon on November 14, 2008.

2009: Risat-2, having different modes of SAR sensor with resolutions of 3 to 50 m, was launched on April, 20, 2009. ISRO-NASA joint experiment to find water/ice on moon begins on August 21, 2009. Chandrayaan loses radio contact on August 29, 2009. PSLV-C14 successfully launches OCEANSAT-2 on Setember 23, 2009.

2010: PSLV-C15 successfully launches CARTOSAT-2B on July 12, 2010. Mini-SAR on Chandrayaan-1 finds ice deposits on Moon's north pole on May 2, 2010.

2011: Resourcesat-2 was launched along with YOUTHSAT and X-SAT (of Singapore) in to polar sun-synchronous orbit on April 20, 2011 from SDSC-SHAR by PSLV-C16. An advance communication satellite, GSAT-8 was launched on May 21, 2011from French Guyana, to be co-located with INSAT-3E.

2012: Risat-1, was launched on April, 26, 2012. This is the heaviest RS satellite (1858 kg), having a resolution of 1 m, will be working in 536 km polar orbit.

* Source: *Annual Report*, DOS, Govt. of India, 2003-2004, press releases and pamphlets issued by DOS.

Suggestions for Further Reading

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Frequently Asked Questions

1. Describe the Landsat Sensor Systems.
2. Describe Sensor System of Indian Remote Sensing Satellites.
3. Write briefly about the Indian Space Programme.

12

SATELLITE IMAGE INTERPRETATION

For deriving information and preparing thematic maps, interpretation of features appearing in the satellite imagery has to be carried out. This is accomplished by visual interpretation of B and W and colour composite satellite imagery or digital analysis of satellite data for classification of areas of interest or both.

12.1 VISUAL INTERPRETATION

Visual interpretation of satellite imagery is essentially a three-step process of detection, categorization and identification.

12.1.1 Detection

Detection is the process of spotting objects, irrespective of whether they are recognizable or not. Detection makes it possible to separate an object (entity) from its background (surroundings). Detection depends mainly on visual sensation rather than on cognizant factors. The simplest case of detection is the contrast detection between an object's contour and the surroundings. This kind of detection might be named "boundary detection." It plays an important role in image analysis and will lead to the possibilities of delineation of homogenous or quasi-homogenous zones which, when correctly selected, correspond to the object to be mapped and identified.

12.1.2 Categorization

Categorization is the act of sorting by designating the set membership of elements of a population. Categorization is possible if the image elements have distinctive and detectable properties that allow determination of their set membership. Categorization of subsets of the image can be done on a descriptive basis, listing characteristic features in terms of tone, texture, pattern, shape, orientation, association, and others of each category. Thus, if subsets of the image consist of "structured fields", each having distinctive characteristics, then it will be possible to partition the data space into mutually exclusive subspaces, and to label each subspace according to the category it belongs to. At this stage, a map can be produced showing the spatial distribution of the different categories. In this map each category represents a unit to be identified. A categorized image contains a number of discrete and non-overlapping units delineated and labeled according to their set membership, but not identified yet.

12.1.3 Identification

Identification is assigning proper names to the categories; essentially, identification is an act of recognition. Basically there are three modes of operation in the identification process, viz., spontaneous recognition, logical inference and ground-truth acquisition.

In spontaneous recognition the interpreter resorts to his memory trained by experience, and he recognizes the objects as he "sees" them. If spontaneous recognition fails, the interpreter may be able to make a decision on the basis of logical inference; by inductive and deductive reasoning he may come to a logically sound decision about the object's identity. The third method of identification, here loosely referred to as "ground truth", actually embraces more than field- checking alone, since it includes also the use of all other external information, such as are obtainable from existing maps, reports and other sources.

In practice each interpretation is carried out in such a way that all three identification methods are applied in combination, and emphasis is shifted from one method to the other depending upon the interpreter's ability, the nature of problems involved, type and amount of available external information and terrain accessibility.

Satellite images may be interpreted in much the same manner as small-scale aerial photographs and images acquired by aircraft and manned satellites. The terminology employed by most of the concerned disciplines is adequate for describing features on satellite images. However, there are certain advantages of satellite images e.g. in interpretation of lineaments or circular features, and that should be emphasized.

12.1.4 Lineament

Lineament is defined as a mappable simple or composite linear feature of a surface, whose parts are aligned in a straight or slightly curving relationship, and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon (O'leary, Friedman and Pohn, 1976).The surface features making up a lineament may be geomorphic (caused by relief) or tonal (caused by contrast differences). The surface features may be landforms, the linear boundaries between different types of terrain, or breaks within a uniform terrain. Straight stream valleys and aligned segments of valleys are typical geomorphic expressions of lineaments. Tonal lineament may be a straight boundary between areas of contrasting tones.

Lineaments may be continuous or discontinuous. In discontinuous lineaments the separate features are aligned in a consistent direction and are relatively closely spaced. Lineaments may be simple or composite. Simple lineaments are formed by a single type of feature, such as a linear stream valley or aligned topographic escarpment. Composite lineaments are defined by more than one type of feature, such as an alignment of linear tonal features, stream segments and ridges.

Although many lineaments are controlled at least in part by faults, however, structural displacement (faulting) is not a requirement in the definition of a lineament. Linear features newly discovered on images may initially be called lineaments. If field checking establishes the presence of structural offset, they can then be designated as faults. No minimum length is proposed here as a requirement for lineaments, but significant crustal features are typically measured in tens of kilometers. An arbitrary categorization of lineaments may be made on the basis of their extent into: Lineament, up to 100 km, Mega Lineament, between 100 to 300 km, and Super Lineament for those extending more than 300 km.

Lineaments also may be recognized on topographic, gravity, magnetic and seismic contour maps by aligned highs and lows, steep contour gradients, and aligned offset trends. Lineaments are well expressed on satellite images because of the oblique illumination, suppression of distracting spatial details and the regional coverage.

The lineaments may be plotted on a radial diagram to obtain the major direction of faults and fractures. Studies have shown that a close coincidence exists of between the pattern of previously mapped faults/fractures and lineaments deciphered from satellite imagery of the same area.

The intersection of lineaments and their densities can also be plotted and density contours drawn. It has been observed that high-density lineament intersection show preferred orientation which are useful in locating groundwater and mineralization zones.

12.1.5 Circular Feature

Rowan and Wetlaufer (1975) recognized 50 circular and elliptical features on the Landsat mosaic of Nevada that is presumed to be centers of igneous activity. Similar circular/oval features in a basement gneissic complex have been observed and have been correlated with mantle domes. Attempts have been made to correlate the circular features with aeromagnetic maps and it was noticed that the features coincide with the aeromagnetic anomalies, denoting probably the surface expressions of centers of igneous activity, emplacement of granitic bosses or diapiric intrusions at deeper levels. Occurrence of circular features in parts of Thar desert of Rajasthan, India was studied by Bakliwal and Ramasamy (1985).

12.2 DIGITAL IMAGE PROCESSING

While a wealth of information can be extracted from satellite data in hard copy format, a large volume of digital data can be analyzed through computer processing which can provide much more data in different combination for further interpretation. Large number of procedures have been evolved to deal with MSS data in computer compatible format viz. CCT, CD, HDD, etc.

Image processing methods of data obtained from satellite may be grouped under the functional categories of Image restoration, Image enhancement and Information extraction. These are discussed in more details.

12.2.1 Image Restoration

Geometric distortion, data errors and noise are compensated during this process with an objective to make the imagery resemble the original scene.

12.2.1.1 Haze Removal

The radiance values derived from different bands will not directly relate to ground reflectance levels because of the added component of skylight scattered from the atmosphere. This causes decrease in image contrast. A rough estimate of skylight can be determined by finding the lowest digital number (DN), in the image data set. Assuming that these pixels correspond to features having nearly zero reflectance, the DN values at these points are due to skylight alone. By subtracting this vaue from all the DNs in the data set, the skylight component is eliminated. This process is called haze removal.

12.2.1.2 Sixth-line Dropout

This phenomenon is typically occurring in across track scanning system. In case of Landsat, if any one of the six detectors ceases functioning, every sixth line will be a blank line, corresponding to the malfunctioning detector. This is corrected by calculating the average DN value of the adjoining pixels in preceding and succeeding lines and applying the average DN value to the pixels of dropout line.

12.2.1.3 Sixth-line Banding

If any one of the six detectors, due to passage of time, becomes more sensitive to radiation, the higher signals from malfunctioning detector will cause a brighter line, as compared to other scan lines. This defect is corrected by multiplying the DN values of the defective scan line with a correcting factor.

12.2.1.4 Scan Line Offset

In this case the scan lines are offset horizontally in either a random or systematic fashion. Proper alignment is restored during the correction stage.

12.2.1.5 Atmospheric Correction

The atmosphere selectively scatters the shorter wavelengths of light. In Landsat MSS band 4 is affected most and band 7 is affected least. The contrast ratio of bands 4, 5 and 6 are improved by calculating the offset needed from band-7 imagery.

12.2.1.6 Geometric Correction

As the scan mirror, in across track scanning system, covers a larger area towards the ends of scan lines, off nadir, the scale becomes smaller at the edges. This results in image compression. This distortion is also corrected during processing.

With geometric correction, it is now possible to get geocoded images where corrected latitudes and longitudes are marked on the image itself.

12.2.2 Image Enhancement

Image enhancement is the process of modifying an image to improve its impact on the viewer. Some of the enhancement techniques are described below.

12.2.2.1 Linear Contrast Stretch

Very few scenes have a brightness range that utilizes the full sensitivity range of the detectors. To produce an image with the optimum contrast ratio, the entire brightness range of the display medium, which is generally the film, should be utilized. To achieve this, the histogram of DN values is obtained to study the distribution of pixels with respect to the DN values. For example, if 90 percent of pixels have DN values varying from 50 to 100; 5 percent of pixels have DN values between 0 and 50 and the rest 5 percent of pixels have DN values greater than 100 but less than 255. For enhancement purposes, the lower 5 percent of pixels are assigned DN value of zero and the upper 5 percent are assigned DN value of 255. The rest of the pixels have redistributed DN values varying linearly between these two extremes. It should, however, be pointed out that there is a trade-off in the loss of contrast at the extreme high and low DN values (Fig. 12.1).

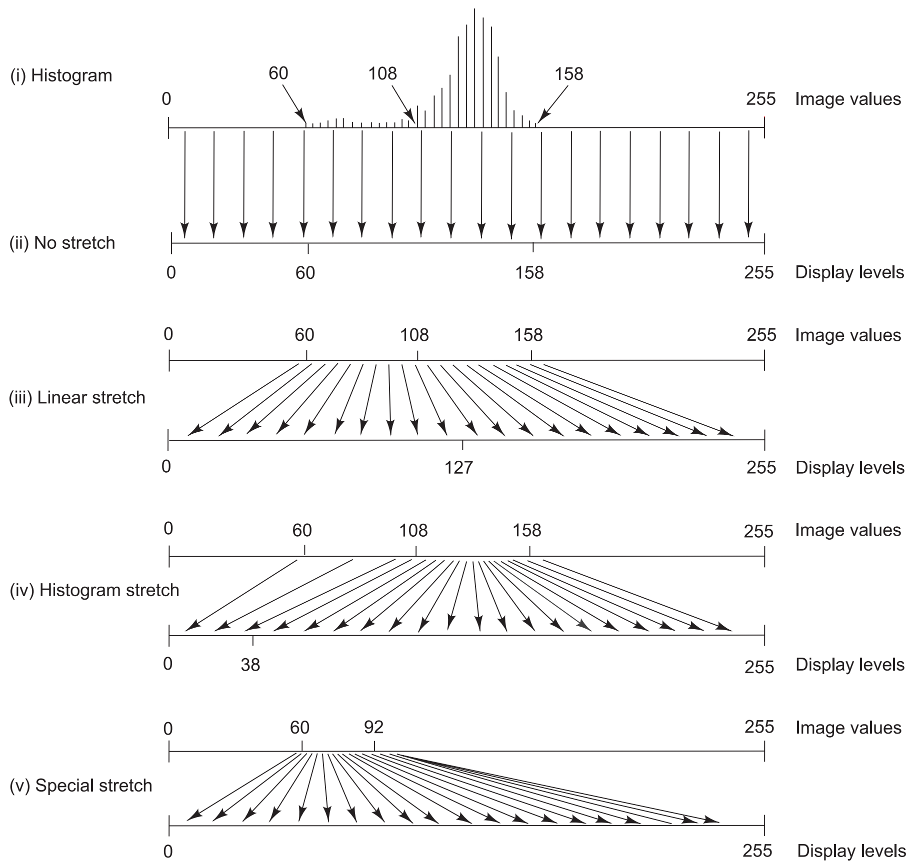


Fig. 12.1 *Principle of contrast stretch enhancement (after Sabins 1991)*

One drawback of linear stretch is that it assigns as many display levels to the rarely occurring image values as to the frequently occurring values. To improve upon this situation, a *histogram equalized stretch* can be applied. In this approach image values are assigned to the display levels on the basis of their frequency of occurrence. As shown in Fig. 12.1(iv), more display values are assigned to the frequently occurring portion of the histogram. The image value range of 109 to158 is now stretched over a larger portion of the display levels (39-255). A smaller portion (0-39) is reserved for the infrequently occurring image values of 60 to 100.

For *special stretch*, specific features may be analyzed in greater radiometric detail by assigning the display range exclusively to particular range of image values. For example, if water features are represented by a narrow range of values of a scene, characteristics in the water features could be enhanced by stretching this small range to the full display range, as shown in Fig. 12.1(v).

12.2.2.2 Density Slicing

This is a process of converting the continuous grey tone of an image into a series of density intervals, or slices, each corresponding to a specified digital range. Different slices may then be assigned colours or suitable printer symbols for viewer presentation. This technique emphasizes suitable grey scale differences that may be otherwise imperceptible to the viewer.

12.2.2.3 Edge Enhancement

This is another technique for emphasizing subtle grey scale variations. Where the adjacent pixels have DN difference by more than a predetermined threshold values; the interface is marked on the image display with a contour or a color change.

12.2.2.4 Spatial Transformation (Filtering)

The complex wave of a beam of white light may be separated into its component wavelengths (different colors) by a prism. In similar way, the complex wave of a Landsat scan line can be separated into its component wavelengths by mathematical process known as *spatial filtering* (Fig. 12.2). Frequency filters are designated as high pass, intermediate pass and low pass, depending on the spatial frequency that is transmitted through the filter.

Spatial filtering is a local operation in which the original image is modified on the basis of grey levels of neighboring pixels. For example, a simple low pass filter may be implemented by passing a moving window of 3 x 3 pixels throughout the original image, thereby creating a second image, whose central pixel's DN value corresponds to the local average value of the 9 pixels in the original image contained in the window at that point. A simple high pass filter may be implemented by subtracting a low pass filtered image from the original image. *Convolution filter* is another variation of moving window (kernel/ operator), which modifies image pixel by pixel.

Directional filters are useful in preferential processing for oriented features in the image to obtain the required edge enhancement. The direction in which the filter is passed across the image determines which linear features are enhanced; those trending normal to the filter direction are enhanced, while linear features parallel with the filter direction are suppressed. Thus there can be directional filters in the vertical, horizontal, diagonal or any other azimuthal direction, depending on the need.

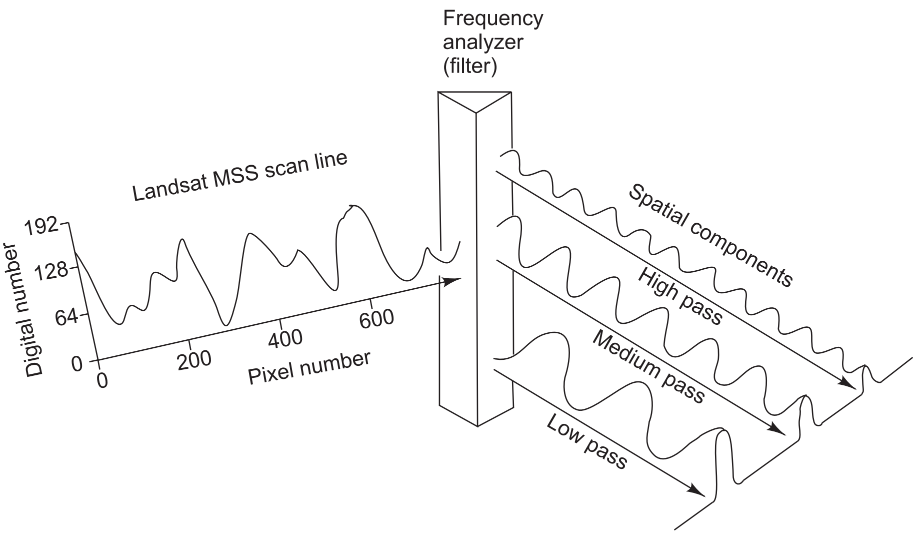


Fig. 12.2 *Spatial frequency filtering of satellite data*

Statistical filters can change the pixel DN value by a local property such as maximum, minimum, median, mode, standard deviation, etc. The process may provide an output image depicting the pixel values as per these statistical parameters. These statistical parameters are useful in noise reduction, textural feature extraction, signal to noise ratio measurement, and so on.

While dealing with spatial filtering with low and high pass filters, it was assumed that the image consisted of two types of components and the image was transformed in a two dimensional spatial scale (x, y). In *Fourier Transform*, this idea is extended to many spatial scales.

12.2.2.5 Colour Images

Color display of images and their enhancement using radiometric transformation further improves the visual interpretation. A few simple techniques are discussed here. In *Mini-Max Stretch*, the linear stretch technique is applied to individual red, green and blue (RGB) bands separately and these three enhanced images are composited to get the final enhanced color image.

Normalization Stretch is applied to each of the three bands (RGB) independently by setting their means and standard deviations equal for all three bands. The enhanced bands are composited to get normalized stretch color image.

In *Color Space Transformation (CST)*, the hue, saturation and intensity (HIS) are used for subjective sensation of color, color purity and brightness respectively, instead of red, green, and blue (RGB) components. Thus by applying CST, first RGB components are changed to HIS components. Then, it is possible to modify any one or all of the components as desired. Now using the inverse CST, the processed images are converted back to RGB color display.

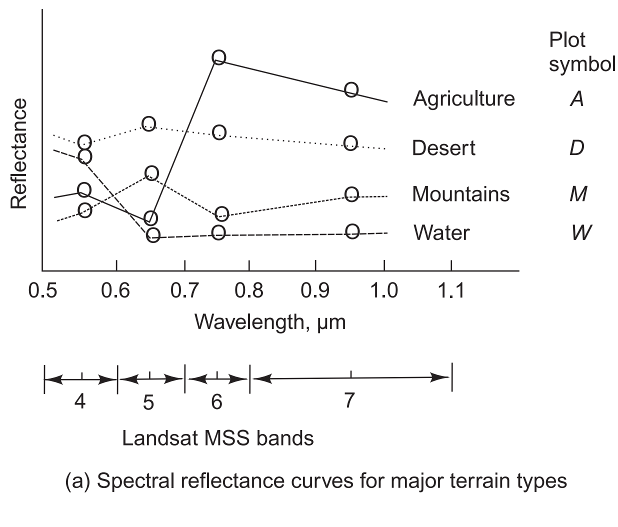
12.2.3 Information Extraction

Image restoration and enhancement processes utilize computers to provide corrected and improved images for the benefit of interpreter, however, no decision making is involved. In the case of information extraction processes, the computer makes decision to identify and extract specific pieces of information. Restoration and enhancement are done separately on each of the bands, while two or more bands are analyzed for information extraction. Some of the techniques used for information extraction are described below.

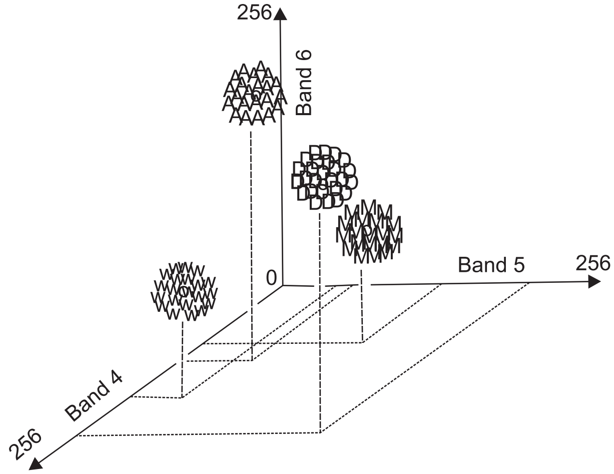
12.2.3.1 Multispectral Classification

In a Landsat image, spectral reflectance for each pixel is recorded in four different spectral bands. A pixel may be characterized by its spectral signature, which is determined by relative reflectance in different wavelength bands. Multispectral classification is an information extraction process that analyzes the spectral signatures and then assigns pixels to categories based on similar signatures.

When spectral responses are plotted against any two bands, the pixels fall in certain groups, which are called *clusters* or classes, and the plotted area is known as *feature space*. In the present case the feature space is two dimensional. If we analyze the spectral response data for three bands or *n* bands, the feature space will be three or n dimensional feature space (Fig. 12.3); the latter is difficult to visualize but can be treated mathematically with the help of a computer.



(a) Spectral reflectance curves for major terrain types



(b) Three-dimensional cluster diagram for classification

Fig. 12.3 *Multispectral classification*

The pixels which are occurring in a feature space may be classified by a computer by applying a suitable *decision rule*. Minimum distance to mean is one such decision rule, where pixels are classified in a class depending on how near they fall to the mean response of the particular cluster representing the class.

Two general types of classification schemes are supervised and unsupervised classifications, which have the following distinctions.

12.2.3.2 Supervised Classification

It uses independent information to define training data that are used to establish classification categories. The independent information may be spectral reflectance data or knowledge of the location of the areas within the image that typify each of the desired classification categories. Such localities are known as training areas. Supervised classification is most widely used of the two classification schemes.

12.2.3.3 Unsupervised Classification

This classification uses only the statistical properties of the image data as a basis for classification. The computer alone defines the classification categories. This method is potentially useful for classifying images where the analyst has no independent information about the scene.

Each of the classification schemes can be further subdivided into (i) parametric classification, which assumes certain mathematical models; (ii) non-parametric classification, which assumes no model restraints. Since the non-parametric classification makes the fewest assumptions, it is considered more powerful of the two.

12.2.3.4 Band Ratio Images

These are prepared by dividing the DN values of one band with corresponding DN values of another band for each pixel and by using the ratio, a new image is generated. Simple band ratio is expressed as

$$R_{mn} = R_m/R_n$$

where R_m and R_n are reflectances/radiances in the Multispectral bands m and n, respectively.

The advantage of ratio images is that a material has the same ratio value regardless of variations in illumination, surface topography, shadows and seasonal changes. A disadvantage is that the differences in albedo are suppressed.

Ratio Vegetation Index (RVI) is defined as ratio of NIR band and red band pixel values and is expressed as

$$\text{RVI} = R_{\text{NIR}}/R_{\text{RED}}$$

The RVI, apart from minimizing the effect of environmental factors, provides unique information useful for discriminating soils and vegetation. It enhances radiance differences between soils and vegetation. While soils and geological materials exhibit similar ratio values near one, vegetation shows larger ratio values of about two or more. Higher ratio values indicate luxuriant crop growth.

Modular Ratio (M_{mn}) is a useful variant of simple ratio expressed as

$$M_{mn} = (R_m - R_n)/(R_m + R_n) \text{ or } (R_{mn} - 1)/(R_{mn} + 1)$$

Normalized Difference Vegetation Index (NDVI) is modulation ratio of near infrared and red bands and is expressed as

$$\text{NDVI} = (R_{\text{NIR}} - R_{\text{RED}})/(R_{\text{NIR}} + R_{\text{RED}})$$

The ratio has been extensively used to monitor vegetation. However, it is a poor indicator of vegetation biomass, if the vegetation cover is low, as in arid and semi-arid regions. Soil-adjusted Vegetation Index (SAVI), Transformed vegetation Index (TVI) and Perpendicular Vegetation Index (PVI) are some of the variants.

12.2.3.5 Change Detection Images

Using two images of the same scene acquired at different times (revisit of satellite), the change in DN values of pixels may be utilized to extract a change detection image. By subtracting the DN values of one image from those of the other image in corresponding band, a difference value, which may be positive, zero or negative, is obtained. The change detection image is then produced by assigning saturated white and black to the maximum positive and negative differences, respectively and natural grey tone to the zero difference. Hues can also be used for display.

12.2.3.6 Principal Component Analysis

In case of band ratio images, the interpreter must choose the most suitable ratio from a large number of band combinations available. It is difficult to determine which combination of bands will produce the best enhancement. An alternative approach to this problem is principal component analysis in which the statistical techniques operate on all bands simultaneously.

Essentially, these operations transform the pixel values on to an alternative set of measurement axes. This concept may be graphically expressed by considering a two dimensional feature space. In Fig. 12.4, a random sample of pixels has been plotted according to their values against band A and band B. By expressing the pixel values as measured, on a rotated set of coordinate axes (Axis I and Axis II), a more efficient data dispersion is achieved.

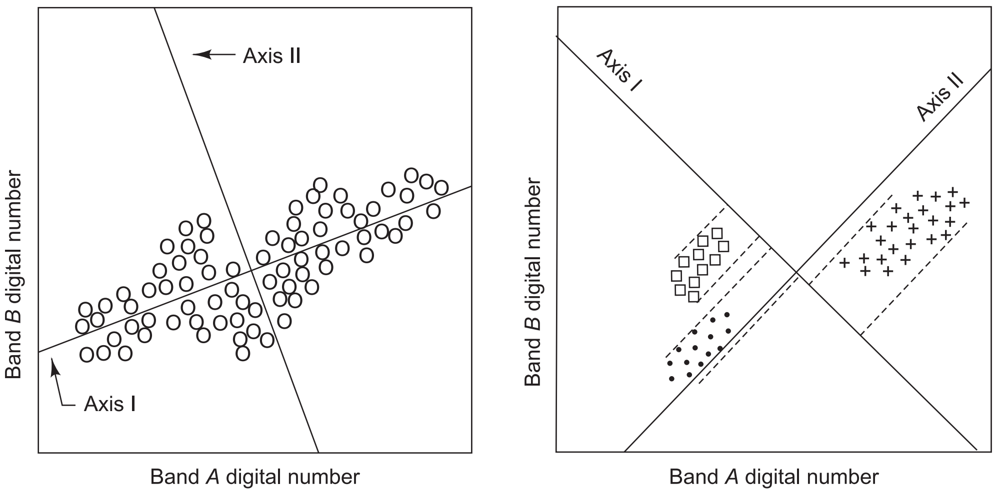


Fig. 12.4 *Rotated coordinate axes used in multispectral transformations*

In Fig. 12.4, the rotated axes have been positioned such that the Axis I values will account for most of the variation in the data set. Axis II expresses the remaining variation in the data. These axes represent principal components. When applied to four channel Landsat MSS data, four axes (or components) would be used. As in two band example, the first component would express a maximum portion of the variance in the data set. Subsequent axes would account for successively smaller portion of the remaining variance.

In *Principal Component Transformation (PCT)*, as discussed above, the transformation is based on covariance matrix. While in *Standard Principal Component Transformation (SPCT)*, the transformation is based on correlation matrix.

Another variation of this type of transformation is *Tasseled Cap Transformation (TCT)*, also known as Kauth-Thomas Transformation. TCT is mostly used for soil and vegetation (especially crop growth).

12.3 APPLICATIONS OF SATELLITE IMAGERY

Remote Sensing from space has revolutionized our understanding and activities in umpteen numbers of fields in natural resource management. It has found application in cartography, environmental studies, disaster management, urban development, soil, agriculture and landuse studies, hydrological studies and water management, forest management, ocean development, etc. It has made an impact in the fields of international communication, meteorology and international cooperation. In fact the list of applications is endless. The imagery can be effectively utilized in all areas of application, where some kind of mapping is involved.

The repetitive coverage by satellite has demonstrated that images acquired in different seasons may enhance various natural features. It helps in monitoring of the crop growth and crop vigor, leading to better estimation of crop yield. Repetitive coverage has been particularly useful in mapping and monitoring dynamic phenomena like floods, earthquake disasters and snow covers. Similarly, change in sun elevation has brought out certain natural features more clearly.

Although remote sensing has been extensively used in different fields of application, as mentioned above, its application in geology is emphasized below.

12.3.1 Applications in Geology

Remote sensing methods have been found application in different aspects of geology; in some cases as a new tool, while in others as a supplement to the existing techniques. The remote sensing systems that are used in different fields of geology are described below:

General Geology: Aerial photographs have been extensively used in geological and allied mapping. Space imagery has a supplementary role, contributing in deciphering regional geological features, lineaments and circular features, etc. (see case studies on Neotectonic activities, Fig. 12.5; River Morphology, Fig. 12.6—see color figures). The satellite imagery has been used for updating existing geological maps. Airborne MSS has only secondary application. Radar has been successfully used for geological mapping in areas covered with forests and constant cloud condition. Thermal IR scanners have been found useful in mapping Quaternary surfaces.

Petroleum Geology: Aerial photographs have a wide application in this field. Airborne MSS is being applied for deciphering facies changes. There is a proposal to use thermal anomalies for locating promising oil structures or 'highs'.

Mineral Exploration: No new mineral discovery has been documented as a sole result of remote sensing. However, indirect help has been rendered by space imagery in locating faults, fracture zones, gossans, intersection of lineaments, etc., which are favorable locations of mineral deposits. Attempts are made to correlate magnetic and geophysical anomalies with the MSS data to locate promising mineral deposits.

Engineering Geology: Airborne MSS has only a supplementary role to the aerial photographs which are being used with advantage for fracture analysis, locating landslides, slumps, soil creep, etc., besides regional planning in route location, material location and dam site location. Situation is changing with availability of improved resolution of satellite imagery.

Hydrology and Snow Surveys: space imagery and airborne MSS have been used for differentiating soil moisture classes and are successfully used for mapping different types of snow with a view to snowmelt prediction and water management.

Surveillance of Volcanoes and Natural Hazards: Thermal IR imagery in 8-14 μm band has been used effectively for surveillance of volcanoes. Monitoring of floods (see case study on Kosi Disaster, Fig. 12.7—see color figure), assessing the damage due to earthquakes and cyclones can be done by space and radar imagery on a regional scale. Conventional Aerial photography has serious limitations due to adverse weather conditions.

Geothermal Energy: Infrared line scanners have been successfully used in locating thermal anomalies.

Environmental Studies: Aerial photographs were previously used. Space imagery now plays a major role in locating and monitoring large pollution plumes, oil slicks etc.

The main advantages of space imagery are low cost, repetitive coverage and multispectral approach, which has a strong potential for development in future. Initially, there were limitations due to low spatial resolution, lack of adequate stereo coverage and restricted spectral range, which are being gradually improved to make the space imagery more versatile. In the present scenario, remote sensing technique is playing a major role along with the conventional methods in natural resource management. Remote sensing along with communication technologies are developing fast and becoming indispensable. It is a major key to understanding the earth, its resources and its environment.

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Frequently Asked Questions

1. Describe the steps involved in visual interpretation of satellite imagery.
2. Write short notes on: Lineaments; Circular features; Image Restoration; Image Enhancement; Supervised Classification; NDVI; Change Detection Images; Principal Component Analysis.
3. Describe different functional categories of Digital Image Processing.
4. Describe briefly the applications of satellite imagery.

PART III

GLOBAL POSITIONING SYSTEM

13

MAP

13.1 INTRODUCTION

The science and art of map making comes in the domain of *Cartography*, which includes all operations from original survey to final printing of map. Preparing a map is the basic requirement for carrying out any developmental activity. Knowledge of surface land forms, sub-surface rocks, and availability of water, drainage, soil and vegetation cover is essential for taking up development project with its associated urbanization. Sustainable development has to be achieved by proper utilization of natural resources, including soil, water and minerals, without seriously disturbing the environment. For all these activities, the first step is preparation of a map. Let us first examine what is a map.

13.1.1 Definition

By cartographic definition, a map is a selective, symbolized and generalized picture of spatial distribution of a large area of earth surface as seen from above on a much reduced scale (orthographic projection). The aim of a map is to show the geographic space relationship between various selected natural and cultural details in an area. A map has an advantage over the text, as the map can be seen at a glance; while words must come in sequence. No description of a region can rival the impact or retention possibilities of a map.

13.1.2 Classification of Maps

There are different types of maps depending on the purpose for which they are produced. These are classified with reference to their scale and content, in two main groups: general and special.

13.1.2.1 Group-I General

General maps are used for a number of purposes, catering to the general requirement of various disciplines. These are subdivided into the following types.

(a) *Topographical Maps* depict the details with symbols and topography with contours. The scale varies from 1:5,000 to 1: 250,000.

(b) *Geographical Maps* are small scale maps which are compiled from topographical maps. The scale ranges from 1:500,000 to 1:5,000,000

(c) *Atlas Maps* are small scale maps representing large regions, countries continents or the whole world in one sheet. The scale varies from 1:5,000,000 to smaller.

(d) *Cadastral Maps* are large scale maps showing the distribution of landed property and ownership and are used for revenue purposes. This type of map normally does not include elevation. The scales are 1:250 to 1:4,000.

(e) *Planimetric Maps* are topographical maps without contours.

13.1.2.2 Group-II Special

The special maps are for specific purposes, which emphasize on certain information. These are subdivided into following types:

(a) *Hydrographic Charts or Admiralty Charts* are used for navigation in the sea.

(b) *Aeronautical Charts* are used for navigation in air.

(c) *Thematic Maps* are topical maps showing only one topic in a map qualitatively such as geology, soil types, forest types, etc.

(d) *Statistical Maps* are topical maps showing distribution of information of the topic in a map, quantitatively, such as map of temperature, rainfall, population density, etc.

(e) *Guide Maps* are prepared for the purpose of enabling people to find their way around large towns, hill stations and other places of touristic interest.

(f) *Engineering Plans* are large scale maps, on scale larger than 1:5,000 prepared for engineering projects, town planning, factory sites, etc.

13.1.3 Scale

Scale is the ratio of a distance on the map to the corresponding distance on the ground. The scale of the map is directly related to the use and size of the map and is dependent on the planimetric accuracy required. It is uneconomical to make a map more accurate than required for its intended use.

Identifiable details are expected to be within 0.25 mm of their position relative to the surrounding details. If larger scale is required to have more working space then this can be achieved by enlarging the surveyed map. Scale is normally represented in any of the following forms.

13.1.3.1 Representative Fraction (R.F.) or Natural Scale

It is denoted by a ratio of unit e.g. 1:50,000 or 1:10,000. When we say that scale is 1:10,000, it simply means that every unit of length on the map represents 10,000 units of the same measure on the ground.

13.1.3.2 Graphic or Bar Scale

The scale is represented by a graduated bar on the map. This scale is most convenient for visualizing the scale at a glance and for measuring distances. We may take any distance on the map and read it off on this scale in miles, yards, feet or kilometers, etc. Graphic scale is good where a subsequent photographic reduction or enlargement of the map is required. When the map is to be kept for a long duration, the error due to shrinkage of paper does not affect the graphic scale.

13.1.3.3 Verbal or Numerical Scale

Verbal or Numerical scale is given by a statement that a certain measure of distance on the map represents a certain distance on the ground. Thus a map on 1:63,360 scale is also referred to as 1 inch to 1 mile scale map (or simply 1″ map).

13.1.4 Map Symbol

Symbols are used for indicating various natural and man made features of the earth's surface on a map in simple, legible and uniform manner. A good symbol is one, which can be recognized without a legend. Such a symbol should either be illustrative of the feature it represents or backed by long usage. Symbols should be small, distinct and easy to draw. Colors add greatly to the distinctiveness. A list of symbols used on a map is called *legend*. These symbols should appear in the legend exactly as they are depicted on the body of the map and are clearly and fully described.

13.1.4.1 Types of Symbol

Map symbols are grouped in three different categories on the basis of dimension and mode of drawing, namely:

(a) *Point Symbols* are denoted by dot, heavy dot, circle, cross etc. A point symbol may either represent kind e.g. a hut or both kind and quantity viz. a graduated circle representing the population of a city.

(b) *Line Symbols* represent features in linear dimension such as roads, streams canals, etc. Line symbols are also used to separate different units of interest or showing equal value in quantity, e.g. geological boundaries and structural features or contour lines and equal temperature lines (isotherms).

(c) *Area Symbols* represent features in two dimensions i.e. an area of surface. Area symbol are qualitative such as blue grass for marshes, patterns to show orchards, tea gardens, soil types, rock types, etc.

13.1.5 Map Design

The main aim of map design is to present the map data in such a manner that the map, as a whole, appears as a harmoniously arranged integrated unit and each item is clear, legible and has an attractive appearance. Map design consists of the overall plan and the style of the map.

The map data (actual mapped area) is enclosed by a neat line. Certain area of the map is shown by enlargement, which is separately put as an *in-set*. Location map, administrative index and map index (position of the map with reference to the adjoining sheets) are given in separate in-sets. Legend, comprising symbols used in the map, is given in the right bottom corner. Symbol of North direction is put in the top right corner of the map and scale is given just below it or at the bottom of the map. An outer neat line is drawn to add to the grace of the map. The Title, in bold font, is written at the top of the map. Sheet number and information about vertical deflection and magnetic declination are given in the right and left corners of the map, outside the outer neat line. The space between the two neat lines could be utilized for indicating graticule values. The map design suggested here is what is generally adapted; however, adjustments can be made to utilize the space available due to a particular shape of the mapped area. The idea is to economize on the space and cost.

13.1.6 Folding and Preservation of Map

Maps are folded in various ways. As a general rule, maps should be folded first horizontally and then vertically to the desired size. By this method the map can be opened at any place with the least amount of manipulation. The maps are best preserved by mounting on cloth or by embedding in plastic sheets. For rigorous use in field, the map is cut and mounted on cloth, attached with card board pieces of appropriate size to keep it safely after folding.

13.2 MAP NUMBERING

The main systems of numbering used on maps published by Survey of India are on spherical layouts. These are (a) International system and (b) India and Adjacent Countries (IAC) system. With the introduction of new National Map Policy (NMP) in 2005, Defense Series Map (DSM) and Open Series Map (OSM) have come in vogue. While the numbering of DSM remains the same, there is new numbering system for OSM.

13.2.1 International System

The International system applies only to 1/M and ¼ inch (1:250,000) sheets of the International Map of the World (IMW) series. It is based on a series of 1/M sheets each covering 4° Latitudes and 6° longitudes. Each sheet number of this series consists of two letters and a number. The first letter is either '*N*' or '*S*' depending on whether the sheet is located in the north or south of the equator. This is followed by another letter, which indicates the latitude of the sheet; each alphabet is serially earmarked for a 4° latitude belt beginning from the equator. Thus all the sheets between 0° to 4° north latitudes are NA and between 4° and 8° N latitudes are NB and so on. The numbering begins from 180° longitude and runs serially from west to east round the world. Thus the number of sheet between latitudes 0° and 4° N and longitudes 0° and 6° E will be NA – 31. The number of 1/M sheet covering part of Himachal Pradesh between latitudes 28° and 32° N and longitude 78° and 84° east is NH – 44 (Fig. 13.1).

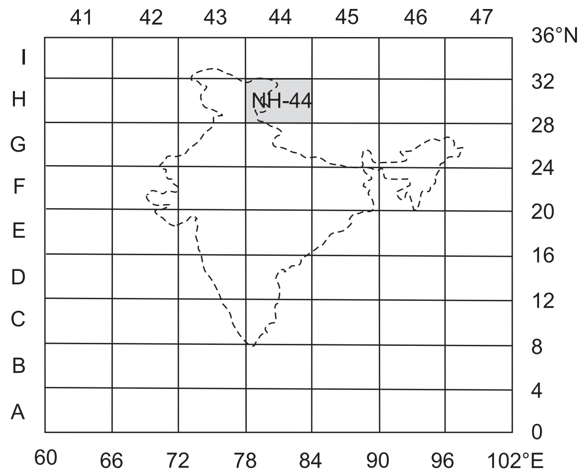

Fig. 13.1 *Numbering of international map of world (IMW) series on 1/m scale*

Each 1/M International sheet is sub-divided into 24 sheets covering 1° (one degree) latitude and 1° longitude. These degree sheets are lettered from west to east starting with A in the northwest corner of 1/M sheet to *X* in the southeast corner. Thus the number of degree sheet between latitudes 3° and 4° N and longitude 0° and 1° E is NA-31A. The number of degree sheet covering Manali area between latitudes 29° and 30° N and longitude 79° and 80° E is NH-44N (Fig. 13.2). The International system of numbering does not extend to sheets larger than ¼ inch (1:250,000) scale.

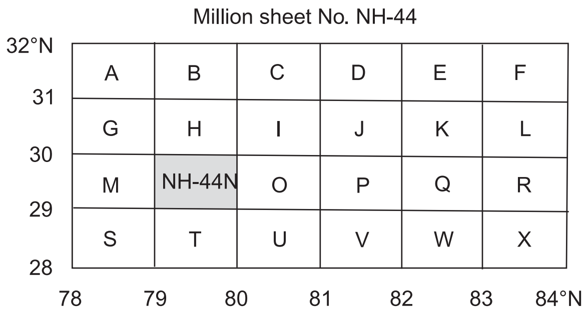

Fig. 13.2 *Numbering of degree sheets on 1:250,000 scale in IMW series*

13.2.2 India and Adjacent Countries (IAC) System

This is an arbitrary system of sheet numbering based on 4° × 4° layout of 1/1M sheets adopted in India and adjacent countries. The sheet number does not give any indication of the geographical position of the sheet (Fig. 13.3).

Each sheet covers an area of 4° latitude and 4° longitude and the numbering is from north to south increasing from west to east. This series does not extend north of latitude 40° N. The sheet No. 1 begins with the northwest corner at latitude 40° N and Longitude

44° E. The 1/M sheet No. for Dehra Dun area bounded by latitudes 28° N and 32° N and longitudes 76° E and 80° E is 53 (Fig. 13.3).

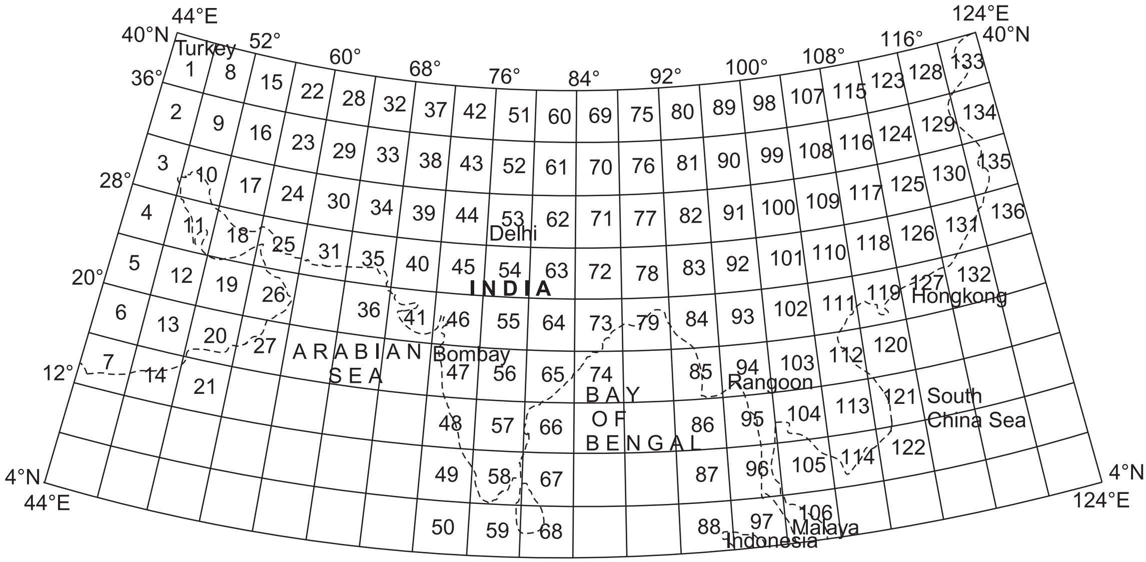

Fig. 13.3 *Numbering of maps on 1/M scale in IAC system*

Each 1/M sheet of this series is divided into 16-degree sheets on ¼ inch or 1:250,000 scale, covering 1° latitude and 1° longitude. These are lettered from north to south beginning with A in the northwest corner to P in the southeast. The sheet covering Dehra Dun, between latitudes 30° N and 31° N and longitudes 78° E and 79° E, is thus numbered as 53J (Fig. 13.4). India is covered by 394 degree sheets on 1: 250,000 scale.

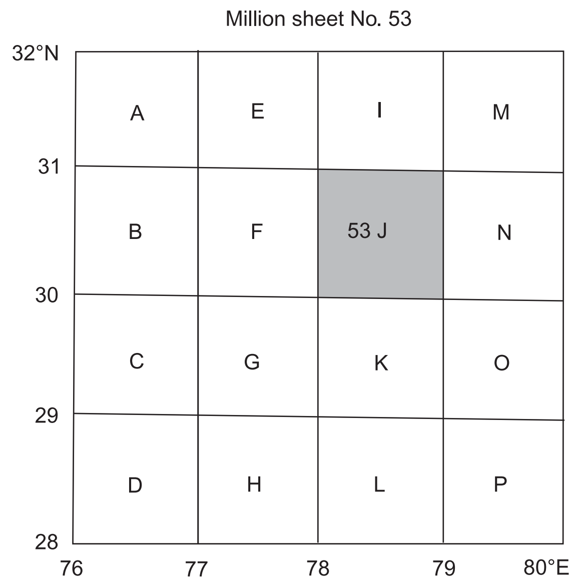

Fig. 13.4 *Numbering of degree sheets on 1:250,000 scale in IAC system*

Each degree sheet is divided into 16 one inch or 1:50,000 scale sheets; each covering an area of 15 minutes of latitude and 15 minutes of longitude. These are also numbered from north to south increasing west to east beginning with No. 1 in the northwest to No. 16 in the southeast. For example, the sheet number for Dehra Dun is 53 J/15 (Fig. 13.5). India is covered by 5,106 sheets on 1: 50,000 scale. In older series, some times a degree sheet was divided in to four ½ inch or 1:126,720 scale. These were numbered as 64G/NW, 64G/NE, 64G/SW and 64G/SE in case of degree sheet 64G.

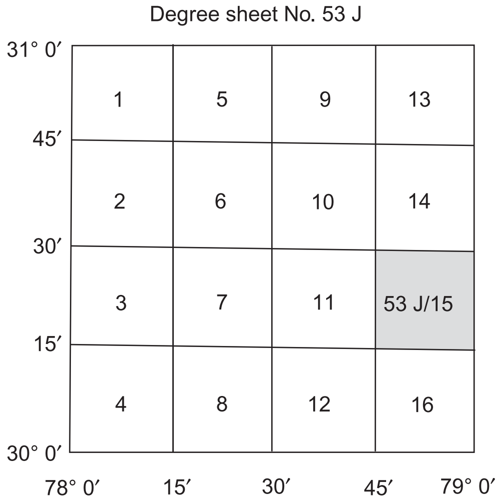

Fig. 13.5 *Numbering of toposheets on 1:50,000 scale in IAC system*

Each one inch or 1:50,000 scale sheet is further sub-divided into 6 sheets on 1:25,000 scale; each of 5 minutes latitude and 7 ½ minute longitude. These are numbered similarly from N to S beginning with No. 1 in the northwest to No. 6 in the southeast corner (e.g. 64 G/11/3). Presently, there are 9 sheets of 1:25,000 scale, each of 5 minutes latitude and 5 minutes longitude, and are similarly numbered from 1 to 9, viz. Raipur near Dehradun is located in sheet No. 53J/15/8, on 1:25,000 scale (Fig. 13.6).

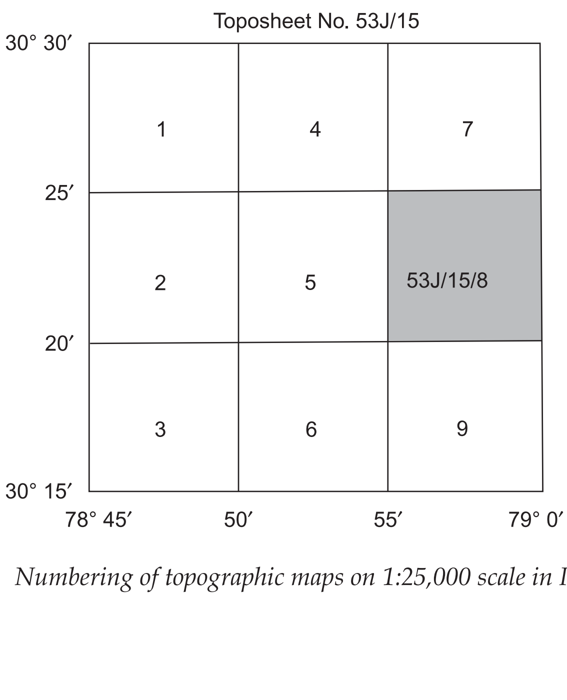

Fig. 13.6 *Numbering of topographic maps on 1:25,000 scale in IAC system*

13.2.3 Open Series Map (OSM) System

The Open Series of Maps are basically required for socio-economic development, conservation of natural resources, planning for disaster mitigation, infra-structure development, etc. Since the series is based on WGS-84 datum and UTM coordinates, the numbering of the 1/M sheet is like IMW series, described above. For example, a million sheet is numbered as NG-43 or G-43, located between latitudes 24° and 28° N and longitudes 72° and 78° E (Fig. 13.7). Each 1/M sheet is divided into 24 degree sheets, covering 1° latitude and 1° longitude (on 1:250,000 scale). The sheets are numbered with alphabets starting with A in the northwest corner, increasing west to east, and ending with *X* in the southeast corner. The degree sheet, between latitudes 24° and 25° N and longitudes 72° and 73° E is numbered as G-43S (Fig. 13.8).

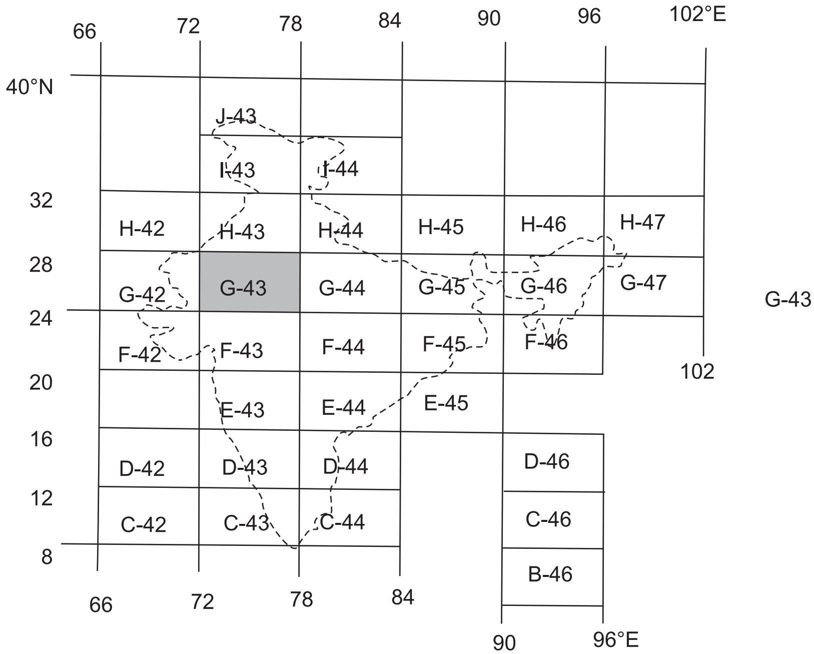

Fig. 13.7 *Numbering of million sheets in OSM system*

The degree sheet is sub-divided into 16 sheets on 1:50,000 scale, covering 15 minute latitude and 15 minute longitude. These are numbered with numerals, starting with 01 in the northwest corner, increasing north to south, and ending with 16 in the southeast corner viz. G-42S/04 (Fig. 13.8). Likewise A sheet on 1:25,000 is numbered as G-42S/04/NW, covering 7′30″ latitude and 7′30″ longitude and on 1:10,000 scale as G-42S/04/01, covering 3′ latitude and 3′ longitude (Fig. 13.8).

The Defence Series Maps (DSM) are used for defence and national security. The maps of this series are on Everest/WGS84 datum and on Polyconic or UTM projections, without diluting the accuracy with regard to height, contour and planimetry of details. The maps of DSM series, in analogue and digital forms, are classified and have restricted use.

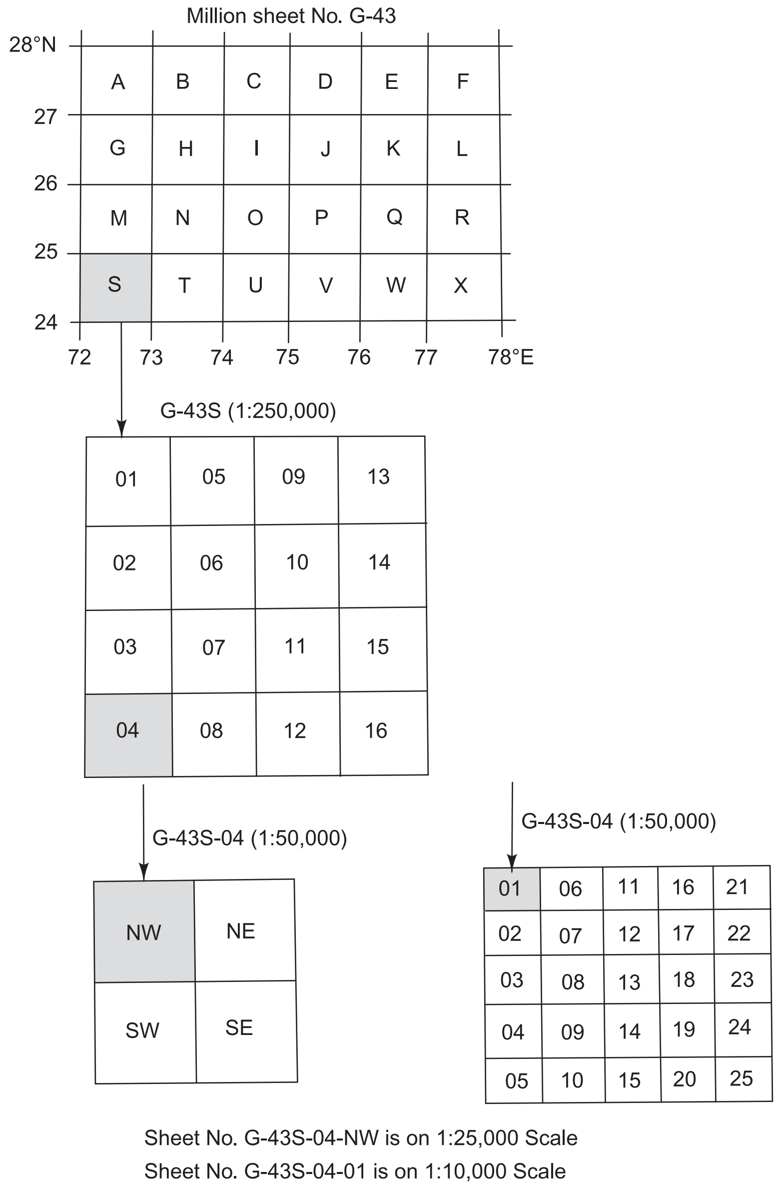

Fig. 13.8 *Numbering of larger scale sheets in OSM system*

13.3 RECTANGULAR GRID SYSTEM

The coordinates of ground control points are often referred to in rectangular coordinate system instead of longitudes or latitude, for ease of reference. Such a rectangular system, composed of network of equal squares, which can be used as a reference system for mapping, is called a grid. The grid is named after the projection system on which it is drawn. The grids used in Survey of India are based on Lambert Conical Orthomorphic (or Conformal) projection and are called Lambert Grid. In order to keep the scale errors and convergence within tolerable limits, India and its adjoining areas have been divided into nine Grid zones, namely, Grid 0, IA, IB, IIA, IIB, IIIA, IIIB, IVA and IVB. Their layout is given in "Index showing layout of India and adjacent Grids (Meters)", published by Survey of India.

Grids have the following advantages over the other systems of reference lines drawn on maps:

(a) Map references are simpler.
(b) The grid system is independent of sheets.
(c) Computation of distances and bearings from the coordinates is much simpler and sufficiently accurate.
(d) They facilitate map compilation.

13.3.1 Grid Origin

Every grid has a point where its north-south and east-west lines coincide with true north, south, east and west. This point is known as 'True Origin' of the grid. In order to avoid negative grid values, the true origin is given an arbitrary position so that values of all points covered by the grid will be positive. The point on the grid, whose easting and northing co-ordinates are zero, is known as 'False Origin'.

All the distances to the east and north are known as Eastings and Northings, respectively. The co-ordinates of the true origin in all the grids are 3,000,000 and 1,000,000 grid yards, respectively for eastings and northings, except in Grid 0, for which these are 2,355,000 and 2,590,000 grid yards, respectively. On the metric system, these are expressed in grid meters and for conversion into meters these are multiplied by conversion factor of 0.9143988. The true origins of nine Indian Grid Zones are given in Table 13.1.

Table 13.1 True origins of nine Indian Grid Zones

Grid	*Latitude N*	*Longitude E*	*Grid*	*Latitude N*	*Longitude E*
0	39°30′	68°00′	IIIA	19°00′	90°00′
IA	32°30′	68°00′	IIIB	19°00′	100°00′
IB	32°30′	90°00′	IVA	12°00′	80°00′
IIA	26°00′	74°00′	IVB	12°00′	104°00′
IIB	26°00′	90°00′			

13.3.2 Grid Convergence

The directions of the true north and the grid north do not coincide, except at meridian passing through true origin. At other points these are inclined to each other at a small angle, called the 'Grid Convergence'. It is reckoned positive in the northern hemisphere, when the point is east of grid origin and negative, when it is west of it. Grid bearing, i.e. bearing measured clockwise from the grid north at a point, is related to true bearing of the point, according to the following formula:

Grid Convergence = True bearing – Grid bearing.

13.3.3 Grid Table

Auxiliary Tables, Part V: Lambert Grid Tables (Metric), published by Survey of India, contain full data compiled in tabular form, for easy and ready reference, for conversion of data from spherical to grid coordinates and vice versa, and for computation of triangulation and traverse, directly in grid terms. Explanations of various grid tables are provided in the beginning (from Pages xi to xx) of the Auxiliary Tables, Part V.

13.3.4 Construction of Grid Lines

A network of grid lines may have to be constructed on a map on spherical projection, as in case of Survey of India maps or for special maps on rectangular grid system.

For plotting of grids on Survey of India maps, where limits are formed by spherical graticule, the detailed procedure is given in "Guide for Preparation of Grid Originals", published by Survey of India. In brief, the following procedure may be adopted:

(a) The grid coordinates or Eastings and Northings of the four corners of the map in meters are determined from Table 9 Grid in Auxiliary Table, Part V.

(b) The distances in meters of the nearest 1000 meters lines, both for Eastings and Northings, from each corner are calculated and arcs are drawn at the correctly scaled distances from the corners.

(c) The appropriate arcs are tangentially ruled up to form periphery of the grid.

(d) For remaining grid lines, the peripheral grid lines are sub-divided at suitable intervals.

13.3.5 Grid Numbering System

The area covered by each grid is divided into primary squares of 500,000 unit sides (Fig. 13.9). Each of these 500,000 units square is again divided into twenty five secondary squares of 100,000 unit sides (Fig. 13.10). In both the cases the squares are lettered from west to east. Thus the letter A is in the north-west and Z in the south-east; the letter I is omitted. The system of 500,000 units square is so placed that the south-west corner of the square 'V' is at the 'false origin' of the grid and its easting and northing values are zero. In the maps on 1: 250,000 and 1: 100,000 scales, every 100,000 unit square is divided into 10,000 unit squares. It is further divided into 1,000 unit squares, on maps of 1: 50,000 and 1: 25,000 scales. On all scales every tenth line is made thick and its full grid value is written along with on the margins.

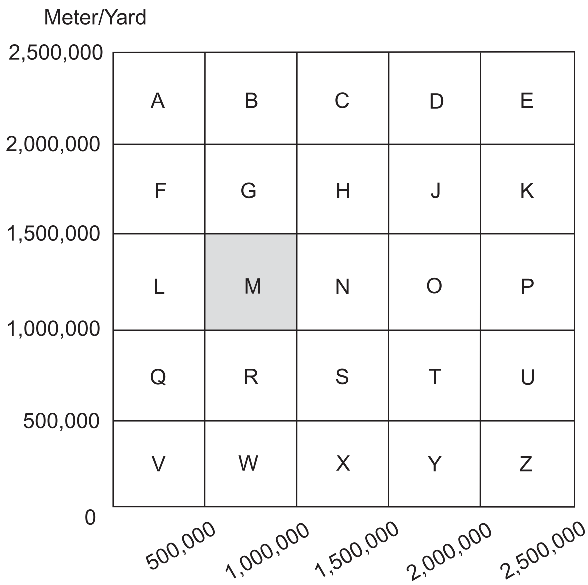

Fig. 13.9 *Numbering of primary (500,000 unit) grid*

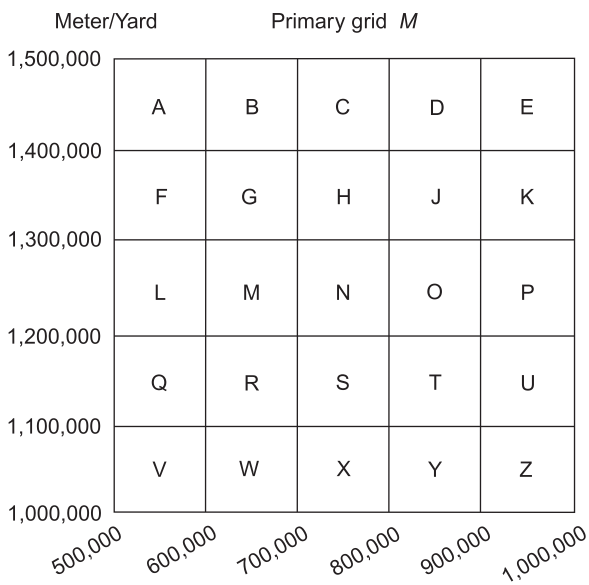

Fig. 13.10 *Numbering of secondary (100,000 unit) grid*

13.3.6 Grid References on Map

Following is the sequence of giving grid reference on the map:

(a) The first letter of the grid reference is the letter of the primary grid square of side 500,000 grid units, in which it lies.

(b) The second letter of the grid reference is the letter of the secondary grid square of side 100,000 grid units, in which it lies. This letter is printed bigger than the letter of the primary grid square on the map.

(c) The first half of the even number of figures after the letter of the secondary grid square denotes easting value and the latter half denotes northing value of the point in reference. Usual grid references are by 10, 8, 6 and 4 figures, which locate the point within 1, 10, 100 and 1000 grid units of its eastings and northings, respectively. Two figure references are used to locate the point on 1:1M maps within 10,000 grid units.

In giving a grid reference, the letters left of those written in bigger type are ignored and the figures on the right, which also appear in the body of the map, are only referred. For example, grid reference of a temple on southern side of Dehradun–Chakrata road, in village Selakua, near milestone No. 12, in one inch sheet No. 53 F/15 is:

L 340881, in 6 figures locating the position within 100 grid yards, and

L 33978812, in 8 figues locating the position within 10 grid yards.

Where 'L' is the letter of the secondary grid square of side 100,000 grid yards, in which it lies.

Suggestions for Further Reading

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Frequently Asked Questions

1. Give definition of: Map; Map Scale; Map Symbol.
2. What are different types of maps?
3. Describe different type of Map Scale and Map Symbols.
4. Write short notes on: Map Design; Folding and protection of map; Grid Origin; Grid Convergence.
5. What is International System of map numbering?
6. Describe India and Adjacent Countries (IAC) System of map numbering.
7. Describe map numbering with illustration in OSM and DSM systems.
8. Describe in brief the construction of grid lines.
9. Describe grid numbering and grid reference on a map.

14

MAP PROJECTION

14.1 INTRODUCTION

Map projection is the process of transforming earth's spherical surface to the plane surface of a flat map. It actually involves geometrically projecting or drawing parallels and meridians in a systematic manner.

14.1.1 Basic Coordinate Systems

Coordinate system helps in locating the position of a point in two or three dimensional space. There are many coordinate systems familiar to students of coordinate geometry and trigonometry. Rene Descartes (1596–1650) introduced a coordinate system, named after him as **Cartesian Coordinate System**, based on two axes intersecting at right angles (orthogonal). Similarly a three dimensional Cartesian Coordinate System can be defined by two orthogonal planes, intersecting at right angle, thereby giving *X*, *Y* and *Z* axes, as shown in Fig. 14.1. In rectangular coordinate system, the axes intersect at a point (O) called the origin (Fig. 14.2). The horizontal axis *OX* is called *X*-axis (or easting); while the axis perpendicular to it (*OY*) is called *Y*-axis (or northing). The coordinates of point *P* is known by perpendicular distances from point *P* to *Y* and *X* axis respectively, as (*x*, *y*). The axes of this system partition the geographic space in to four quadrants, numbered counter clockwise starting from the top. A sign convention has to be observed for locating position of points in

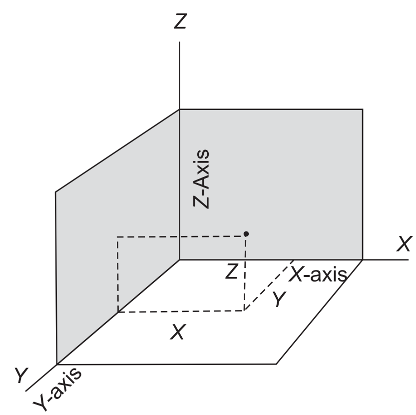


Fig. 14.1 *Three dimensional cartesian coordinate system*

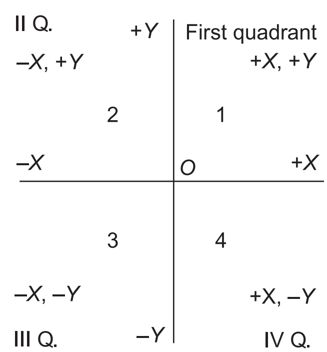


Fig. 14.2 *Rectangular or plane cartesian coordinate system*

different quadrants. The distance on X axis is positive toward east and negative toward west from origin. Likewise, distance along Y axis is positive towards north and negative toward south (Fig. 14.2).

Another system based on angular measurement from a baseline and a linear measurement to fix the position of a point is known as **Plane Polar Coordinate System**. The system consists of a single line, called *polar axis*, which passes through the origin, called *pole* (Fig. 14.3).The position of point P is determined by the distance OP (r) and the angle it subtends on the polar axis at the pole (θ). The radius vector (r) should be followed by Vectorial angle (θ) in defining the point. Polar coordinates can be readily converted to rectangular coordinates and vice versa, using the following formulae:

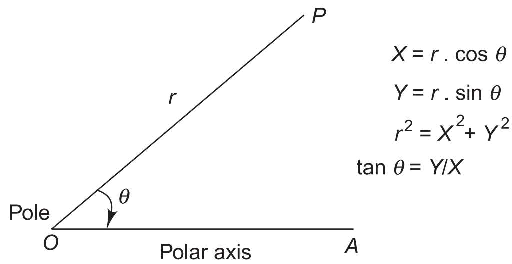


Fig. 14.3 *Plane polar coordinate system*

$$X = r \,.\, \cos\theta \text{ and } Y = r \,.\, \sin\theta$$

Or $$r^2 = X^2 + Y^2 \text{ and } \tan\theta = Y/X$$

14.1.2 Linear Transformations

Transformation is the process of deriving new set of coordinates of a point whose coordinates are known in another system. Linear transformations are simple transformations using equations of single power. Conversion of polar coordinates to Cartesian system or vice versa are examples of linear transformation, where change in scale or shape of geographical space is not involved. Two types of simple transformations, used in surveying, cartography and photogrammetry, are Similarity and Affine transformations. These are briefly described below:

14.1.2.1 Similarity transformation is brought about by horizontal shift, change in rotation angle and change in scale factor, and is expressed by the following simultaneous equations:

$$X = ax - by + c,\ Y = bx + ay + d,$$

Where x and y are coordinates in the subsidiary (new) system, and X and Y are the coordinates in the principal (old) system. Since there are four unknowns to solve, a minimum of two points are to be given in both the systems. These are known as *control points.* After applying the transformation, the shape of original figure may not change but the size and orientation towards the axes may change.

14.1.2.2 Affine Transformation makes use of the following simultaneous equations for a rectangular coordinate system:

$$X = ax + by + c, \text{ and } Y = dx + ey + f$$

Since there are six unknowns to be determined, a minimum of three points in both the systems are required to solve the simultaneous equations. In this transformation, straight lines remain unchanged and parallel lines remain parallel. However, the angles undergo slight change resulting in change of shape, for example a circle will become ellipse. The affine transformation is used more often in geographic system where change of shape is invariably involved. The two transformations can be extended to multidimensional space, viz. in analytical and digital photogrammetry, where elements of exterior orientation of camera are determined.

14.1.3 Geographic Coordinate System

The three dimensional spherical coordinate system to locate any point on the Earth is known as Geographic Coordinate System. The system, in use since over 2000 years, is based on a network of latitude and longitude (known as *graticule*).The concept of spherical earth is available in ancient Indian literature. However, the postulation of latitude and longitude can be traced back to the works of Greek astronomer Hipparchus in the middle of second Century B.C., which was formalized by Claudius Ptolemy, a mathematician, astronomer and geographer, in 2nd Century A.D. Aryabhat's contribution in calculating the diameter of earth, its axial rotation, position of planets in space and planetary orbits, during 5th Century A.D., is well known.

The two primary reference points on the earth surface are North and South poles, through which the axis of earth's rotation (polar axis) passes. Between the poles, the plane dividing the Earth into two equal halves is called an equatorial plane. This plane cuts the Earth's surface through a line called *equator*. The polar axis passes through the equatorial plane at the center of the Earth, which is taken as the origin of Geographic Coordinate System. The position of a point on the surface of the Earth is determined by two angles, *latitude* and *longitude*. The latitude of a point is a vertical angle measured at the origin with reference to equatorial plane (φ in Fig 14.4); while its longitude is the horizontal angle measured from an orthogonal (perpendicular) plane called meridian plane (λ in Fig. 14.4). In 1884 the world mapping community decided to use Greenwich meridian, near London as the *prime meridian* (i.e. with a longitude of 0°).

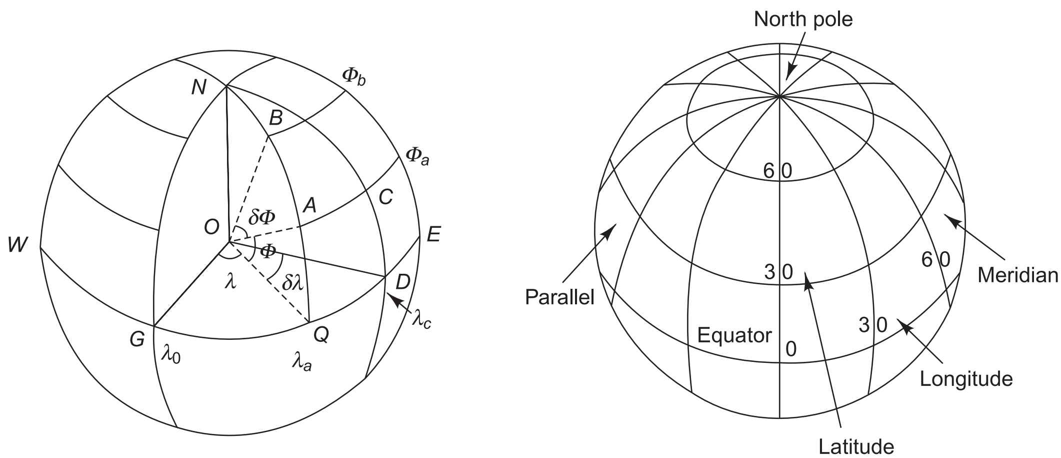


Fig. 14.4 *Geographical coordinate system*

The latitude is measured in angular unit, north or south of equator. Thus the latitude of equator is 0° and that of North Pole is 90° N and for South Pole it is 90°S. By convention, the latitudes north of equator are taken as positive ($+\varphi$) and south of it are negative ($-\varphi$). The line joining all points of equal latitude form a circle which is parallel to the equator. Hence the latitudes are denoted by *parallels*. These parallel circles have successively reduced diameters towards the poles, where it is zero.

The longitude is measured as horizontal angle from prime meridian, along the equator. The line joining all points of equal longitude is called a *meridian* which forms a circle passing through the poles. The meridian circles (or great circles) are equal in dimension. Conventionally, the longitudes are measured east of prime meridian up to 180° E and are denoted by positive sign ($+\lambda$); while the longitudes measured west of prime meridian up to 180° W and are denote by negative sign ($-\lambda$). The longitude 180° E or W is known as *ante meridian* and denotes (approximately) the International Date Line. On the surface of the Earth, the parallels and meridians cross each other at right angles.

14.1.4 Properties of Map Projection

Earth can be regarded as a perfect sphere. To represent it on a flat plane is like squashing an orange on a flat surface; some of the properties of the spherical earth will be lost. There are four properties to consider: (1) area (2) shape (3) distance and (4) direction. For a spherical Earth all these four properties are correct. However, once the Earth is transformed into a plane, only some of these properties can be maintained. Thus all the different map projections have been designed to produce a network of meridians and parallels that can achieve one or two of these properties in the final map for specific purposes of representation. We shall deal these properties in more details.

14.1.4.1 Area

A map projection may be designed to be equal area, so that any area measured on the map is same as that measured on the Earth. The map projection is called *equal area* or an *equivalent* projection. This property can be accomplished by distorting the shape of the graticule. Equal area projections are best used to show political units, population, land use and land cover, soils, wetlands, wildlife habitats and natural resources inventories. The trade-off of preserving true area is that spatial features on the maps will inevitably be distorted in shapes, distances, and, occasionally, directions. The examples are the Albers Equal-Area Conic Projection, Lambert Azimuthal Equal-Area Projection, and Sinusoidal Equal-Area Projection.

14.1.4.2 Shape

A map projection can maintain the correct shape of the spatial features represented. This is possible only by making the scale same along the meridian and parallel. Consequently, the relative local angles at every point on the map are correct. The meridians and parallels intersect at right angles. This type of projection is known as *Conformal*, or *Orthomorphic* (“straight shape” in Greek). These projections are important for topographic mapping and navigational purposes. The need to retain shape inevitably distorts both area and distances.

A good example is Mercator projection in which the area of Greenland is shown to be larger than South America, although, in reality Greenland is only one eighth the size of South America. A conformal map projection in the conic type is the Lambert Conformal Conic (LCC) Projection.

14.1.4.3 Distance

The distance between two points measured on the map is equal to the distance between the same two points on the earth surface, as per the scale of the map. Obviously this property is not possible at all the points on the map. It can be achieved only by selecting certain lines along which the scale remains true. These lines can be along every meridian. These lines of true scale include the *central meridians* of the cylindrical class of projections, as well as the *standard parallels* of the conical class of projections. This type of projection is called *equidistant*. The equidistant map projection is used in Atlas maps. Examples are Azimuthal Equidistant Projection and Equidistant Conic Projections.

14.1.4.4 Direction

Direction of any point on the surface of the earth is indicated with reference to North, viz. N20°E, N40°W, etc. True North is given by the direction to the North Pole or Pole Star, which differs from the Magnetic North, given by the magnetic needle of the compass (Fig. 14.5). The magnetic North Pole moves due to changing geophysical conditions of the earth's crust and the core. The *bearing* of an object is the angle between the N-S line and the line joining the object and the observer, measured clockwise (Fig. 14.6).

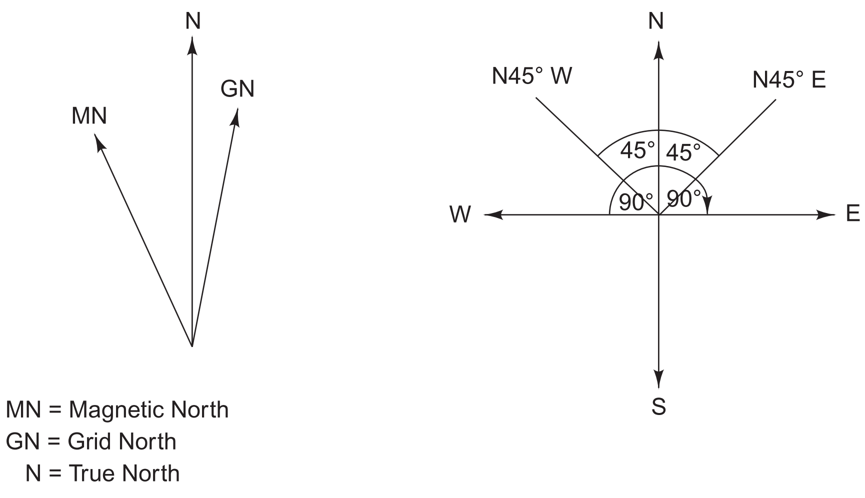


Fig. 14.5 *Directions*

The directional property of the map is likely to be altered in different type of map projections. However, the objective that the direction measurements made on the map should be the same as those made on the Earth. True direction is an inherent property of azimuthal class of map projections because all meridians pass through the pole. This particular property can be retained simultaneously with one or two properties described above. Since the conical map projections preserve shapes, they naturally have true direction. However, in conformal map projections, accurate directions are measured only along one or two directions. The most notable exception is the Mercator projection that preserves true direction in all directions and in all parts of the map. True direction is a useful property for air and sea navigation charts. Examples of true direction map projections include the different variants of Azimuthal and Mercator projections.

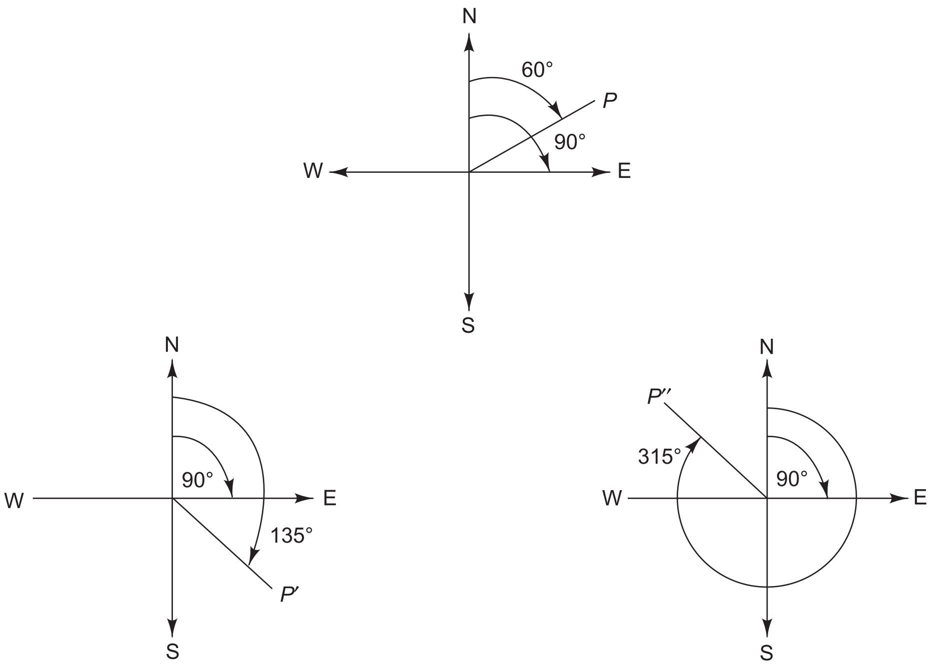


Fig. 14.6 *Bearings*

14.2 CLASSIFICATION OF MAP PROJECTIONS

There are different ways to classify map projections. One simple way is to classify map projections according to the type of developable surface on to which the network of longitudes and latitudes are projected. A developable surface is a surface that can be laid out flat without distortion. There are three types of developable surfaces and hence three types of projections are: 1. Cylindrical, 2. Conical, and 3. Planar or Azimuthal.

14.2.1 Cylindrical Projection

A cylinder is assumed to circumscribe a transparent globe, marked with meridians and parallels, such that the cylinder touches the Equator throughout its circumference [Fig. 14.7(a)]. Assuming that a light bulb is placed at the centre of the globe, the graticule of the globe is projected on to the cylinder. By cutting open the cylinder along a meridian and unfolding it, a rectangle shaped cylindrical projection is obtained. The meridians are parallel straight lines perpendicular to the Equator. The parallels will be horizontal straight lines at some selected distance from the Equator and from each other.

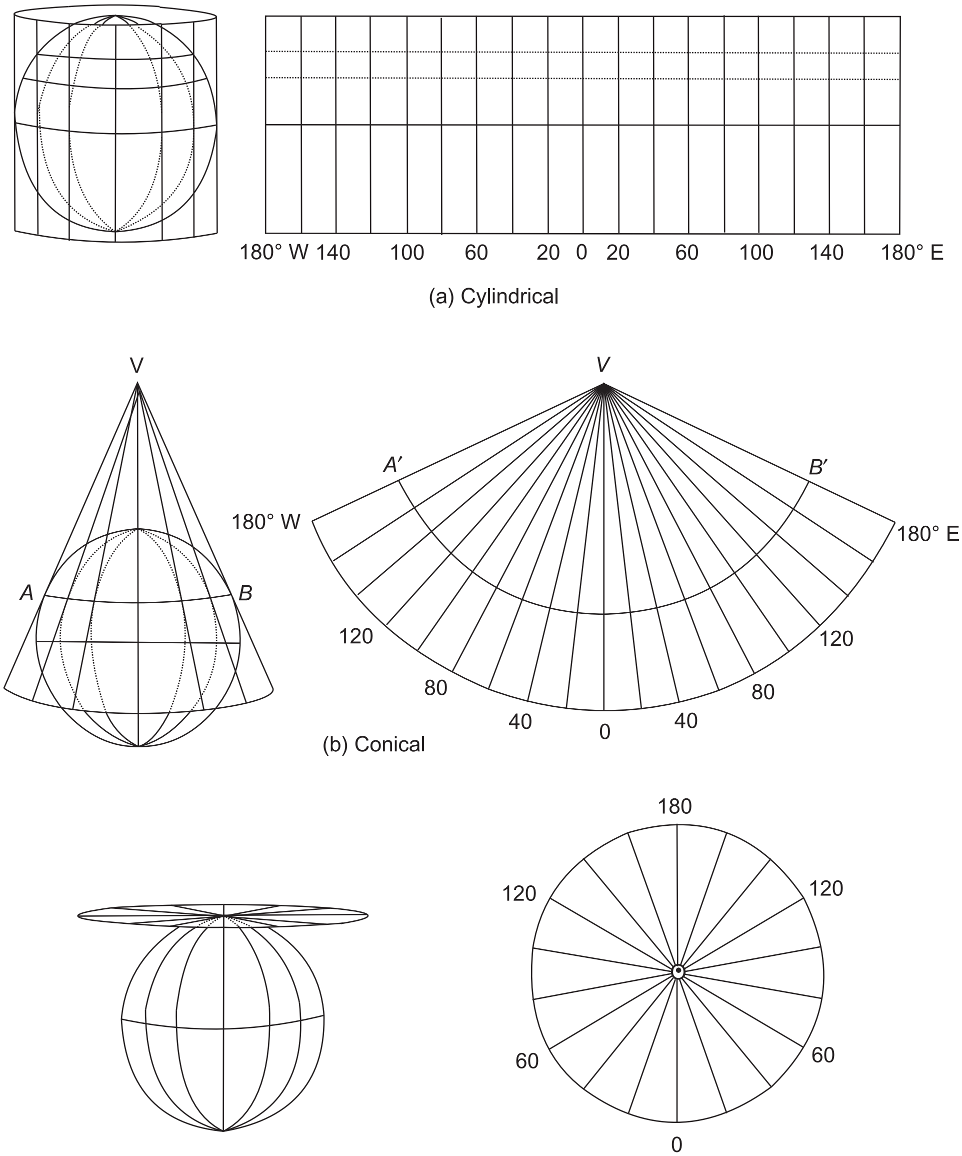


Fig. 14.7 *Type of map projections based on developable surface*

14.2.2 Conical Projection

A cone is placed such that it touches the globe along a parallel or latitude, and its apex is exactly above the pole [Fig. 14.7(b)]. The parallel of latitude which is touched by the cone is known as standard parallel, which can be selected by the cartographer. Along this standard parallel the scale is correct and distortion is the least. When the cone is cut open along a meridian and laid flat, a fan shaped map is produced, with meridians as straight lines radiating from the vertex at equal angles, while parallels are arcs of the circles, all drawn using vertex as the centre.

14.2.3 Planar or Azimuthal Projection

A plane is placed such that it touches the globe at the North or South Pole [Fig. 14.7(c)]. This is a limiting case of the cone becoming increasingly flattened, the apex angle becoming 180 degrees. The resulting projection is better known as Polar Azimuthal Projection. It is circular in shape with meridians projected as straight lines radiating from the centre of the circle (the tangent point of the plane), which is the pole. The meridians are spaced at their true angles. The parallels are complete circles centered at the pole.

In these three projection types, the developable surface is assumed to touch the surface of the globe to form a tangent cylinder, a tangent cone, a tangent plane. Mathematically, it is possible to make the developable surface cut through globe as secant cylinder, a secant cone, and a secant plane. The purpose of this is to minimize the amount of distortion that occurs away from the standard parallel or the pole. In the case of secant cylinder and secant cone, two standard parallels are generated, where the scale will be more correct than other part of the map.

14.2.4 Aspects of Map Projection

There is still one more consideration known as the **aspect** of a map projection. The developable surface may be placed in three different ways relative to the globe: (1) normal, (2) transverse, and (3) oblique.

14.2.4.1 Normal Aspect

The axis of the cylinder or cone is coincident or parallel to the polar axis of the Earth, and the plane is tangent to the equator [Fig. 14.8(a)]. Our previous discussions on map projection are based on the normal aspect of the map projection.

14.2.4.2 Transverse Aspect

If the axis of the cylinder or cone is placed at 90 degrees to the polar axis, it will produce transverse aspect of map projection [Fig. 14.8(b)]. In this case, the Polar Regions will appear in the central part of the map and the graticule will be totally different from that of the conventional type. In case of azimuthal projection, the plane is placed touching the Equator and is more commonly called the *equatorial aspect*.

14.2.4.3 Oblique Aspect

If the axis of the cylinder or the cone or the centre of the plane is located somewhere between the pole and the Equator of the Earth, an oblique aspect is produced [Fig. 14.8(c)]. The oblique projections are applied to mapping of the areas that lie at mid-latitudes.

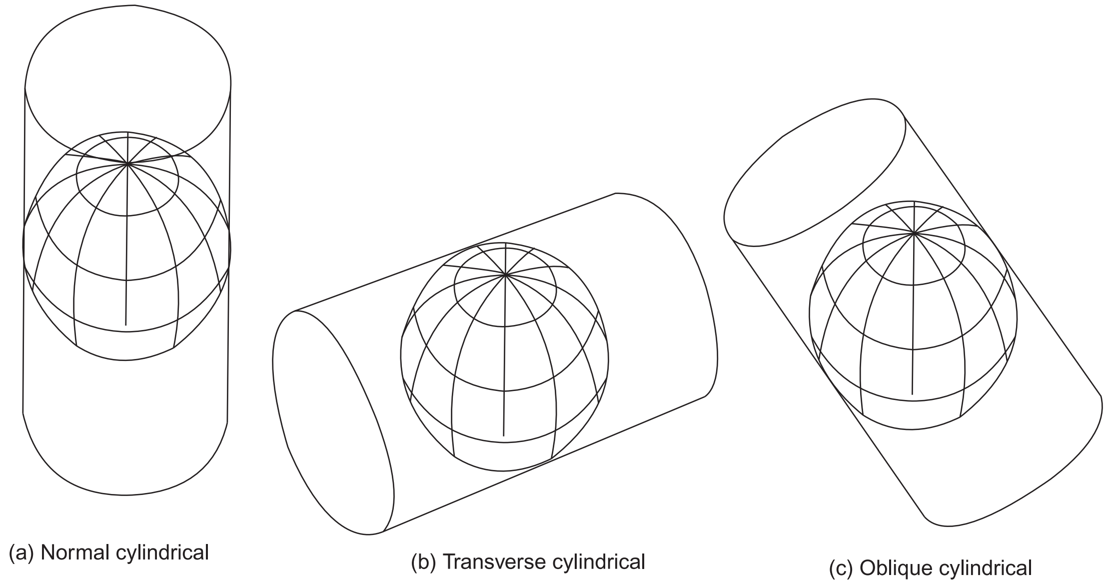


Fig. 14.8 *Aspects of map projection*

The transverse and oblique aspects are transformations of the normal aspect of the map projection so that certain desired properties may be preserved for a particular area to be mapped. A notable example is the Transverse Mercator Projection in which the equator of the projection is rotated by 90 degrees to coincide with the desired central meridian, thus making the central meridian true to scale no matter how far north and south the map extends (thus solving the excessive scale change problem of the regular Mercator Projection as parallels and meridians move north and south away from the Equator), while retaining conformality.

14.2.5 Viewpoints of Map Projection

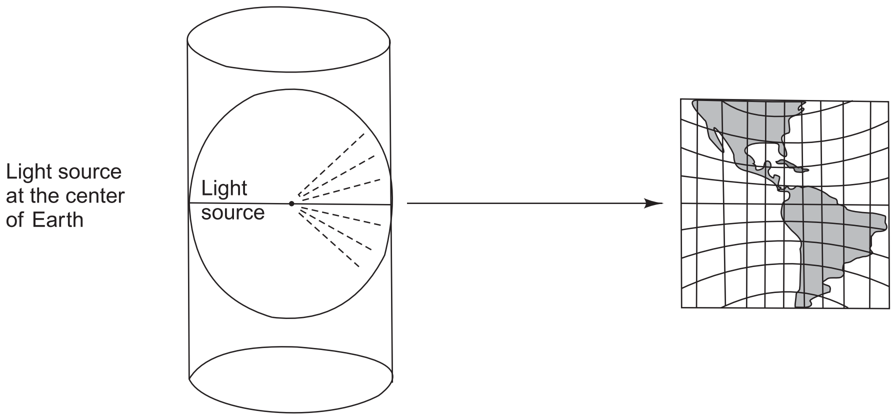
A map projection may be produced from three view points: the light source may be at the centre, at the infinity and on the surface of the globe on the opposite side of the developable surface. This gives rise to three basic variants of map projections.

14.2.5.1 Gnomonic Projection

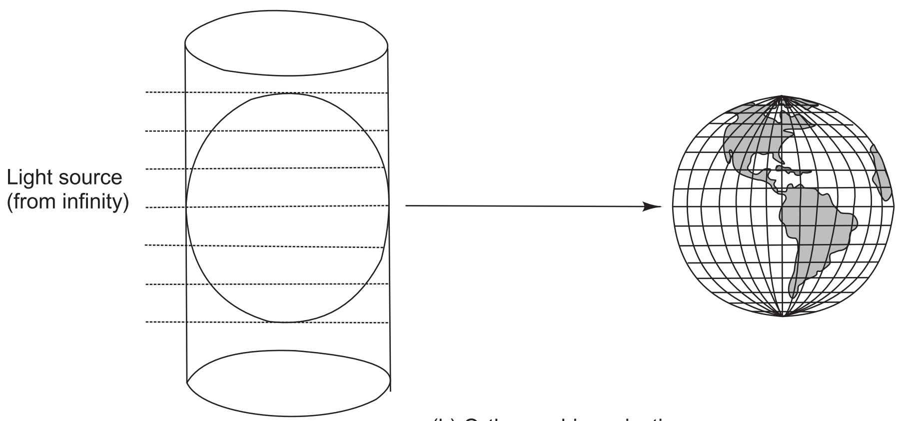
These are projections with the viewpoint (or projection point) at the centre of the globe. Great Circles (meridians) are straight lines [Fig. 14.9(a)], while parallels are curved. Since a great circle is the shortest distance between two points on a sphere, gnomonic projections are used for navigational charts.

14.2.5.2 Orthographic Projection

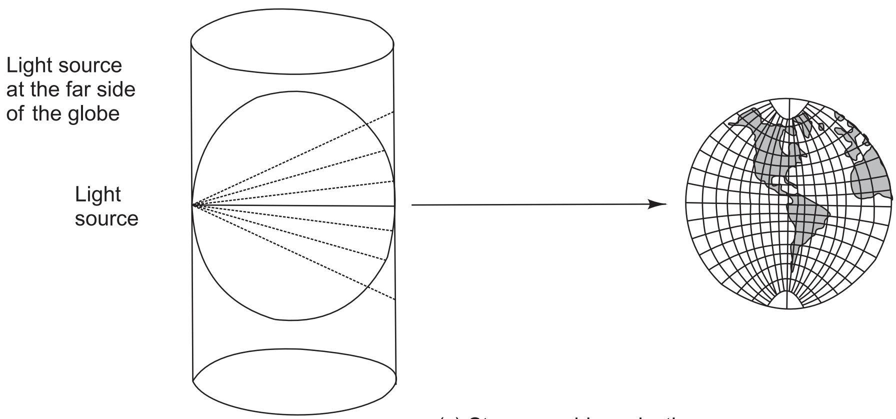
These projections are obtained by placing the view point at infinity. When applied to the planar equatorial case, Earth will appear to be similar to a view from space [Fig. 14.9(b)]. When applied to the cylindrical normal case, the longitudes remain parallel and are at equal distances apart; while the latitudes remain parallel and straight but are at successively decreasing distances apart towards the pole, thus preserving the areas locally.



(a) Gnomonic projection



(b) Orthographic projection



(c) Stereographic projection

Fig. 14.9 *Map projections from different view points*

14.2.5.3 Stereographic Projection

Stereographic projections are projections obtained by placing the viewpoint on the surface at the far side of the globe. When applied to the planar equatorial case, both latitudes and longitudes appear to be curved lines. However, since the projected latitudes and longitudes intersect at almost 90 degrees, the shape property is preserved for small areas around the intersections. Therefore, stereographic planar projections are conformal projections. When applied to the cylindrical normal case, the longitudes will remain parallel and are at equal distances apart; while the latitudes will remain parallel but are at successively decreasing distances apart towards the equator [Fig. 14.9(c)]. By using two standard parallels, it minimizes distortions around the equator.

14.3 SOME USEFUL PROJECTIONS

14.3.1 Mercator's Projection

This is one of the most renowned and familiar of all map projections. In this projection, the axis of the cylinder is coincident with the axis of the earth and cylinder itself is tangent to the equator, hence this is a normal case. Spacing of the parallels is adjusted in such a way that *the scale along the meridian at any particular point is equal to the scale along the parallel at that point*. Since all meridians intersect all parallels at right angles, this adjustment of scale serves to make the projection orthomorphic. Shape of small area is sensibly correct, but areas become grossly exaggerated away from the equator i.e. in high latitudes.

In spite of the above disadvantages, this projection is of great value because it possesses one very important property, namely, *that a straight line on the projection is a line of constant bearing*. Because of this property, Mercator's projection is widely used for the construction of navigational charts, both Marine Survey and Aeronautical Charts. This is also popular for world maps of all kinds.

14.3.2 Transverse Mercator Projection

This is a cylindrical projection in which the cylinder touches the globe along a meridian i.e. transverse to the Mercator's projection. This is an excellent projection for countries of *limited extent from east to west*. In transverse Mercator projection, the meridians and parallels intersect one another at right angles, the central meridian being a straight line. The graticule can be plotted by rectangular co-ordinates by laying down the point of intersection of various meridians and parallels. Magnification of distance and area becomes greater as distance from the central meridian is increased and only small areas retain their true shape. But, if the country (say of the size of U.P.) is *within a narrow longitudinal belt* and meridian, is chosen carefully, scale, shape, area and bearing are all projected with very little, if any, distortion and an almost perfect map is produced. This is an **orthomorphic** projection.

14.3.3 Universal Transverse Mercator (UTM) Projection

UTM projections have been used to cover the whole world using 60 standard meridians dividing the world in zones of 6^o wide between the standard meridians. The projection is on WGS 84 (World Geodetic System 1984) ellipsoid. Survey of India has adapted a new National Map Policy wherein all the maps on 1:50,000 scale have been digitized by converting them to WGS 84 ellipsoid and UTM map projection. In the process a seamless map data is being generated.

UTM projection is different from the regular Transverse Mercator projection in the following ways:

1. The projection is applied repeatedly by using multiple cylinders that touch the globe at 6° intervals, resulting in 60 projection zones each having a width of 6° longitudes (Fig. 14.10).

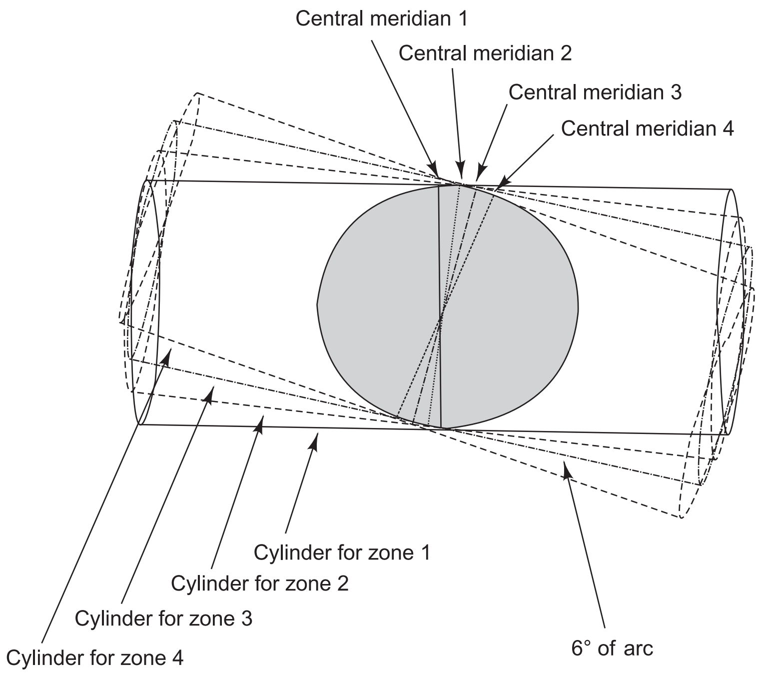
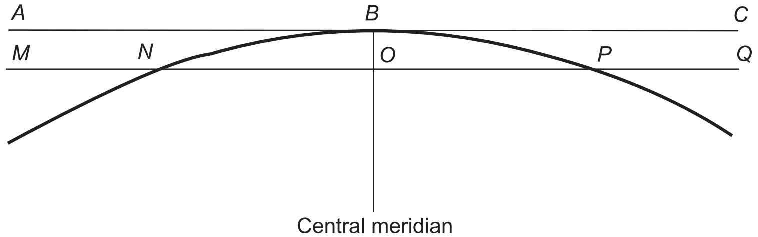


Fig. 14.10 *Universal transverse mercator (UTM) projection*

2. In order to avoid the extreme distortions, occurring in the polar areas, the projection zones are limited at 84° N and 80° S.
3. To improve the overall accuracy of measurements within a projection zone, the cylinder is made to intersect the globe at two standard meridian that are 180 km east and west of the central meridian (i.e. a secant cylinder). This results in true scale at two standard meridians of longitude instead of one along central meridian.
4. To compensate for the scale distortion thus introduced along central meridian, a scale factor of 0.9996 is applied to all measurements in the central part, while a scale factor of 1.0004 is applied to all measurements near the zone boundaries (Fig. 14.11).



For projection plane *AB*, scale is correct at *B*, scale factor at *A* and *C* = 1.008
For projection plane *MQ*, scale is correct at *N* and *P*, scale factor at *O* = 0.9996 and scale factor at *M* and *Q* = 1.0004

Fig. 14.11 *Scale distortions in UTM projection*

The UTM coordinate system is formed by superimposing a regular square grid on each UTM projection zone of 6° longitude width. The grid is aligned so that the vertical lines are parallel to the central meridian. The UTM zones are numbered from 1 to 60, starting at the antemeridian (180° longitude) coinciding with the International Date Line, proceeding from west to east. Thus, zone 1 extends from 180°W to 174° W, with the central meridian at 177° W. North America lies between zone 3 and zone21. India is covered by UTM zones 41 to 46.

Each UTM zone is divided into horizontal bands spanning 8° latitude. These bands are identified by letters, south to north, beginning at 80° S with the letter *C* and ending with the letter *X* at 84° N (Fig. 14.12). The letters *I* and *O* are skipped to avoid confusion with 1 (one) and 0 (zero) of the computer system. The northernmost band *X* has a span of 12° latitude.

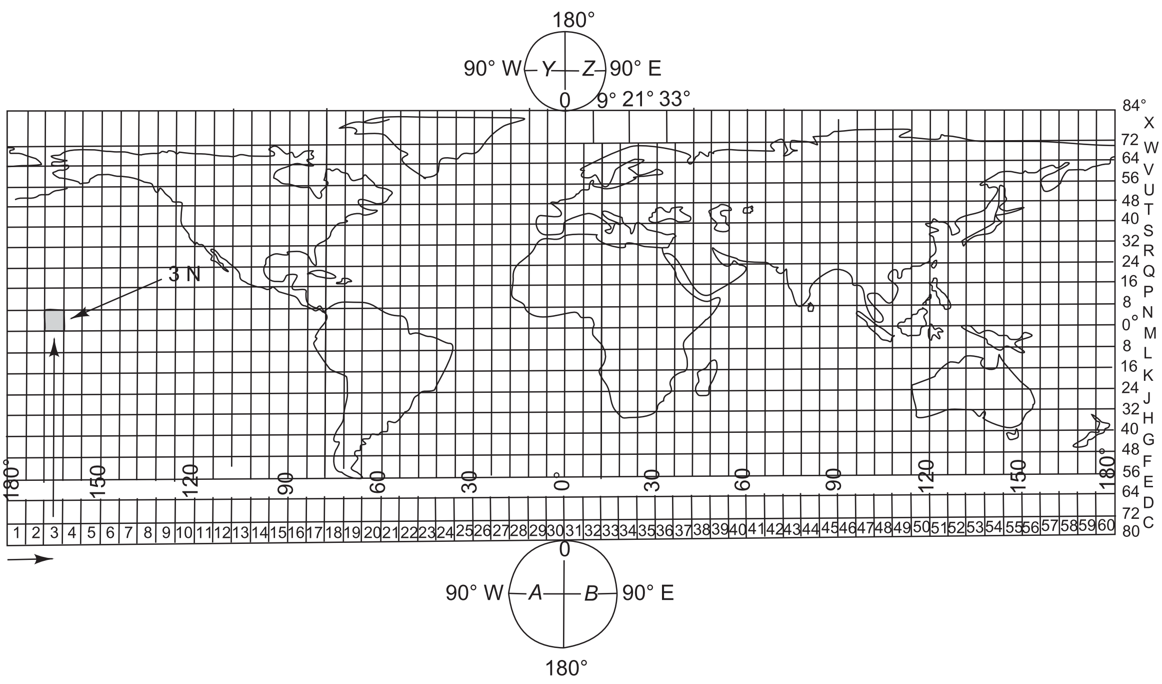


Fig. 14.12 *UTM grid zone designations for the world (shown on equidistant cylindrical projection)*

14.3.4 Indian Map Projection

Indian topographic maps have been based on Polyconic projection. Due to colonial legacy, the same projection is used in the neighboring countries. With the introduction of New Map Policy (NMP) in 2005, the Universal Transverse Mercator (UTM) projection is being adopted for the Open Series Map (OSM), using WGS-84 ellipsoid; while the Defense Series Map (DSM) will remain on Polyconic projection, using Everest 1956 spheroid.

14.3.5 Lambert's Conical Orthomorphic (or Conformal) Projection

In this projection the scale along the meridian is everywhere deliberately made wrong by an amount equal to the inevitable scale error at right angles to the meridian to achieve *orthomorphism*. The scale is deliberately made too small in the centre of the two standard parallels by half the amount by which it would otherwise be. This is an excellent projection for countries with a somewhat limited extent from north to south. This projection is used by Survey of India for all geographical maps in scales 1: 1M and smaller. The Survey of India Auxiliary Tables (1972) includes calculation of distances in this projection for various scales.

14.3.6 Polyconic Projection

This projection belongs to the family of conical projections. It is called Polyconic because several cones are involved in developing this projection. Here each parallel has the same characteristic as the standard parallel of a simple conical projection. The scale along each parallel and along the central meridian is correct. The scale along the other meridians increases away from the central meridian. The parallels are arcs of circles, which are not concentric; while central meridian and equator are straight lines. The projection is very nearly orthomorphic.

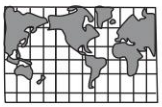
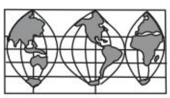
In Survey of India, the projection has been used for topographical maps with longitudes limited to the sheet width so that the distortions are negligible. It has rolling fit with the adjacent topographic maps in E-W direction. Serious errors are introduced in joining adjacent sheets; hence there are problems in preparing seamless data/images in rectangular co-ordinate system, as each sheet is projected separately. Care has to be taken when a large area on this projection is taken for GIS application.

A modification of this is used for the 1/Million International map series. For ease of reference and comparison, the characteristics and major uses of different map projections are summarized in Table 14.1.

14.4 GEOREFERENCING

The primary function of the map is to portray accurately real-world features that occur on the curved surface of the earth. Geographic referencing, which is sometimes simply called as *georeferencing*, is defined as the representation of the location of real-world features within the spatial framework of a particular coordinate system. The objective of georeferencing is to provide a rigid framework by which the position of real world features are measured,

Table 14.1 Common map projections, their properties and major uses (after Chou 1996)

Projection/Construction	*Appearance*	*Properties*	*Major uses*
Albers Equal-Area/Conical	 (a)	Equal area; conformal along standard parallels	Small regional and national maps
Azimuth Equidistant/Planar	 (b)	Equidistant; true directions from map center	Air and sea navigation charts; equitorial and polar area large-scale maps
Equidistant Conic/Conical	 (c)	Equidistant along standard parallel and central meridian	Regional mapping of midlatitude areas with east-west extent; atlas maps for small countries
Lambert Conformal Conic/Conical	 (d)	Conformal; true local directions	Navigation charts; U.S. State Plane Coordinate System (SPCS) for all east-west State Plane Zones, continental U.S. maps; Canadian maps
Mercator/Cylindrical	 (e)	Conformal; true direction	Navigation charts; conformal world maps
Polyconic/Conical	 (f)	Equidistant along each standard parallel and central meridian	Topographic maps; USGS 7.5 - and 15-minute quadrangles
Robinson/ Pseudo-Cylindrical	 (g)	Compromise between properties	Thematic world maps
Sinusoidal/ Pseudo-Cylindrical	 (h)	Equal area; local directions correct along central meridian and equator	World maps and continental maps
Stereographic/Planar	 (I)	Conformal; true directions from map center	Navigation charts; polar region maps
Transverse Mercator/Cylindrical	 (j)	Conformal; true local directions	Topographic mapping for areas with north-south extent; U.S. State Plane Coordinate System (SPCS) for all north-south State Plane Zones

computed, recorded, and analyzed. In practice, georeferencing can be seen as a series of concepts and techniques that progressively transform measurements carried out on the irregular surface of Earth to a flat surface of a map. Map data are different from all other forms of data by this characteristic of georeferencing, and the ability to manipulate and analyze georeferenced spatial data is what distinguishes Geographical Information System (GIS) from Computer aided Design (CAD) and other types of computer graphic systems. The concept of georeferencing is illustrated in Fig. 14.13. Georeferencing involves a series of transformations that progressively flatten the irregular surface of the Earth so that measurements on the curved surface on Earth can be represented on flat surface of the map.

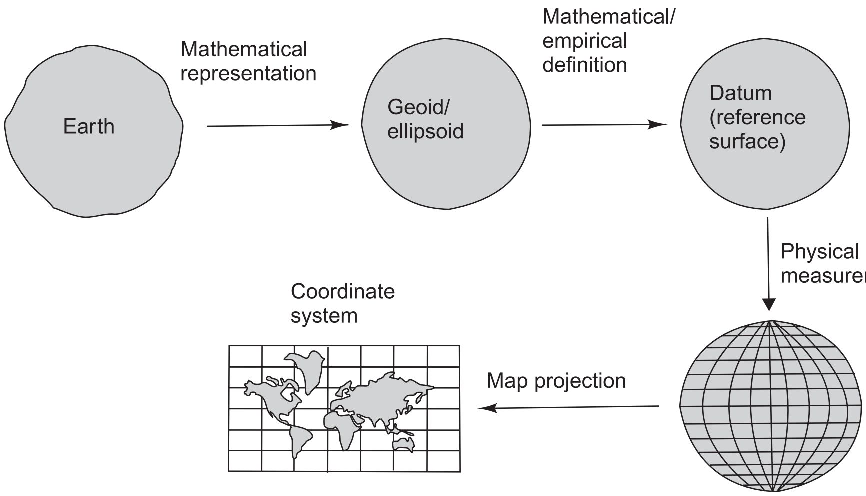


Fig. 14.13 *Concept of georeferencing*

The concept of representing the physical shape of Earth by means of a mathematical surface and the realization of this concept by the definitions of the **geoid** and the **ellipsoid** are fundamental to georeferencing.

14.4.1 Ellipsoid and Geoid Models

So far, we have assumed that the shape of Earth is a perfect sphere. From a geophysical perspective, the shape of Earth is highly irregular. The irregular shape of Earth makes it impossible to transform systematically the geometric relations from the three dimensional surface of Earth to the two dimensional surface of a map without some assumptions.

The ellipsoid-geoid model is the commonly used mathematical surface that represents the shape of Earth. In the context of georeferencing, the ellipsoid and the geoid are two distinct surfaces for different purposes. The ellipsoid is the reference surface for horizontal positions and the Geoid is the reference surface for elevations. The relationships between Earth's irregular surface, the geoid, and the ellipsoid are shown in Fig. 14.14.

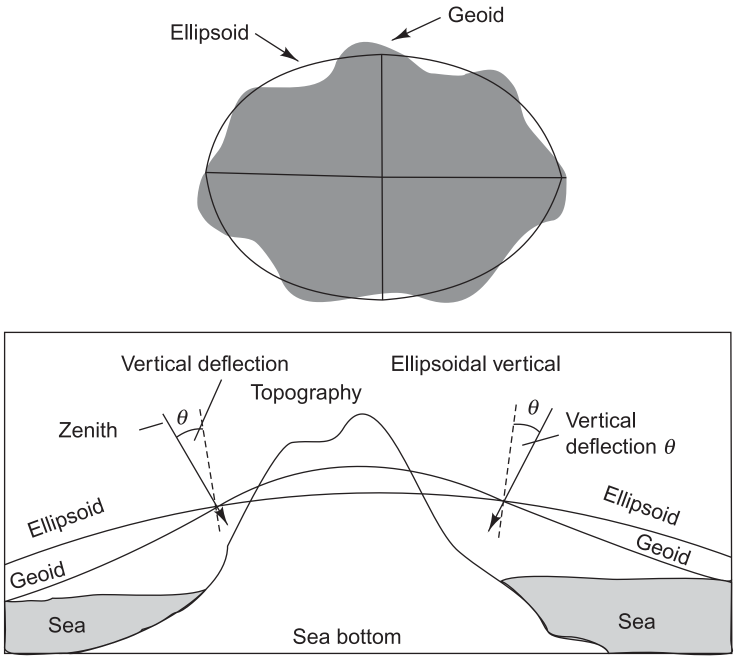
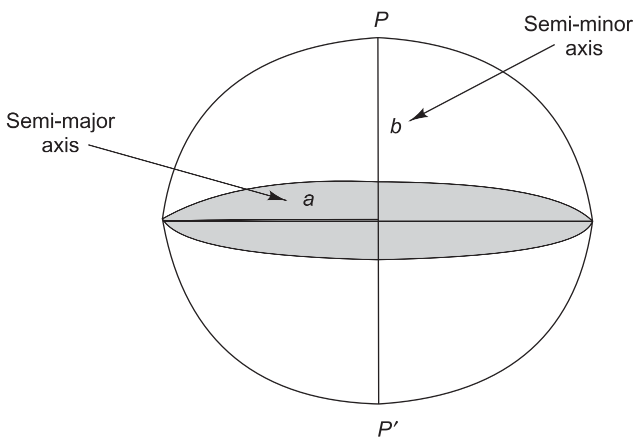


Fig. 14.14 *Relationships between earth's irregular surface, ellipsoid and geoid (after Seeber, 1993)*

14.4.2 Ellipsoid

Earth has been found to be slightly flattened at the poles, and the physical shape of the real Earth is closely approximated by the mathematical surface of the *rotational ellipsoid* or the solid obtained by rotating an ellipse on its minor axis (Seeber, 1993) (Fig. 14.15). The ellipsoid is widely used as the reference surface for horizontal coordinates (latitude and longitude) in geodetic networks. Because the flattening occurs at the poles, the figure may be further defined as an oblate spheroid, with polar radius of 6,356 km and equatorial radius of 6,378 km. The amount of polar flattening can be determined by the following formula:

$$f = (a - b)/a,$$



a = Major semi-axis of ellipsoid = Equatorial radius of the Earth
b = Minor semi-axis of ellipsoid = Polar radius of the Earth
PP′ = Axis of revolution of Earth's ellipsoid

Fig. 14.15 *Major and minor semi-axes of an ellipsoid* where *a* and *b* are the lengths of the major and minor semi-axes of the ellipse, which correspond to the equatorial and polar radii of Earth respectively. The flattening (f) is very close to 1/300. The difference in length between the equatorial and polar radii is about 11.5 km, therefore,. the polar axis is about 23 km shorter than the equatorial axis.

For Everest Datum, the semi major axis (a) = 6377301.243 m or 20922932 ft and semi minor axis (b) = 6356100.231 m or 20853375 ft, thus flattening (f)= 1/300.8017.

Spheroid and ellipsoid are used synonymously. The word spheroid is used in India and Britain while ellipsoid is used in America and Russia.

Since the 18th Century, geodesists have been attempting to determine the polar flattening value that would produce the best Earth-fitting ellipsoid. In the process, tens of ellipsoids were generated. Practically all these early ellipsoids were defined using constants determined by measurements in a particular area of interest, e.g. a country or a continent. Ellipsoids defined in this way could naturally fit well that part of Earth's surface in or around the area of interest but not necessarily in other part of the world. Today, some 30 ellipsoids are in common use. These include, for example, Everest (1830 and 1956), Clarke 1866, International 1924, and Geodetic Reference System (GRS) 1980 (Table 14.2).

Table 14.2 Ellipsoids used in national and regional mapping

Ellipsoid	*Semi-major axis (a) (m)*	*Inverse flattening (1/f)*
Airy 1830	6,377,563.396	299.3249646
Australian National	6,377,340.189	298.25
Clarke 1866	6,378,206.4	294.9786982
Clarke 1880	6,378,249.145	293.465
Everest 1956	6,377,301.243	300.8017
International 1924	6,378,388	297
GRS 80	6,378,137	298.257222101
WGS 84	6,378,137	298.257223563

Since 1960s, new values of equatorial and polar radii have been obtained by satellite based observations. There has also been greater international cooperation in scientific study of the shape of Earth, through organizations such as the International Union of Geodesy and Geophysics (IUGG). These efforts allowed new ellipsoids to be defined. Based on satellite measurements, using centre of the mass of the whole planet Earth as the origin, these ellipsoids are called *geocentric* or *Earth-centered* ellipsoids. As these newly proposed ellipsoids are able to represent the entire Earth more precisely, many countries have adopted them in their georeferencing systems. The USGS has now adopted Geodetic Reference System of 1980 (GRS 80) ellipsoid, originally proposed by IUGG. The Global Positioning System (GPS) is using World Geodetic System 1984 (WGS 84) ellipsoid.

14.4.3 Geoid

The term geoid means earth like. It is the shape of the Earth that would be formed if the oceans were allowed to flow freely under the continents to create single undisrupted global sea level covering the entire planet Earth and adjusted to gravity. Geophysically, the geoid is defined as an *equipotential* surface (i.e. a surface on which the gravity potential is constant everywhere) to which the direction of gravity is everywhere perpendicular. Therefore, the method of determining the geoid, known as geoid modeling, is based on precise measurement of gravity across the continents and around the world. As the densities of Earth's rock constituents vary from one another and are irregularly distributed, readings of gravity measurements tend to vary from place to place. This means that the Earth's equipotential surface and by extension, the geoid, are both irregular surfaces. Since gravitational forces are greater over the continents, where the Earth's crust is thicker, than those over the ocean floor, where the Earth's crust is thinner, the geoid generally rises over the continents and is depressed over the oceans. More locally, the geoid shows various bumps and hollows that can depart from the average smooth surface by as much as 60 m in some instances.

In general, the geoid coincides very well with mean sea level (MSL) in the open oceans that make up most of the Earth's surface. It is based on water flow criterion, as water flows from one potential or energy level to another. The MSL, therefore, represents an equipotential surface (the Geoid surface) and all the elevations in surveying are computed relative to the geoid as represented by the MSL. In other words, geoid is reference surface for vertical coordinates.

Since the ellipsoid is defined entirely by the mathematical method, it is a smooth surface that is different from the geoid obtained by gravity measurements. The separation between these two surfaces at a particular point on Earth's surface is known as *geoid undulation*, *geoid separation*, or *geoid height*. The angle between the perpendicular to the ellipsoid surface and the perpendicular to the geoid surface (i.e. plumb line) is called vertical deflection (Fig. 14.14). The geoid and ellipsoid, in context of vertical and horizontal positions in georeferencing, are called **datum**.

14.4.4 Indian Datum

Initially, the geodetic datum adopted in India was the Everest ellipsoid (1830) which was based on Great Trignometrical Survey (GTS) network, initiated in 1802. Kalyanpur (Latitude 24°07′11.26′N; Longitude 77°39′17.57″E), in Central India, was taken as initial point. The Everest ellipsoid (1830) was subsequently refined and modified after readjustment of the Indian Geodetic Network data existing in 1888. The modified Everest ellipsoid (1956) is being used presently.

The south Asian region was sub divided into four quadrilaterals, namely NW, NE, SE and SW and the southern region for the adjustment. An unsuccessful attempt was made in 1937-38 to readjust the geodetic network. With lot of geodetic data accumulated so far and advanced computational methods available, it is now possible to take up integrated adjustments leading to redefinition of the datum. Serious attempts are being made in this direction. This will certainly improve the accuracy of the datum and thereby higher accuracies in geodetic coordinates, distances, azimuths and gravity anomalies would be possible. Geoid based on mean sea level is used as datum for finding out height of any point.

14.4.5 Mean Sea Level

At tidal observatories, sea level is monitored on continuous basis (or hourly basis). Mean of the measurements of high and low tides over a metonic cycle of 19 years is taken as Mean Sea Level (MSL). It includes all possible changes through 18.67 years period for the regression of moons nodes, which affect sea level changes due to gravitational pull. Averaging of tidal observations over a specific 19 year cycle is part of National Tidal Datum Approach.

In India, the vertical datum for height measurements has been chosen as the Mean Sea Level of a group of nine tidal observatories situated at different Indian ports. Observations at these ports were carried out for a number of years and it was assumed that mean sea level of these ports belong to the same level surface. These ports serve as issue points for the level net. Survey of India has the primary responsibility in this regard. The first level net and the vertical datum were established in 1909. In order to further refine the datum, a second level net was mooted in 1977.

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Frequently Asked Questions

1. What are the basic coordinate systems?
2. Describe Geographic Coordinate System.
3. Describe in brief the similarity and affine transformations.
4. Describe different properties which get changed in a map projection.
5. Classify map projections on the basis of Developable Surface.
6. Classify map projections on the basis of Aspect.
7. Classify map projections on the basis of Viewpoint.
8. Describe different types of Mercator's projection of maps.
9. Describe map projections used by Survey of India.
10. What is Georeferencing? Define Ellipsoid and Geoid.
11. Write short notes on: Indian Datum; Mean Sea Level; UTM Zones.

15

GLOBAL POSITIONING SYSTEM

15.1 INTRODUCTION

Global Positioning System (GPS) started as a navigation tool for ships. It has revolutionized positional concepts and now finds application in various fields viz. geodesy, geophysics, marine, military and social activities, etc.

The most prevalent GPS is NAVSTAR (Navigation Satellite Time and Ranging), developed by Department of Defense (DOD), USA, as a result of prolonged efforts since 1973. The technique was available in 1980 and was adopted in Survey of India in 1990. It is a satellite based radio navigation system providing precise three dimensional positions, navigation and time information to suitably equipped users everywhere in the world on a continuous basis. It is primarily a military system with limited access to civilian users. The system consists of 24 satellites placed in near circular orbits arranged in six orbital planes at 20,200 km altitude (Fig. 15.1). The satellites have 12 hours cycle, so that at least 4 satellites are always available for determining position on ground/sea/air at any time, through out the year anywhere in the world. The GPS receivers have been developed to observe signals transmitted by the satellites and

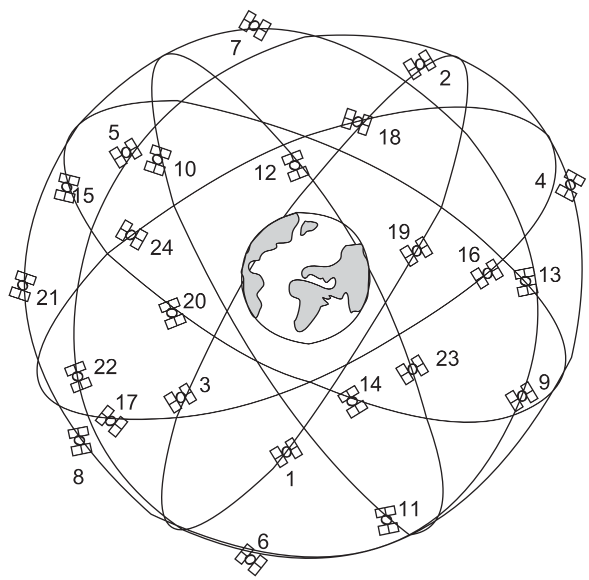

Fig. 15.1 *Satellites in global positioning system (GPS) (after Agarwal, 2006)*

achieve sub-meter accuracy in point positioning and a few centimeters in relative positioning. The basic principle of positioning with GPS is illustrated in Fig. 15.2. The Global Positioning System has following advantages over the classical methods:

(a) All weather, day and night operation
(b) Intervisibility between points is not required
(c) Distance up to thousands of kilometer can be measured
(d) Fast and economical

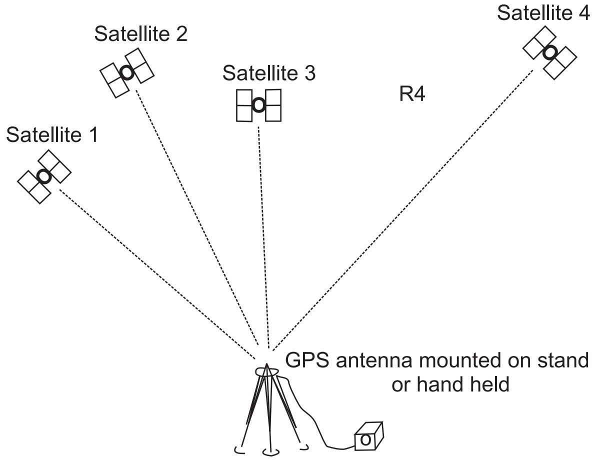

Fig. 15.2 *Basic principle of positioning with GPS*

15.2 COMPONENTS OF GPS

The system has three distinct segments: space segment, control segment and user segment. These are described below.

15.2.1 Space Segment

The space segment consists of 24 satellites including three active spares. These satellites are placed in near circular orbits at an altitude of 20,200 km above the earth surface. The satellites are placed in six orbital planes inclined at 55 degrees. The orbital period is 12 hours of sidereal time and provides repeated satellite configurations every day, four minutes earlier with respect to universal time. The signal is transmitted from each satellite on L1 and L2 band carrier waves (wavelength 19.05 and 24.45 cm and frequency 1575 and 1227 MHZ, respectively). Navigation and system data including satellite ephemeris, atmospheric propagation correction data and satellite clock bias information is superimposed on these signals. On board power supply is managed by two solar energy panels that continuously track the sun and charge three batteries for use when the earth eclipses the sun. Each GPS satellite is provided with propulsion system for maintaining orbital position and for stability control.

15.2.2 Control Segment

The tasks of control segment are:

to monitor and control the satellite on continuous basis

to predict the satellite ephimerides and monitor satellite clocks, and

to update periodically the navigation message for each satellite.

The control segment consists of Master Control Station (MCS), several Monitor Stations (MS) located around the world, and Ground Antennas (GAs) for uploading data on to the satellites.

The monitor stations receive all satellite signals. Using these signals, the MSs determine pseudo ranges of all visible satellites and transmit the range data along with the local meteorological data to MCS. From these data, the Master Control Station precomputes satellite ephimerides and the behavior of the satellite clocks. The MCS then formulates navigation data (message), which are transmitted to the ground antennas (GAs) and up linked through S-band to the satellites in view.

15.2.3 User Segment

A GPS receiver is required for receiving signals from GPS satellites, for navigation and positioning purposes. A large number of manufacturers of GPS receivers with hundreds of models are available in the market, ranging in price between Rs. 5,000 and Rs. 100,000. Garmin, Magellan, BlackBerry, Brunton, Suunto, Lowrance are some of the popular brands. SXblue III-L is the latest and smallest GPS receiver from OmniSTAR.

The receiver system includes the following components:

(a) Antenna with preamplifier
(b) Radio Frequency (RF) section with signal identification and signal processing (channel)
(c) Microprocessor for receiver control, data sampling, data processing (navigation solution)
(d) Precision oscillator
(e) Power supply
(f) User interface, command and display system
(g) Memory, data storage

The antenna has to be very sensitive and circularly polarized in order to receive rather weak satellite signals from all elevations and azimuths of the visible hemisphere.

15.3 OPERATIONAL PRINCIPLE

NAVSTAR GPS is a one way ranging system and operates on the signal travel time between satellite antenna and receiver antenna, scaled into range measurement using propagation velocity of the signal.

15.3.1 Pseudo-range

One way ranging means that a clock reading of transmitter antenna is compared with the clock reading of the receiver antenna. However, it can not be assured that the two clocks are strictly synchronized. Thus the observed signal travel time contains a systematic synchronization error, also known as time bias. The ranges derived with time bias are called pseudo-ranges. Therefore, the GPS basically determines pseudo-ranges. Simultaneous observation of four pseudo-ranges is required to derive three coordinates of the object (user antenna) and the clock synchronization error. However, it is also necessary to know satellite position and satellite time.

15.3.2 PRN Codes

In order to get positions of objects in real time through the GPS, the carrier wave (signal) is modulated with pseudo-random noise (PRN) codes. These are sequences of binary values (0 and 1 or +1 and –1) which appear to have random character but are unequivocally identified. The pseudo-ranges are derived from the travel time of an identified PRN coded signal. Presently, two different codes are in use. These are:

(i) P-code, which means precision or protected code, and
(ii) C/A code, which means clear/acquisition code. This code is also known as S code or standard code.

In order to determine the signal propagation time, the user needs a copy of the code sequence in his receiver. The code sequence is shifted in time step and correlated with received code signal till best fit is achieved. The shift in the two sequences gives a measure of signal travel time between the satellite and receiver antennas (Fig. 15.3).

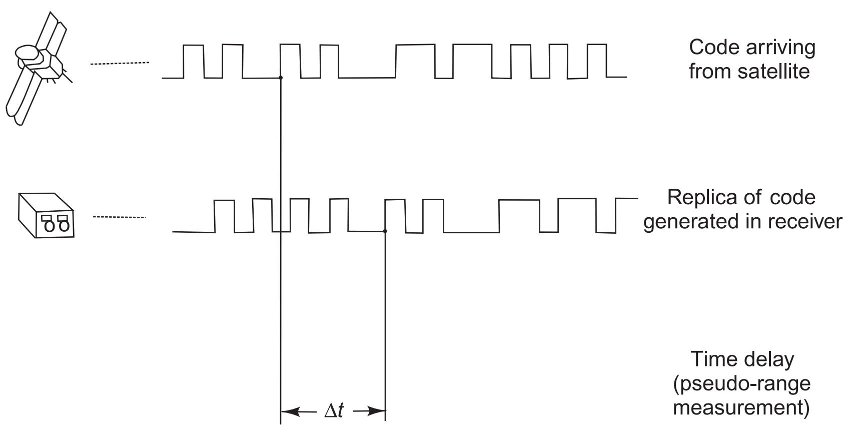

Fig. 15.3 *Pseudo-range measurements*

For precise geodetic applications, the pseudo-ranges have to be derived from phase measurements on the carrier signals because of their better resolution (Fig. 15.4). This technique, however, requires a solution to the problem of ambiguity determination.

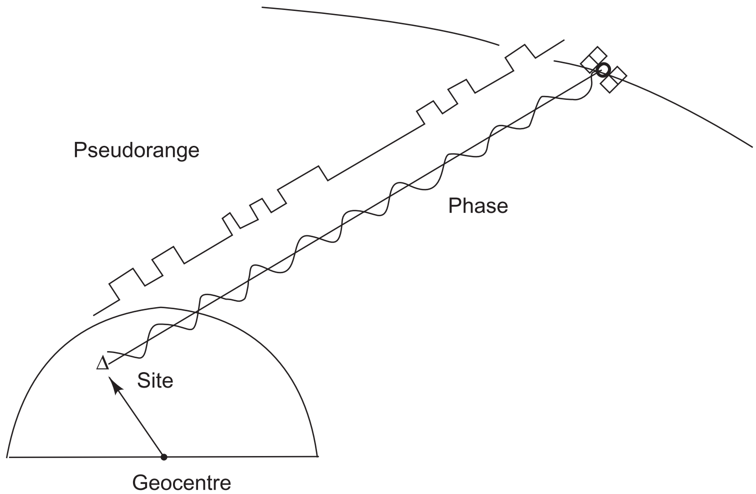

Fig. 15.4 *Pseudo-range and phase measurements*

15.3.3 Solution of Ambiguity

Carrier phase measurements are affected by an unknown number of complete wavelengths, present between satellite and the receiver antennas, known as ambiguity. This needs to be solved if GPS observations are to be made accurate. The main approaches to solve the ambiguity problem are:

(a) Geometric method
(b) Code and carrier phase combinations
(c) Ambiguity search method
(d) Combined method

These methods have their advantages and limitations and a particular approach is selected depending on the requirement of the user.

15.3.4 Jamming of Signal

GPS is an excellent tool for military and civilian applications. During war, it is used not only for navigation but hitting opportunity targets and other surgical operations. Therefore, jamming of GPS signals is an important military operation, taken recourse to by either side. Depending upon the internal and external threat perceptions, US Department of Defense can resort to theatre jamming of the L1 signals to deny adversaries the use of GPS. P-code is exclusively used for defense purposes and is denied to civilian users by Anti Spoofing. An unintentional jamming may also occur from neighboring users of the radio spectrum. Civilian GPS receivers are more vulnerable to jamming like the other radio navigation systems. Awareness about jamming of the signals, intentional or unintentional, could help in averting the serious consequences and safety threats. For using GPS in various applications, a note of caution is necessary to cope up with this hazard.

15.4 FACTS AND LIMITATIONS OF GPS

The facts and limitations of GPS are discussed in the following broad categories:

(a) System accuracy
(b) Receiver independent exchange format
(c) Reference system coordinates

15.4.1 System Accuracy

GPS is a military navigation system developed by the US Department of Defense (DOD) to meet national security requirements of the United States. Accordingly, a limited access to the total system accuracy would be available to the national and international civil user community. After due deliberations in 1993, the USDOD has decided that only 'Standard Positioning Service' (SPS) will be available to civilian users whereas 'Precise Positioning System' (PPS) is reserved for authorized (mainly military) users. Under the policy, the accuracy available to SPS users is 100 m 2D-RFS (Radio Frequency Section), meaning thereby that a horizontal two dimensional position accuracy of about 100 meters can be expected by a stand alone system. PPS provides full system accuracy of 10 to 20 meters in three dimensions. To achieve this, two modes of limitations are activated: (i) Anti Spoofing (AS) and (ii) Selective Availability (SA).

15.4.1.1 Anti Spoofing

This entails encryption of a protected code named Y-code, which is accessible to authorized users as AS is activated. However, subsequent developments in GPS receiver technology lead to overcome this hurdle and better accuracies were possible to achieve.

15.4.1.2 Selective Availability

Since limiting the accuracy to SPS users could not be achieved by AS technique, a programme called Selective Availability (SA) was developed. The SA programme uses (i) Ephemeris data manipulation and (ii) Dithering or systematic destabilizing of the satellite clock. Both these techniques introduced errors in the measurement of pseudo-ranges, thereby limiting the accuracy to the SPS users. However, fast growing services, provided at governmental, civilian and commercial levels, are using other sources for precise determination of orbital ephemeris. Likewise, clock dithering can be completely removed in differential operations. Under the circumstances, the SA programme has been discontinued. Now the accuracy of about 15 to 20 meters is possible in point positioning mode with Standard code and 3 to 5 meters with P-code.

15.4.2 Receiver Independent Exchange Format

Each receiver type has its own binary data format and defined observables. Time tags are defined in transmission time or in fractional parts of cycles; codes and phase may have different or identical time tags, and satellites may be observed simultaneously or at different epochs. Consequently, data of different receiver types can not be easily processed with a single GPS data processing software package. To solve this problem, either all manufacturers should use the same data output format, or a common data format has to be defined that can be used as an interface between all geodetic receiver types and different data processing software systems. A common data format, namely 'Receiver Independent Exchange (RINEX) format, was developed in 1989. It has been accepted by the international user community and the receiver manufacturers.

For most geodetic receivers, translator software is provided by the manufacturer that converts data obtained by receiver into the RINEX format. Likewise all major data processing software require RINEX as data input. Hence, RINEX serves as a general interface between receivers and multipurpose data processing software. The users are advised, while buying GPS receiver, to ensure that the manufacturer provides the translator software which can convert the receiver data into RINEX format.

15.4.3 Reference System Coordinate

GPS operates on a well defined World Geodetic System 1984 (WGS 84). Therefore, coordinates obtained through GPS receiver pertain to WGS 84 datum. However, all national maps are on local geodetic datum (Everest spheroid in India). Coordinates obtained through GPS may, therefore, differ from the national system coordinates (on local datum) up to 100 meters or even more. It is possible to transform the coordinates from WGS 84 to Everest through transformation parameters. However, it is difficult to get transformation parameters due to restricted nature of the maps in Indian situation and the user should be aware of this problem and the accuracy constraints arising thereof. One solution for precise positioning could be to use two GPS receivers and measure vectors between two points in relative positioning mode. The other solution, for slightly less accurate positioning, is to use two receivers keeping one of them fixed at a known station in local geodetic datum and get the constrained solution of another point in the same system.

15.5 GPS RECEIVERS

GPS receivers can be grouped into various categories using different criteria. On the basis of available data types and their output, these are grouped as receivers with:

(i) C/A-code
(ii) C/A-code + L1 carrier phase
(iii) C/A-code + L1 carrier phase + L2 carrier phase
(iv) C/A-code + P-code + L1, L2 carrier phases
(v) L1 carrier phase (not frequently used)
(vi) L2 carrier phase (not frequently used)

On the basis of availability of channels, receivers are grouped as:

(i) Multichannel receiver
(ii) Sequential receiver
(iii) Multiplexing receiver

Finally the receivers can be classified on the basis of their application. These are:

(i) Military receiver

(ii) Civilian receiver

(iii) Navigation receiver

(iv) Timing receiver

(v) Geodetic receiver

For geodetic application the GPS receiver should have both L1 and L2 carrier phase data as observables. It is essential to have access to P-code, at least for larger distances and in geographical regions with strong ionospheric disturbances (low and high latitudes).

There has been a fast development in the manufacturing of GPS receivers. Further developments will include the possibility to track all visible satellites, to provide all information on both frequencies (full wavelength), to decrease noise level in code and phase measurement and to guarantee full operational capability with activated AS. Receivers will be further miniaturized, with higher performance and reduced costs. Some of the important features for selecting GPS receiver are:

(i) Tracking of all satellites

(ii) Both L1 and L2 frequencies

(iii) Full wavelength on L2

(iv) Low phase noise

(v) Low code noise

(vi) High sampling rate for L1 and L2

(vii) High memory capacity

(viii) Low power consumption

(ix) Full operational capability under AS

A dual frequency receiver is recommended for applications in geodesy and surveying because of ionospheric disturbances and advantage in ambiguity resolution. Survey of India is a major user of GPS in geodetic surveying and latest information regarding the technique and receiver can be obtained from its Geodesy and Research Branch at Dehra Dun. Survey Training Institute at Hyderabad conducts a number of courses in GPS. It is advantageous to consult Survey of India and other experts before placing order for GPS receivers. GPS world buyers' guide, published in 'GPS World' every year in January issue, provides up-to-date information.

A very large market is developing for navigation receivers. Hand-held receivers are becoming popular for updating maps and navigational applications. Position and velocity of moving objects are derived from C/A code pseudo-range measurements and can be displayed on a computer screen. Relative accuracy, between 3 and 5 meters, is considered sufficient for integrating data in GIS system or for locating control points on satellite imagery. Sub-meter accuracy can be obtained with optional carrier phase module.

15.6 TOTAL STATION SURVEYS

A total station is an electronic/optical instrument used in modern surveying. The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point. Robotic total stations allow the operator to control the instrument from a distance via remote control. This eliminates the need for an assistant staff member as the operator holds the reflector and controls the total station from the observed point.

Normally, determining coordinates of the locations surveyed by a Total Station requires a direct line of sight between the two points. Angles and distances are measured from the total station to points under survey, and the coordinates (X, Y, and Z or northing, easting and elevation) of surveyed points relative to the total station position are calculated using trigonometry and triangulation. Modern Total Stations are now having a GPS interface which does not require a direct line of sight to determine coordinates. However, such measurements may require longer occupation periods and offer relatively poor accuracy in the vertical axis.

Most modern total station instruments measure angles by means of electro-optical scanning of extremely precise digital bar-codes etched on rotating glass cylinders or discs within the instrument. The best quality total stations are capable of measuring angles to 0.5 arc-second. Inexpensive "construction grade" total stations can generally measure angles to 5 or 10 arc-seconds.

Measurement of distance is accomplished with a modulated microwave or infrared carrier signal, generated by a small solid-state emitter within the instrument's optical path, and reflected by a prism reflector or the object under survey. The modulation pattern in the returning signal is read and interpreted by the computer in the total station. The distance is determined by emitting and receiving multiple frequencies, and determining the integer number of wavelengths to the target for each frequency. Most total stations use purpose-built glass corner cube prism reflectors for the EDM signal. A typical total station can measure distances with an accuracy of about 1.5 millimeters over a distance of up to 1,500 meters.

Some models include internal electronic data storage to record distance, horizontal angle, and vertical angle measured, while other models are equipped to write these measurements to an external data collector, such as a hand-held computer. When data is downloaded from a total station onto a computer, application software can be used to compute results and generate a map of the surveyed area. The new generation of total stations (e.g. Hilti POS 15/18) can also show the map on the touch-screen of the instrument right after measuring the points. A typical Total Station for surveying is shown in Fig. 15.5 (see color figure).

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Frequently Asked Questions

1. What is Global Positioning System (GPS)? Describe its different segments.
2. Describe the operating principle of GPS.
3. Write short notes on: Pseudo-range; PRN Code; Solution of Ambiguity; Anti Spoofing; Selective Availability; RINEX Format; Total Survey Station.
4. Describe measurement accuracy and limitations of GPS.
5. Describe different types of GPS Receivers available and their usage.

16

DIFFERENTIAL GPS

16.1 INTRODUCTION

Differential GPS (DGPS) requires two GPS receivers to have better positional accuracy. If one receiver is set up at a known location, called reference point, it's computed position through GPS can be compared. The difference in position is due to pseudo-range modeling error and is called differential corrections. These corrections are transmitted to the other receiver or rover (moving receiver), observing the same set of satellites, to correct the measured pseudo-range, before computing the coordinates of the new location. The definitions of Point positioning, Relative positioning and DGPS are given below for clear understanding.

16.1.1 Point Positioning

In point positioning, the coordinates of a point is determined by single GPS receiver by observing four or more satellites (Fig. 16.1). This is also known as absolute positioning.

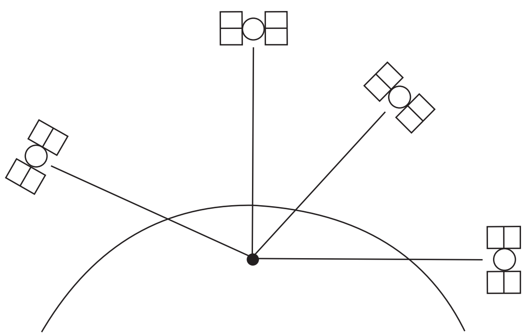

Fig. 16.1 *Point positioning*

16.1.2 Relative Positioning

In relative positioning the coordinates of an unknown point is determined with respect to a known point. The vector between the two points (base line concept) is determined by observing four or more satellites by two receivers, placed at these points, simultaneously (Fig. 16.2).

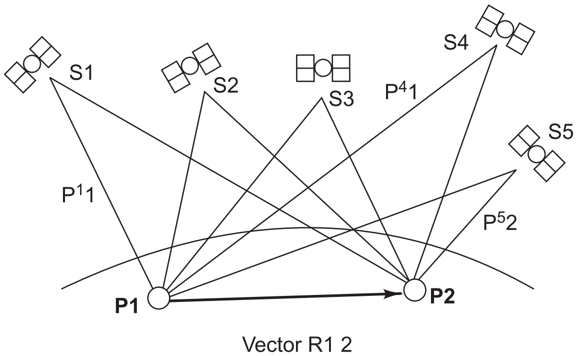

Fig. 16.2 *Relative positioning*

16.1.3 Differential GPS

In DGPS, the differences between computed and observed position, known as differential correction, at a reference point, is transmitted to the receiver at another point to improve its positional accuracy (Fig. 16.3).

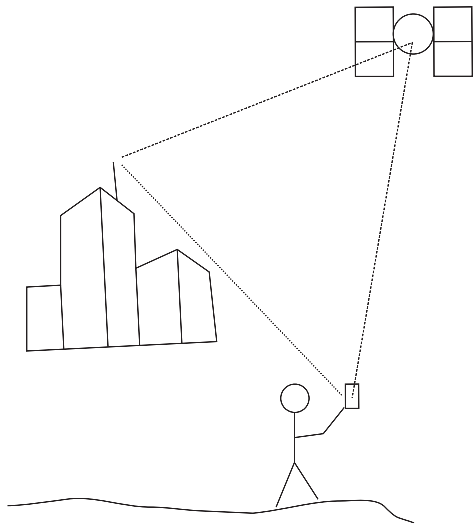

Fig. 16.3 *Differential GPS (DGPS)*

The DGPS is mainly a navigation system wherein there is a fixed reference station and the coordinates of the moving station or rover are determined in real time. Relative observations with code phase or carrier smoothed phases are made simultaneously. Differences are computed at the reference station between the known position and observed position in point positioning mode. Alternatively, the difference between observed pseudo-range and computed pseudo-range from transmitted satellite coordinates and known coordinates of the reference point is computed. These differential corrections are transmitted to the rover station where the user receiver computes navigation solution by using these corrections (Fig. 16.4).

The corrections are transmitted via radio data link or satellite communication link. A generally agreed format for transmission of corrections is the RTCM (Radio Technical Committee for Marine service) message format. It has a data rate of 50 baud (bit per second).

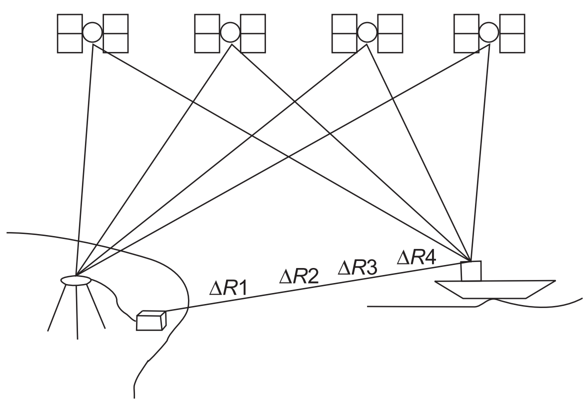

Fig. 16.4 *Transmission of range corrections to mobile users*

16.2 DGPS CONCEPTS

Different concept used in DGPS for real time applications are:

(i) Transmission of coordinate corrections
(ii) Transmission of pseudo-range corrections
(iii) Transmission of the complete data stream (code and carrier phase data)

16.2.1 Coordinate Corrections

Easiest way of using DGPS is by the mode of coordinate corrections. However, care has to be taken that both the receivers are tracking the same set of satellites, especially when the distances are large. Introduction of errors up to 10 meters are possible if the same set of satellites are not tracked. The accuracy decreases with increasing distances.

16.2.2 Pseudo-range Corrections

The mode of pseudo-range corrections is used in most of the DGPS services. In this concept the reference receiver tracks all visible satellites. The observed ranges are compared with computed ranges, based on satellite broadcast and known coordinates of reference station. The differences (pseudo-range corrections) are transmitted to the rover receiver, which corrects its observations utilizing these corrections. The accuracy achievable in this mode is about 2 to 3 meters.

High performance algorithms, based on a combination of code and carrier phase observations, are now available. The carrier phase observations are considered as time differenced pseudo-ranges with a much higher level of accuracy than the pseudo-ranges from code observation alone. A combination of both observations with proper weightage yields smooth series of pseudo-ranges.

16.2.3 Complete Data Stream

In this concept the complete data from code and carrier phases are transmitted to the rover station for position solution. In this method, carrier phases are primary observables and the ambiguities are resolved using code phase data and other methods. An accuracy of 10 cm or better is achievable. The method is also known as *pure Kinematic mode*.

16.3 TYPES OF DGPS

Many types of Differential GPS are utilized in various applications. These are described below.

16.3.1 Local Area DGPS

The DGPS system utilizing a single reference station to transmit differential corrections for each satellite to the user receiver, is known as Local Area DGPS. If the time in receiving the corrections is within ten seconds, the accuracy is likely to be between 1 to 5 meters (Fig. 16.5).

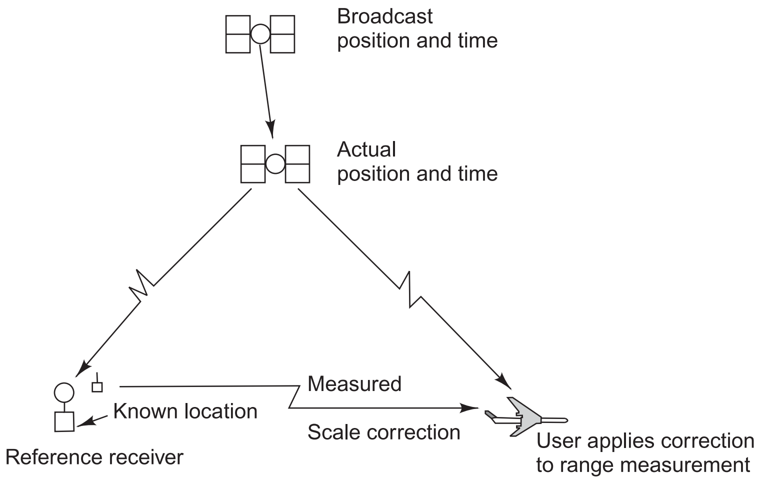

Fig. 16.5 *Local area DGPS concept*

16.3.2 Wide Area DGPS

In Wide Area DGPS a network of reference stations is used to get vector corrections for each satellite. These errors include vector position error, clock bias and ionospheric corrections, which are transmitted to the user receiver. The accuracy of the system depends on the latency of the corrections. Latency is the total time from the reference station measurement of error to the application in the user receiver, including transmission time and calculation delays. Such a network is used for continental or world wide coverage (Fig. 16.6).

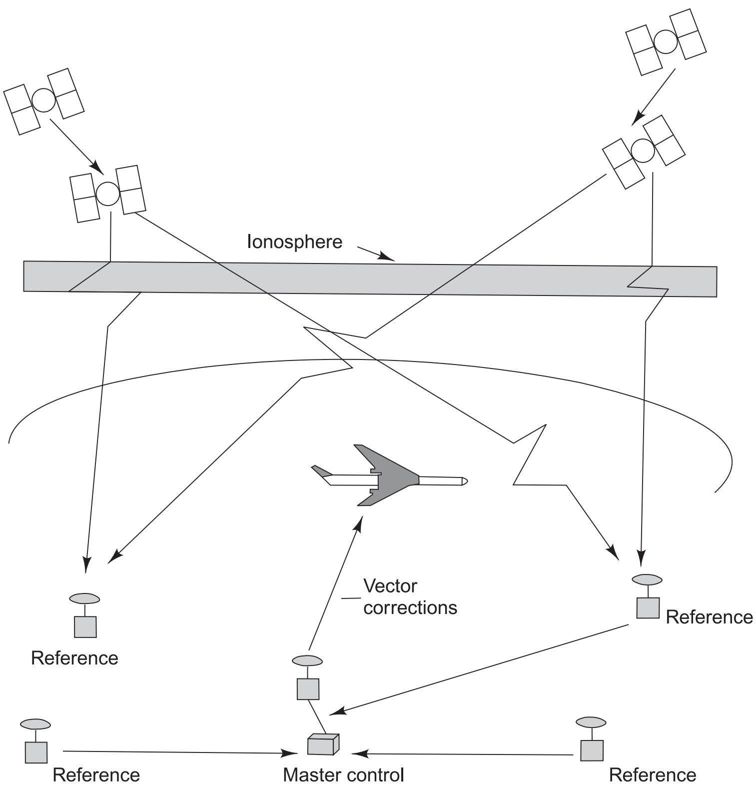

Fig. 16.6 *Wide area DGPS concept (after Agarwal 2006)*

16.3.3 Carrier Phase DGPS

In geodetic surveying, etc. where stringent accuracy is required, Carrier Phase DGPS system is employed. In this system, carrier phase of the user receiver is measured and compared with the carrier phase measurement of the reference station receiver. This process can achieve range measurement precision up to cm level. However, the estimated position is ambiguous due to unknown number of wavelengths, known as ambiguity, which needs to be resolved to get the correct position.

16.3.4 GPS Pseudolites

Pseudolites are ground based transmitters that can emit GPS like signals for enhancing accuracy in positioning and navigation. A pseudolite transmits signal with code phase, carrier phase and data components with the same timing as the satellite signal and in similar format. The rover receiver acquires the signal and derives code and carrier phase pseudo-ranges to be used in the navigational algorithm. As compared to the satellite, a pseudolite does not have precise atomic clock and its position is given in geographical parameters instead of orbital elements.

Pseudolites can be located on high towers, high building rooftops or any elevated location in the vicinity of the area to be surveyed. The angles measured by pseudolite is low as compared to GPS satellites. Such pseudolites strengthen determination of positional geometry, especially in height direction. Thus the height accuracy is improved by 'Vertical Dilution of Precision (VDOP)'. This is important in aircraft precision approach and landing. Pseudolites may also facilitate ambiguity resolution. India is acquiring this facility for its major international airports. The advantages of pseudolite system are enumerated below:

1. Provides increased accuracy in positioning and navigation
2. Monitoring integrity of GPS satellites
3. Pseudolites can be linked to support DGPS to enhance its accuracy
4. Serves as additional ranging source
5. Pseudolites can be designed to self determine their own locations.

Typical applications of Pseudolites are as follows:

1. Can be used as indoor/outdoor local positioning system
2. Personnel tracking system
3. Mobile object tracking and control system in large factories
4. Precision harbour entry
5. Aircraft precision landing system
6. Agricultural automation (precision farming)
7. Heavy industry control in dangerous areas
8. Open pit mining
9. Military and special applications

16.3.5 DGPS Data Link and Programmes

The following data links and programmes are being developed by different countries.

16.3.5.1 LAAS

The Local Area Augmentation System (LAAS) is being installed at US airports by the Federal Aviation Administration (FAA) of the United States. The system is designed to provide accurate approach and landing facility. This will increase domestic air space capacity, improve on timely arrivals in adverse weather conditions and monitor surface vehicles at the airports. The LAAS transmits high accuracy real time differential corrections through VHF broadcasts from reference station covering distances of about 30 km from the airport.

16.3.5.2 WAAS

GPS Wide Area Augmentation System (WAAS) is being developed in USA. The system will use INMARSAT-3 satellites and cover very large areas. Russia is developing Russian Differential System (RDS), Wide Area Differential System (WADS) and Local Area Differential System (LADS). Local DGPS and or Coastal DGPS already exist in many countries. Global DGPS is likely to be available soon for worldwide use.

16.3.5.3 Other Programmes

Ministry of Defence of Russian Federation is developing a Global Satellite Navigation System (GLONASS), although not fully operational due to lack of full 24 satellite constellation in orbit. The objective of the system is to continuously provide coordinates and time information. China is also developing its Beidou Navigation System, which may have mixed geostationary and medium orbit earth satellites.

In addition European Union has proposed Global Navigation Satellite System (GNSS) under Galileo Programme. The programme will have 28 mid orbit earth satellites at 23,616 km, having orbital planes inclined at 56^o angle, and 8 geosynchronous satellites. It will have more power and higher band width as compared to NAVSTAR.

GPS, and will have a network of ground control stations in order to provide worldwide coverage. India has agreed to join the Galileo Programme, which is being implemented.

India also plans to have its own satellite based GPS system, named GAGAN, which stands for GPS and Geo-augmented Navigation. The Union Ministry of Civil Aviation in collaboration with Indian Space Research Organization (ISRO) has mooted this programme. The objective is to fill the gap between European and Japanese space augmentation systems so that seamless navigation of aircraft is possible globally. The system will take help of geostationary satellites and the GNSS core satellites to provide low cost satellite based navigation system having 7 geo-stationary satellites always visible and covering the region (Fig. 16.7).

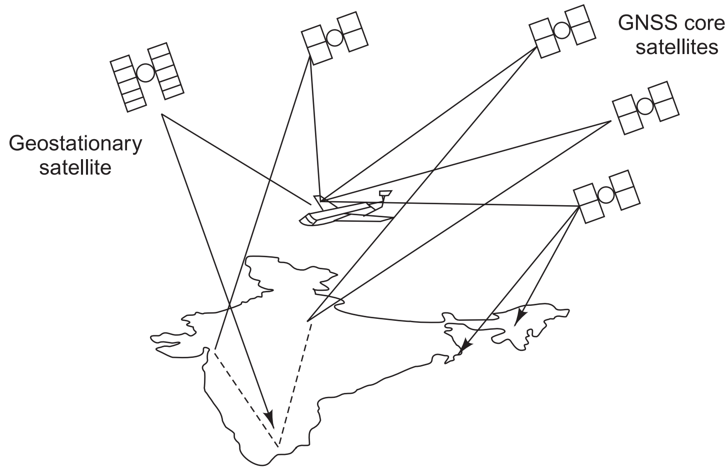

Fig. 16.7 *GAGAN system*

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Frequently Asked Questions

1. What is Differential GPS?
2. Write short notes on: Point Positioning; Relative Positioning; GPS Pseudolites; LAAS; WAAS; GLONASS; GAGAN.
3. Write about different corrections used in the concepts of DGPS.
4. Describe different types of DGPS.

17

GPS APPLICATIONS

17.1 AREAS OF APPLICATION

GPS became fully operational in 1993 and has contributed significantly since then in every walk of life. It is most effective tool to determine time place and motion. The system, being all weather continuously available, economic and precise in positioning, finds unlimited use in the following broad areas of application.

Geodesy, Geophysics, Geology, Mining and Geodynamics.

Surveying and mapping including surveys for cadastral, town planning, agriculture, irrigation, power, forest, environment, communication networks, etc.

Geographical Information System (GIS), Photogrammetry and Remote Sensing.

Aviation and Atmospheric Research

Navigation, Hydrology and Oceanography, Marine and Glacial geodesy

Time Transfer

Engineering and Monitoring

Entertainment, Amusement and Recreation

Military and Police

Specific details of GPS applications are further discussed.

17.1.1 Surveying and GIS

GPS can be used effectively and economically for all types of *surveys*, which include cadastral, town planning, agriculture, irrigation, power, forest, environment, communication networks, etc. GPS contributes to all types of geodetic *control surveys* viz. Zero order (1 in 250,000), 1st order (1 in 100,000) 2nd order (1 in 20,000), 3rd order (1 in 5,000) and 4th order (1 in less than 5,000), for continental, national, regional and local reference networks. It is further used in new control surveys, densification of existing control, inspection, analysis and improvement of existing network. GPS is used in determination of height and Geoid; however the former needs to be supplemented by spirit leveling.

GPS is a powerful tool to support *GIS* as it provides:

1. Uniform basic geometric frame
2. Geometric location of objects that enter the GIS, e.g. streets, buildings, communication lines, property boundaries, utilities, etc.
3. Its integration in command and control system for moving vehicles and machines.

With the help of dual frequency geodetic receivers in relative mode and prolonged observation period, it is possible to get mm level accuracies which can be utilized in *Geodynamics*. The following fields of application are identified in deformation analysis.

1. Global and continental plate movements
2. Regional crustal movements, and
3. Local crustal movements, subsidence including neo-tectonic movements.

17.1.2 Engineering

There are vast possibilities of application of GPS in the field of engineering. To achieve cm level accuracies, integration with electronic distance measuring instruments and/or total station are required. Some of the applications are:

1. Ground subsidence or rise; landslides
2. Dam deformation
3. Subsidence of off-shore structures
4. Settlement of buildings
5. Providing control points for engineering projects like tunnel surveys, bridge construction, road, pipe line, communication lines, etc.
6. Construction of water ways, drains and canals
7. Real time guidance viz. taxi fleet management, construction vehicles, dumpers and excavators in open pit mining, etc.

17.1.3 Navigation, Marine Surveys and Hydrology

DGPS provides high accuracy and real time capability for wide range of applications in marine survey and navigation. These applications can be divided into the following three user groups, based on accuracy requirements.

1. Low accuracy requirement, 10 to 100 m in position and 1m/S in velocity
2. Medium accuracy requirement, 1 to 10 m in position and 0.1m/S in velocity
3. High accuracy requirement, better than 1 m in position and 0.01m/S in velocity

User group (1) shall be satisfied with single navigation C/A code hand-held receiver. DGPS may be used for better accuracies. The applications for this group are:

General navigation in high seas

Research in oceanography

Positioning of ships in small bathymetry

Position and velocity in small scale gravimetric, magnetic and seismic surveys

User groups (2) and (3) will have to use DGPS. Typical applications of user group (2) are as follows:

Precise navigation in coastal waters

Harbour approach in Exclusive Economic Zone (EEZ)

Hydrographic surveys

Precise gravimetric, magnetic and seismic surveys

Positioning of underwater areas for mineral prospecting

Some of the applications of user group (3) are given below:

Precise hydrographic surveying

Monitoring silt accretion and erosion in rivers, lakes, estuaries, coastal waters and harbours

Real time dredge guidance and control

Marine geodynamics

Altitude control of ships, buoys, floating platform, etc.

17.1.4 GPS in Mines

GPS has direct contribution in open pit and indirect one in underground mining. It is used in Real Time Kinematic (RTK) mode. Point positioning, Relative positioning and Differential GPS are used in different situations. The accuracy requirements vary from (a) cm to meter, (b) 1 to 5 meters, (c) 5 to 10 meters and (d) more than 10 meters. The following possible applications are listed below:

1. Surveys for preparation of mine plans and acquiring lands
2. Connection of mine plans to national datum and grid
3. Ore body delineation
4. Precise positioning of drill equipment
5. Tracking, monitoring and navigation of heavy equipments
6. Design and construction of roads
7. Determination of profile and volumes in open pit mines
8. Land reclamation of surface mines
9. Proximity of Warning System (PWS)

17.1.5 Space Applications

In the field of Photogrammetry, Remote Sensing and other space applications, the GPS contributes in the following manner:

1. Providing ground control point (GCP)
2. Navigation of aircraft
3. Sensor platform coordinates and orientation

4. Positioning and navigation of other space vehicles
5. Radar altimetry
6. Mapping from space

17.1.6 Research and Time Transfer

The applications can be as given below:

1. Atmospheric research and ionospheric monitoring
2. Long term monitoring of tide gauge for sea level studies
3. Weather forecasting
4. Astronomy and orbit determination
5. Time signal transmission by laboratories

17.1.7 Military Applications

Some of these are listed below:

1. En-route navigation
2. Photo reconnaissance and target acquisition
3. Remotely operated vehicles
4. Sensor emplacement
5. Missile guidance
6. Precise bombing
7. Monitoring nuclear detonations
8. Command and control

17.1.8 Miscellaneous Applications

These include:

1. Earthquake prediction by studying and monitoring surface profiles using an array of GPS receivers placed in the earthquake prone areas and active fault zones.
2. It is widely used in recreational activities like hiking, trekking, fishing, sailing, treasure hunt, golfing, skiing, car racing, etc.
3. Global Maritime Distress and Safety System (GMDSS) is interfaced with GPS, which is useful and mandatory in shipping.
4. Charting efficient flight routes by using GPS.
5. Pesticide spraying and seed control in agriculture.
6. Glacial geodesy.
7. GPS has been used in synchronizing communication network from cell phones to the internet.
8. It has been extensively used in approach and landing of aircrafts in adverse conditions by using DGPS and Pseudolites.

9. Used in the study of animal behavior and mapping disease infested areas.
10. May be used by police in tacking and catching of criminals.

Suggestions for Further Reading

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Frequently Asked Questions

1. Describe the areas of application of GPS.
2. How GPS is used in: Surveying and GIS; Navigation, Marine Survey and Hydrology; Mine Surveys; Space Applications; Military Operations?

PART IV

GEOGRAPHICAL INFORMATION SYSTEM

18

DATABASE MANAGEMENT SYSTEM

18.1 INTRODUCTION

Geographical Information System (GIS) is a computerized system that helps in maintaining data about geographic space. It is a tool to juxtapose thematic spatial layers to get new information. It requires geographic location of different features and its description. Thus database concept is central to GIS, which differs from a computer based cartographic system producing good quality maps. Database Management System (DBMS) is an important component of GIS to visualize, model, analyze and query the database. A simplified presentation of GIS is given in Fig. 18.1. Computers help in organizing, processing and retrieving the data and managing the database.

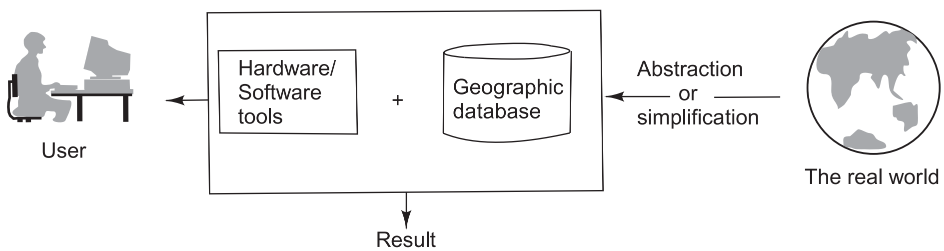

Fig. 18.1 *Diagrammatic presentation of geographical information system*

18.1.1 Computer System

In order to understand how computers process data into information, it is important to understand the components of the computer system and how it works. Irrespective of their size, computers process and display the data using same basic principles.

A contemporary computer system consists of a central processing unit (CPU), primary storage, secondary storage, input devices, output devices and communication devices. The central processing unit manipulates raw data into a more useful form and controls the other parts of the computer system. Primary storage device (Random Access Memory, RAM) temporarily stores data and programme instructions during processing, while secondary storage devices (magnetic tape, magnetic and optical discs, etc.) store data and programmes when they are not being used in processing. Input devices such as key board or computer 'mouse', convert data and instructions into electronic form for input to the computer. Output devices, such as printers, video display terminals, convert electronic data produced by the computer system and display it in a form that user can understand. Communication devices provide connections between the computer and communication networks. Buses are paths for transmitting data and signals between the various parts of the computer system.

In order that information flows through a computer system and be in a form suitable for processing, all symbols, pictures or words must be reduced to a string of binary digits. A binary digit is called a *bit* and represents either a zero or one. Digital computers operate directly with binary digits either singly or in strings of eight bits called *byte*. Each byte can be used to store a decimal number, a symbol, a character or part of a picture.

For depicting alphabetical characters or symbols, the manufacturers of computer hardware developed standard binary codes. There are two such codes:

1. Extended Binary Coded Decimal Interchange Code (EBCDIC)
2. American Standard Code for Information Interchange (ASCII)

18.1.2 Evolution of Computer Hardware

The first and second generations of computer hardware were based on vacuum tube and transistor technology, whereas the third and fourth generations were based on semiconductor technology. These are dealt in more details below.

18.1.2.1 First Generation (1946-56)

The first generation of computers relied on *vacuum tubes* to store and process data. These tubes consumed lot of power, generated great deal of heat and were short lived. Colossal in size, the first generation computers had extremely limited memory and processing capability. These were used for very limited scientific and engineering works. The maximum main memory size was approximately 2000 bytes (2 kilobytes), with a speed of 10 kilo instructions per second. Rotating magnetic drums were used for internal storage and punched cards for external storage. Jobs, such as running programmes or printing output, had to be coordinated manually.

18.1.2.2 Second Generation (1957-63)

In the second generation of computers, **transistors** replaced vacuum tubes as the device for storing and processing data. Transistors were much more stable and reliable than vacuum tubes. They consumed less power and generated less heat. However, each transistor had to be made individually and wired into a printed circuit board manually, which was a tedious process. Magnetic core memory was the primary storage technology of this period. It was composed of small magnetic doughnuts (about 1 mm in diameter), which was polarized in one or other direction to represent a bit of data. Wires were stung along and through these cores to both write and read data. This system was to be assembled by hand and, therefore, was very expensive. Second generation computers had up to 32 kilobytes of RAM memory and speed reaching to 200 to 300 kilo instructions per second. The enhanced processing power and memory of second generation computers enabled them to be used more widely for scientific and engineering works. These were used for such business tasks as automated payrolls and billing.

18.1.2.3 Third Generation (1964-79)

Third generation computers relied on *integrated circuits*, which were made by printing of hundreds and later thousands of tiny transistors on small silicon chips. These devices were called semiconductors. Computer memories of this generation expanded to 2 megabytes of RAM and speed accelerated to 5 million instruction per second (MIPS). This boost in processing power made it possible to develop special software, called operating system that automated the running of programmes and communications between the CPU, printers and other devices. Third generation computer technology introduced software that could be used by people without extensive technical training, thus, making it possible to enlarge their role in business.

18.1.2.4 Fourth Generation (1980 onwards)

Computers in this period use *very large system of integrated circuits (VLSIC)*, which are packed with as many as 200,000 to over 3 million circuits per chip. Costs have fallen to the point where desktop and laptop computers are inexpensive and widely available for use in business and everyday life. The power of a computer that once took up a large room can now reside on a palmtop. Computer memory sizes have mushroomed to over 4 gigabytes, which is increasing day by day. Processing speed has also increased correspondingly to over 2000 MIPS and more.

VLSIC technology has fueled a growing movement towards micro-miniaturization. The proliferation of computers, that are so small, fast and cheap, can be seen in every walk of life. For instance, many of the 'intelligent' features that have made automobiles, stereos, toys, watches, cameras and other equipments easier to use, are based on microprocessors.

18.1.3 Types of Computer

The computers are categorized into the following types depending on their RAM and processing time etc. However, the classification has only historical value as faster developments in computer technology have changed the concept.

1. Mainframe: Largest category of computer, classified as having 50 megabytes to over 1 gigabytes of RAM
2. Minicomputer: Middle range computer with about 10 megabyte to over 1 gigabyte of RAM
3. Microcomputer: Desktop or portable computer with 640 kilobyte to 64 megabytes of RAM (now far more RAM is available in desktops and laptops).

4. Workstation: Desktop computers with powerful graphics and mathematical capabilities and the ability to perform several tasks simultaneously.
5. Supercomputer: Highly sophisticated and powerful computer that can perform very complex computations extremely rapidly.

18.2 DATABASE MANAGEMENT SYSTEM (DBMS)

There has always been demand for information from the data collected and stored over the years. This is especially true for all organizations engaged in survey of natural resources. For simple information, one can go to a file, extract the relevant data and compile the information. For example, it is easy to get figures of mineral production for a particular year, pertaining to different type of minerals from a Mineral Year Book. However, as more and more attributes are added, the information generation becomes complex and processing of data becomes necessary before information is generated. Thus, for retrieving data, one may have to consult different files, collect, collate and process the data for arriving at new information/data/result. It is clearly seen that there are two types of approaches for data management.

1. File based system, and
2. Data based management system

There are drawbacks in a file based system, which include data redundancy, unanticipated queries, data isolation, concurrent access anomalies, security and integrity problems. In contrast, data based management system has clear advantages in these areas. It is easy to enforce standards, better controls and reduced maintenance costs by using DBMS.

The data based systems are broadly categorized in to three types viz. Hierarchical, Network and Relational systems. The Hierarchical Data Base System has a tree like structure; the data is accessed with two nodes at a time. It requires level by level search sequence (Fig. 18.2). Network Data Base System is an extension of hierarchical data base, requiring extensive prior knowledge of and about the data being organized. The data base is organized by record 'types', which are defined and maintained through 'data sets'. The sets describe one or more relationships among various record types. The data base is searched through one of many possible network paths. To arrive at a point, one has to travel whole length of network, thus taking more time.

The Relational Data Base Management System (RDBMS) has access to each database independently, hence it is faster. It permits the user to relate many data tables through a common item. The RDBMS is more suitable to storage of natural resources survey data, which are having a number of attributes and these are interdependent significantly. It is important to GIS since information from different map levels, with associated attributes can be analyzed and manipulated without having to append all the necessary data to a common table.

A quote from Arthur Anderson 'Information and capable persons are there, which need to be connected through proper technology to enable sharing so that knowledge grows exponentially'.

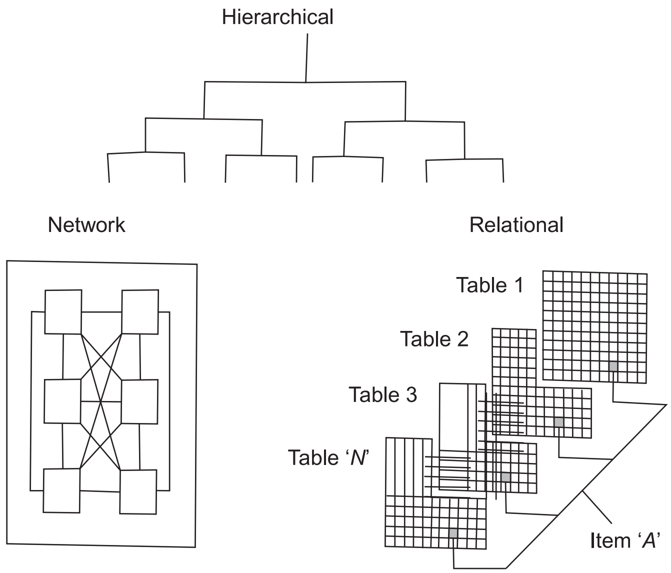

Fig. 18.2 *Attribute database types*

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Frequently Asked Questions

1. What is Geographical Information System (GIS)?
2. What are the essential components of a computer system?
3. Write about Data Base Management System and its types.

19

GEOGRAPHICAL INFORMATION SYSTEM

19.1 GIS CONCEPT

In real word, there are many geographical features which include topographic features, land use, land cover, soils, forests, rocks, water bodies, agriculture, city, streets, communication lines, district, etc. These are spatial data often represented by a map. Information about these features is attribute data which may form part of an information system. Geospatial information along with attribute data is vital for decision making at different levels and is required for day to day activities and planning further development. Space borne images cover vast areas and have larger information content through multispectral and repeat observation ability. These are suitable for mapping and monitoring regional and global environment. Vast amount of information and statistics lying in different departments and survey organizations can be integrated in GIS environment to generate new information and to formulate the best policy for development and optimum utilization of earth's resources. GIS, in nutshell, is spatial visualization of information. GIS may be defined as "a computerized system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with Georeferenced data".

19.2 COMPONENTS

The GIS is organized through skilled manpower, data with its analytical methods, computer hardware and software (Fig. 19.1). The essential components of GIS are examined in more details in the following paragraphs.

19.2.1 Personnel involved

It is important to be clear on the type of user while designing a data model, building software or writing user documentation. Following are the primary roles that people play in the GIS.

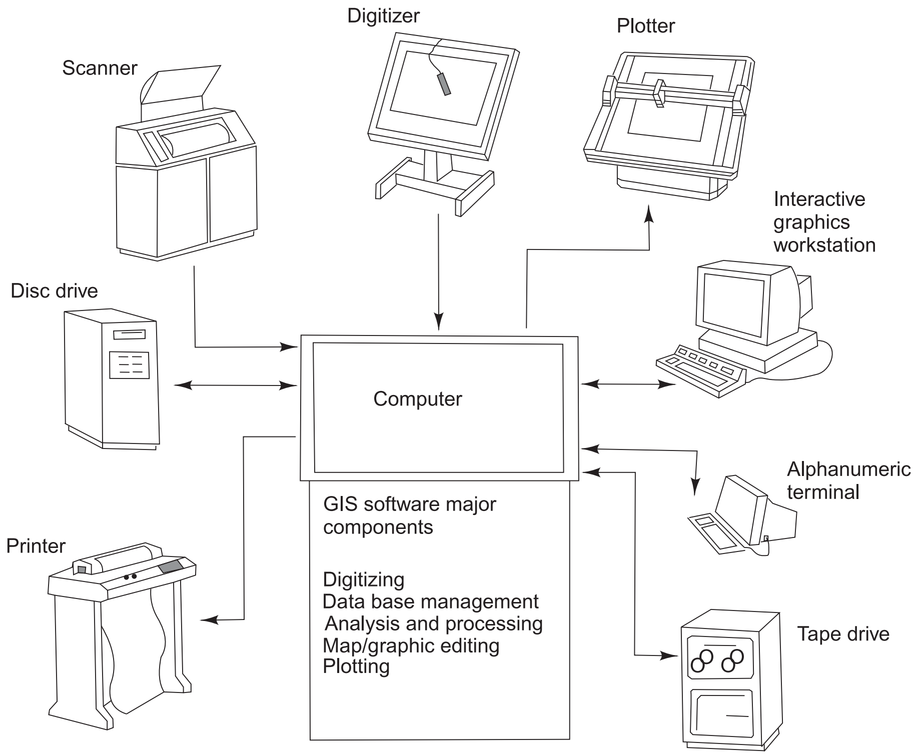

Fig. 19.1 *Main hardware and software components of GIS (after Panda 2005)*

1. All member of public are map users. They use the map created for general or specific purpose. A map user is the end consumer of a GIS.
2. A map builder (cartographer) uses different map layers from several sources and adds data to make a customized map. A map publisher prints maps and is dedicated to high quality cartographic output.
3. A theme analyst solves geographic problems pertaining to different themes, such as chemical dispersion, finding the best route, site location of public utility, etc.
4. A system analyst inputs geographic data using different techniques of editing, converting and data access.
5. A database administrator manages GIS database and ensures that the GIS operates smoothly.
6. A database designer builds logical data models and implements physical data designs.
7. A developer customizes GIS software to serve the specific needs of an industry.

19.2.2 Data Sources for GIS

The GIS processes any data that has a spatial component. Data can be of spatial, statistical or attribute types. It may come from quite diverse sources, viz. aerial photographs, satellite imagery, maps, a collection of terrain contours, digital map of built environment, legal records of land ownership, etc.

Geographic data can also reside in some unexpected places, for example, any company that keeps database of its customers, with their geographic locations. It is possible to calculate the location of a place on the earth by its postal address pin code. However, the position of geographic data must be in some coordinate system (Lat-Long, Grid, etc.).

Geographical features are represented as a number of related data layers called GIS files. These are depicted in Fig. 19.2.

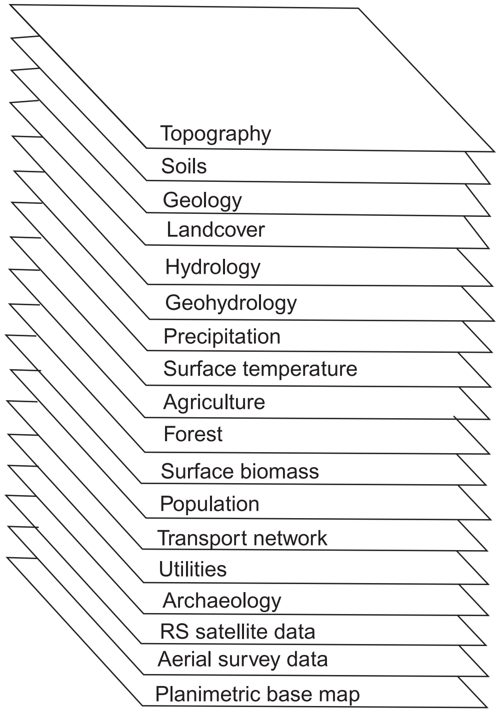

Fig. 19.2 *Various related data layers (GIS files)*

19.2.3 Computer hardware

Computers are available in all sizes comprising palm to mainframe. A general configuration of computer hardware is given in Fig. 19.1. GIS software is available for nearly every type of computer. With the improvements in network bandwidth, a client server or n-tier architecture is the preferred configuration for enterprise scale GIS.

The Internet is joining computers into a global network and is an important way to access data. Local area net (LAN) and wide area net (WAN) help in establishing data flow and access in a local and regional situation, respectively. Another trend is the increasing use of Global Positioning System (GPS) to locate people and heavy equipment in real time.

19.2.4 Computer Software

GIS links spatial data with descriptive information about a particular feature on the map. The information is stored as attributes of the geographically represented features. It can also use the stored attributes to compute new information about the feature. We need to know three pieces of information about every feature stored in the computer, namely (a) what it is, (b) where it is, and (c) how it relates to the other features. There are three noteworthy characteristics with regard to the link between spatial (graphic) and descriptive (tabular) data. These are:

1. A one-to-one relationship is maintained on the map and records in feature attribute table,
2. The link between the feature and record is maintained through unique identifier assigned to each feature, and
3. The unique identifier is physically stored in the files containing x, y coordinates with the corresponding record in the feature attribute table.

The GIS software, like ARC/INFO, SPANS, PAMAP, MAPS, GEOSPACE, INGIS, URAS/MASMAP, ISROGIS, etc automatically creates and maintains this link.

The main idea about GIS software is that it is, in fact, a geographic database management system. Geodata bases are implemented directly so that the capabilities of commercial database software, which include data backup, table definition, transaction management and system administration tools, could be utilized. The GIS software extends relational database so that it can efficiently store geographic data, produce maps and perform spatial analytic tasks.

Some of the functions that GIS software adds to a relational database management system are:

1. The ability to store the geometric shapes of feature directly in a database column.
2. A framework to define map layers on data and specifies drawing methods; these can be drawn based on attribute values.
3. An infrastructure to support creation of simple and sophisticated maps. Many common map making tasks are simplified.
4. The creation and storage of topologic relationships that exist among features, such as network connectivity and integrated polygon topology.
5. A spatial index spanning two dimensions for rapid retrieval of geographic features.
6. A set of operators for determining geographic relationships such as proximity, adjacency, overlay and spatial comparison.
7. Many tools to support spatial queries such as network tracing and polygon overlay analysis.
8. A workflow system that allows the editing of geographic data by many users and manages different versions.

GIS can be thought of as a spatially enabled database management system. This architecture gives the best of commercial database technology and sophisticated geographic software.

19.3 SPATIAL DATA REPRESENTATION

Spatial or geographic data is represented by visual elements like point, line and polygon or area (Figs 19.3 and 19.4). A point is a single coordinate, without having any dimension or area. A line represents a linear feature, having a string of coordinates. Every line is stored as an arc having two end points called nodes. A polygon is bound by lines, joined from node to node. The beginning and end point of a polygon is same. It can be left-handed or right-handed. A polygon has property of area and perimeter and topologic property of containment. These elements, which compose the picture, are linked with geographic data through the processing software. The visual data elements can be structured into two basic ways, namely raster and vector. Raster and vector data are described below.

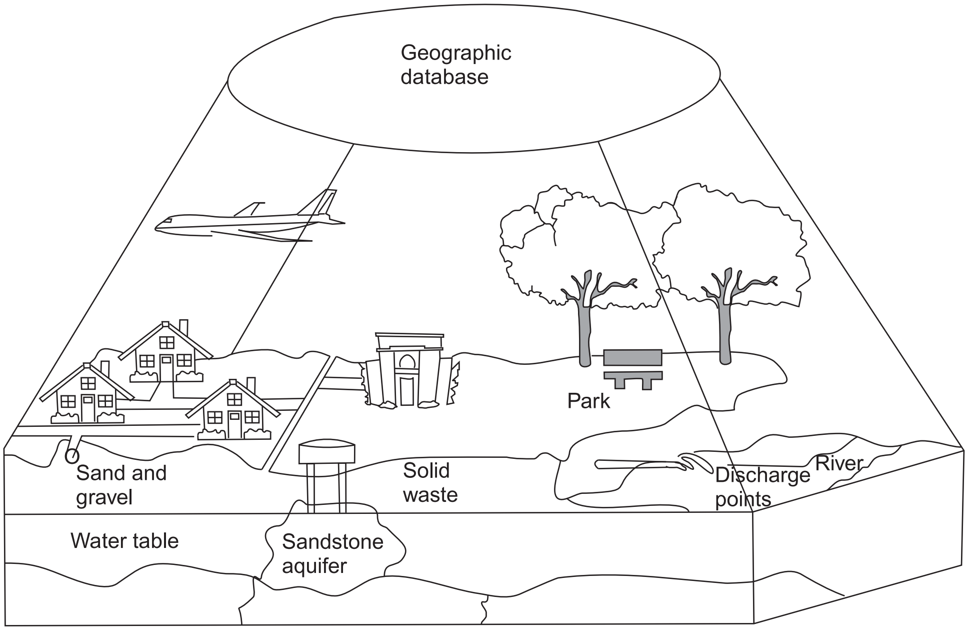

Fig. 19.3 *Spatial and descriptive data form geographic database*

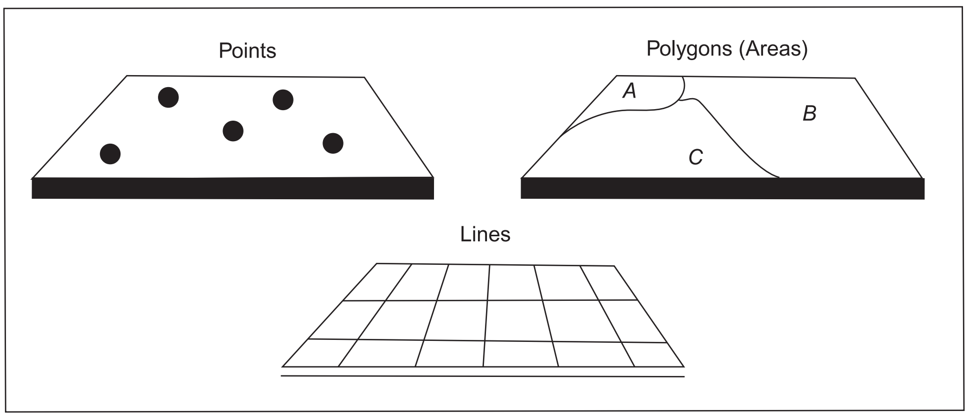

Fig. 19.4 *Visualization of geographic data through points, lines and polygons (after Panda 2005)*

19.3.1 Raster

Raster is a term used in digital display. It is an area on a scanning line which can be individually illuminated, analogous to pixel. Raster data represent a point, a line and an area as a matrix of values. A raster database requires that all values or entities be defined by a single raster or a group of raster. The size of the cell defines the resolution of the database as well as the display (Fig. 19.5).

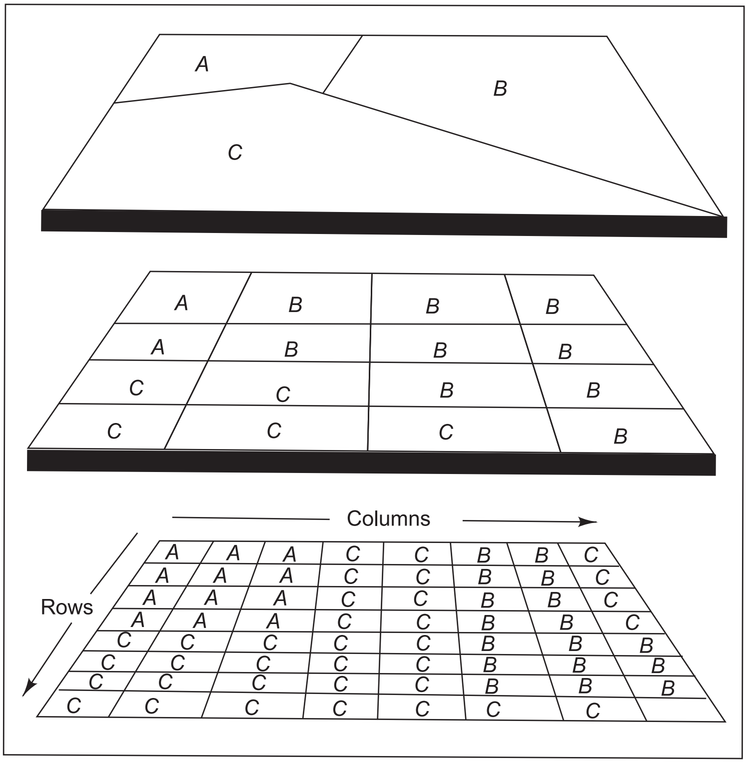

Fig. 19.5 *Raster presentation of point, line and polygon as matrix*
(The resolution depends on the size of the cells/grids in the matrix)

A map, in a raster based system, is represented as an array of rectangular or square cells, representing location and its assigned value. Display of satellite imagery, which resembles a television image composed of picture elements (pixel), is essentially in a raster system. The system has following advantages:

1. A grid pattern is particularly useful where spatial pattern (e.g. land features) need to be recognized for comparison and analysis.
2. A grid based GIS can be easily used in a computer.

However, the system has its own disadvantages. Some kinds of information do not fit into a cell, for example, a cell may represent 75% agricultural land and 25% wasteland, but when coded in raster system, it may indicate all as agricultural land. To overcome this difficulty, a parcel system is used whereby the boundaries are rendered more accurate.

19.3.2 Vector

A vector model defines graphic elements (point, line and area) using basic geometry, namely magnitude and direction. Vector data is represented by directed line; the length of the line represents magnitude and its orientation in space represents direction (Fig. 19.6).

Points are normally represented by Cartesian coordinates (x, y), a line by a string of coordinates and an area or polygon by a string of coordinates starting and ending at the same point. For visual display, the vector data model requires more precise definition of entities in the primary data. Thus, vector display has better resolution, although it is slower due to considerably more calculations involved in the process. Advances in hardware and software developments have improved the situation considerably. Conversion of raster to vector data formats are given in Fig. 19.7 and conversion of a map to vector or raster data formats are depicted in Fig. 19.8.

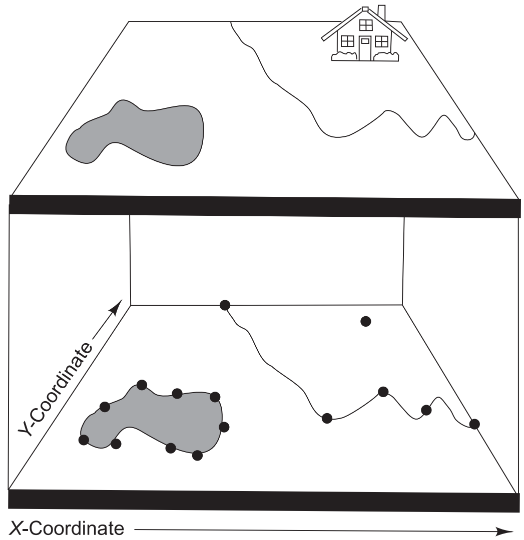

Fig. 19.6 *Vector presentation by coordinates (a point is represented by cartesian coordinates, a line by string of coordinates and an area by string of coordinates starting and ending at same point)*

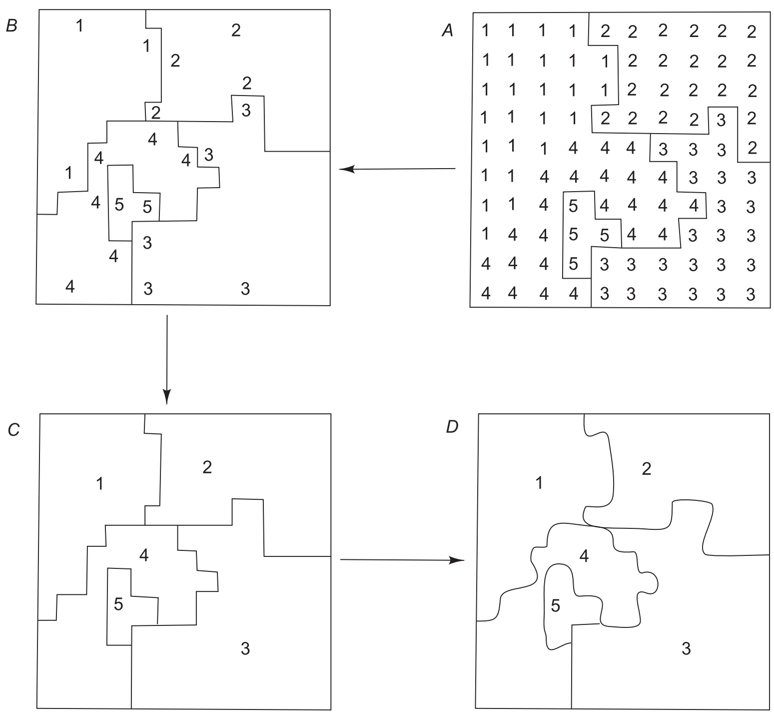

Fig. 19.7 *Conversion of raster to vector data*
Here a satellite image is classified into five land use categories, presented in raster format in (A). It is converted to the vector format in (D) by smoothening the border lines through (B) and (C)

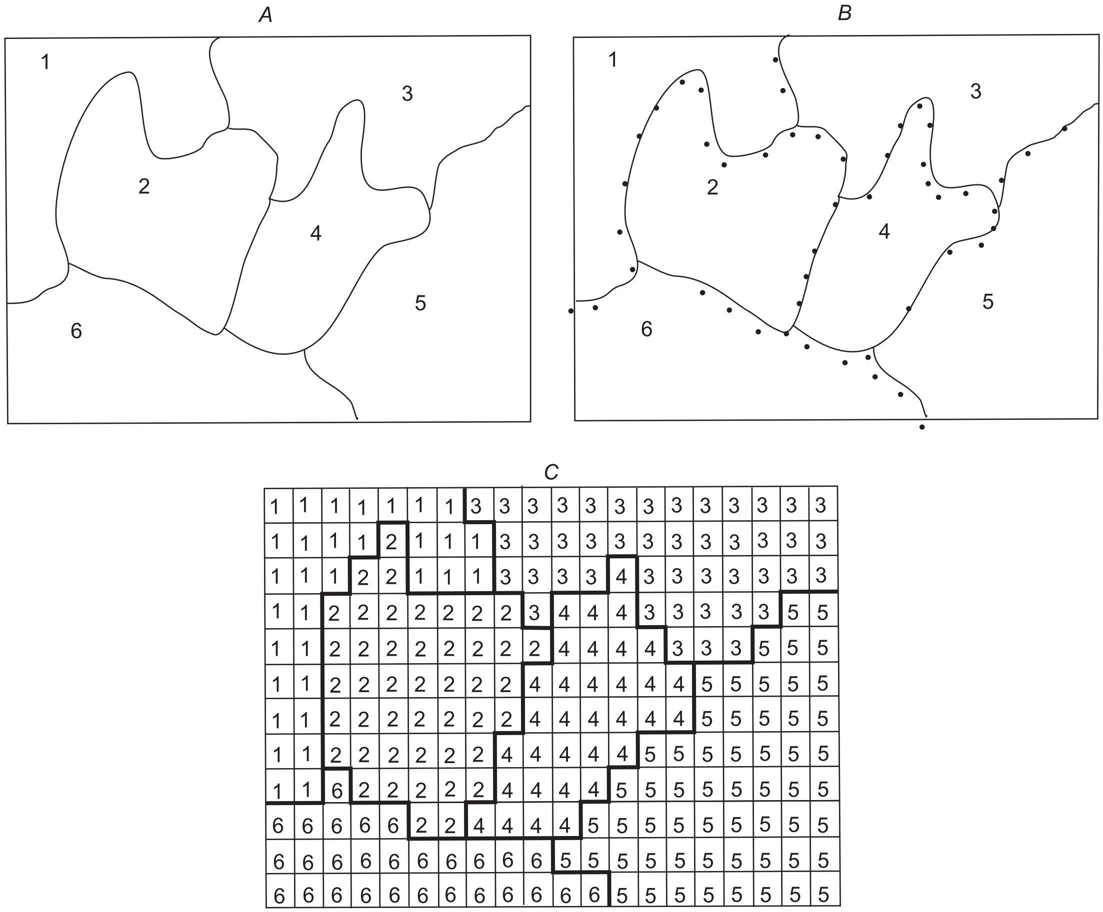

Fig. 19.8 *Conversion of map to vector and raster data formats*
Here a map A having six land use categories is first digitized in vector format B which is subsequently converted to raster format (c). In raster presentation C, the number in each cell (grid) indicates a polygon or a thematic class

An advantage of the vector based system is that it indicates thematic maps precisely and needs less storage space. However, satellite imagery cannot be represented as vectors.

19.3.3 Features in Space

Features on earth's surface present a multifaceted mosaic of cultural and natural environments. Features of cultural environment are easy to recognize viz. streets, houses, utilities, business facilities, etc. Their boundaries can be easily determined and drawn on the map with appropriate symbol. There can be sub-classification activity-wise, such as sales activity in a geographic region or population density within administrative block and so on.

Defining boundaries in natural environment is more difficult, natural features tend to exist as continuous variable. The thematic specialists classify continuous data representing natural features viz. rocks, soils, forest types, agriculture, etc. into discrete manageable units.

Storing information about the landscape requires that the space is classified into a series of objects or features, which can be defined discretely in the computer system. Since all the objects, pertaining to different themes are present in the same feature space, the easiest way to classify similar object into various thematic layers. These layers might be geology, soils, forest types, agriculture, landuse, landcover, communication lines, etc. (Fig. 19.9).

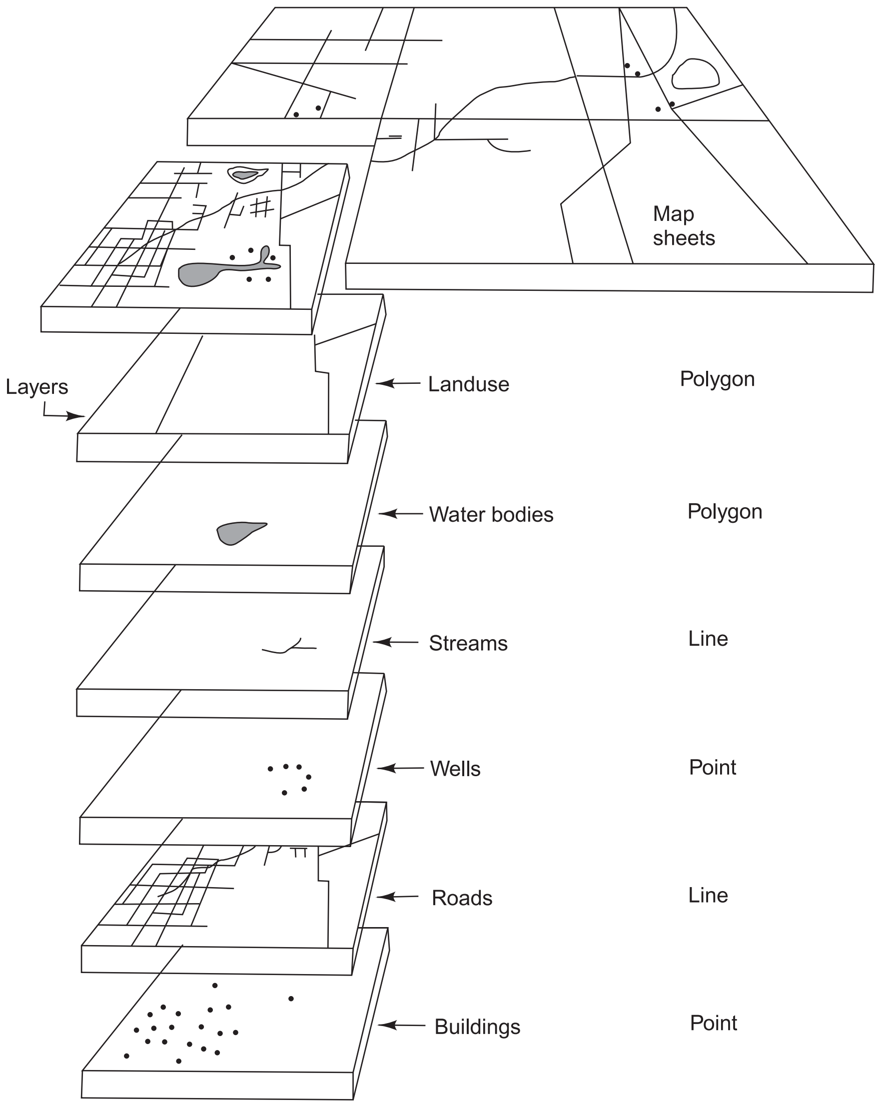

Fig. 19.9 *Presentation of spatial data (a set of geographic layers) (after Panda 2005)*

Spatial data capture is done by manual or automatic digitization for individual layers, which provide further information. It is appropriate to separate and maintain each layer in a spatial database.

Some components of the real world change more rapidly than others. It is better to separate those layers that have different update cycles and are updated by different groups. For example, zoning may change on a monthly basis, while administrative boundaries change only once in a year or more. Likewise, it may be appropriate to separate those layers which are standard input into a particular analysis.

19.3.4 Spatial Data as Coverage

In two dimensional feature space, there are three classes of spatial objects, namely point, line and polygon. These objects are referred to as feature classes in ARC/INFO environment and can be stored separately in a structure called coverage. Thus there are point, line and polygon coverages. Each of the coverages is composed of a set of files; some store spatial data while others store attribute data. Table 19.1 gives location and attribute files for different feature classes.

Table 19.1 Files associated with point, line and polygon coverages

Feature class	*Spatial data*	*Attribute data*
Point	LAB- Point coordinates	PAT- Point Attribute Table
Line	ARC- Arc coordinates	AAT- Arc Attribute Table
Polygon	PAL- Polygon Arc List	PAT- Polygon Attribute Table

A thematic layer may contain more than one coverage type. For example, a hydrology layer may contain tube wells, streams and lakes, representing point, line and polygon coverages in terms of storage in GIS. However, the decision regarding layers and coverages lies in the domain of database design, which controls the use and maintenance of the data.

19.3.5 Spatial Objects

As described earlier, geographic features are abstracted to become point, line and polygon. In ARC/INFO, a point is an elemental unit, a line is made up of a string of points and polygon is made up of a line or series of lines. These are discussed in more details.

19.3.5.1 Point

A point is defined by a single coordinate pair (x, y), when we work in 2D or coordinate triplet (x, y, z) when working in 3D. Point represents a geographic feature, too small to be seen as an area. It has no geometric property, except its location. This includes all the features represented by point symbol in a map. The representation depends on the scale and purpose of the map. In a city tourist map, parks will not be considered as point features, while telephone booths could be represented as point features. In ARC/INFO database the point is numbered and stored with a single coordinate (x, y) denoting its location and a series of administrative and thematic attributes describing its characteristics (Fig. 19.10). Each of the point features of the map is represented as *record* in the database. A point has a coordinate location and attributes are stored in Point Attribute Table (PAT). For phone booth, in above example, the attribute data may include the name of owner, phone number, the date last serviced, etc.

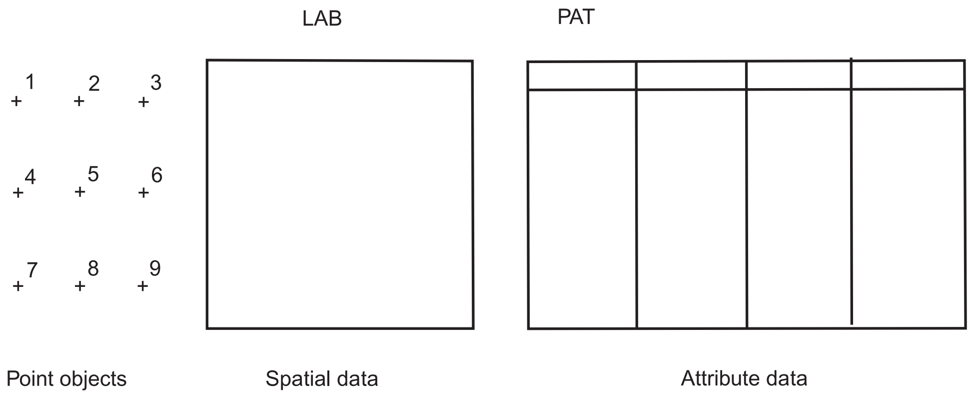

Fig. 19.10 *Representation of point objects in GIS database (point coverage)*

19.3.5.2 Line

Line data are used to represent one dimension, linear objects such as roads, railroads, canals, rivers and power lines, etc. There is again issue of relevance for application and scale. For example, a tourist map shows roads as line feature, while in a cadastral map, a road may be represented as two dimensional feature having width as well. A line is represented by two end nodes and zero or more internal nodes or vertices. The vertices of a line help to shape it and obtain a better approximation of the actual feature. The straight parts of a line, between two consecutive vertices or end nodes are called line segments. In Fig. 19.11, there are 2 end nodes, 3 vertices or internal nodes and therefore, 4 line segments.

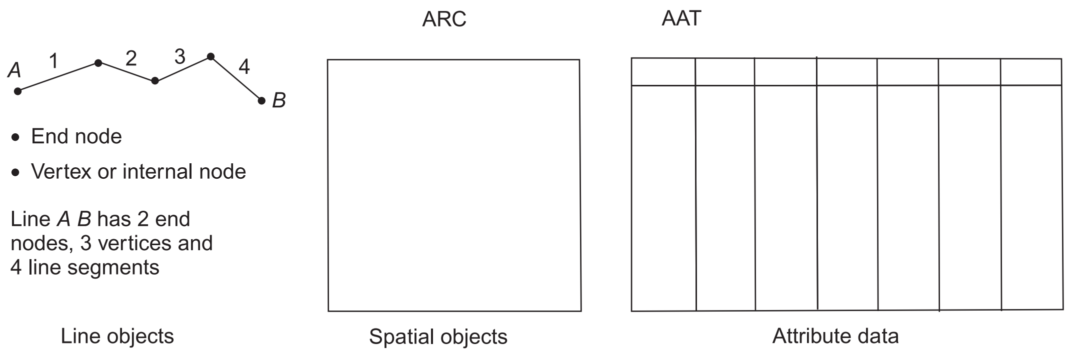

Fig. 19.11 *Representation of line objects in GIS database (line coverage)*

Lines representing linear features are usually stored as string of coordinates with descriptive attributes. In ARC/INFO database, every line is stored as an arc and has two end points called nodes. Generally, a line begins or ends where it meets another line or change in curvature. This kind of connections is defined by arc-node topology. Each arc has a string of coordinates and attributes, which are stored in Arc Attribute Table (AAT). These attributes include the geometric property of length and topological properties of connectivity and adjacency (from node-to-node).

19.3.5.3 Polygon

Polygon coverage has all the three types of spatial objects. Nodes define the end of arcs and the boundary of each polygon is defined by a list of connecting arcs. Each polygon should have a label point (different than a point feature) within it. Polygon attributes are stored in PAT (Fig. 19.12).

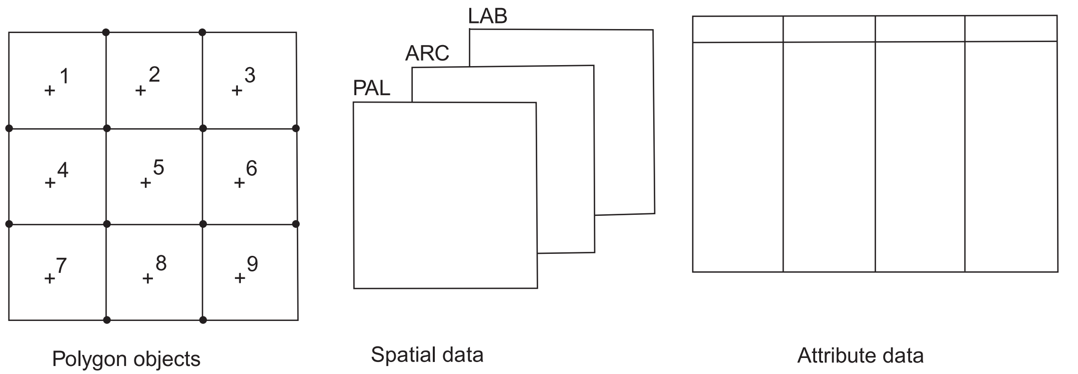

Fig. 19.12 *Representation of polygon objects in GIS database (polygon coverage)*

Polygons are identified by their label points and their boundaries are defined by a series of connected arcs and nodes. These arc could be listed to be left or right side (generating left or right polygon).

The polygon has geometric property of area and perimeter and topologic property of containment. These properties and relationships are stored in several related data files. There is one-to-one relationship between a polygon in a coverage and a record in the PAT.

19.4 RELATIONSHIPS OF SPATIAL OBJECTS

The most common way of describing the location of a geographic feature is by relating the feature to some other observable features. While describing any location we use terms like left of; right of; at the end of, etc. It is easy for us to understand and interpret but computer requires discrete decision rules.

Spatial objects are not independent entities. They exist within space and show relationship to each other. This is formally studied in topology. Once the data has been entered as spatial objects, coverage topology is constructed. This includes verification of data, identification of errors and establishing spatial relationships between the objects. Normally three types of topological relationships, namely (a) adjacency, (b) connectivity and (c) containment are considered, as depicted in Fig. 19.13. These are further discussed.

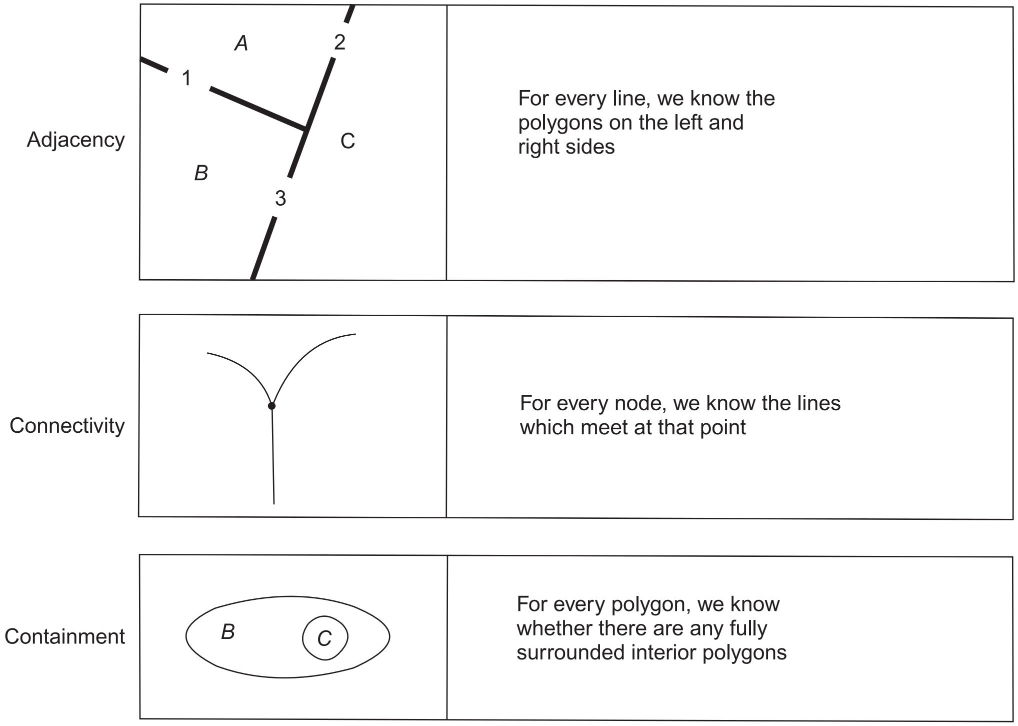

Fig. 19.13 *Basic elements of relationships between spatial objects*

19.4.1 Adjacency

Adjacency indicates being next to it or adjoining. Two adjacent polygons share a common boundary. Polygon, lines, and nodes can have the property of adjacency. The following examples can be considered in this regard.

19.4.1.1 Polygon–Polygon

Figure 19.14 shows a water body (polygon A) surrounded by polygons of forest types, soil types, etc. The query 'find all polygons surrounding water body' will be translated into an operational definition—find all the polygons which share a common arc with polygon –A.

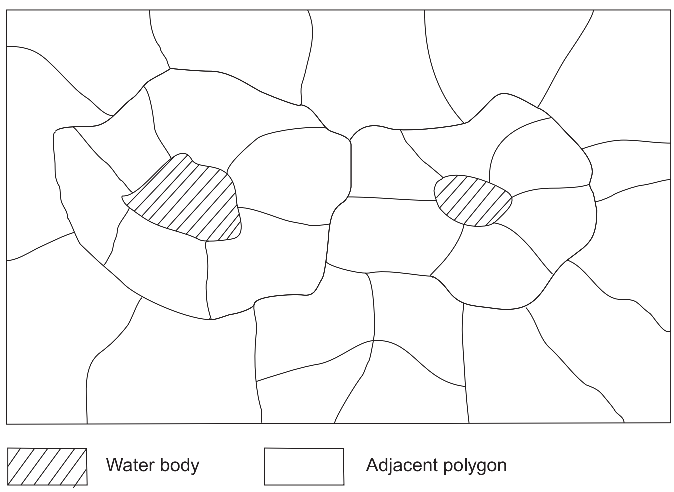

Fig. 19.14 *Polygon-polygon adjacency*

We may further expand the query for the whole area as 'find all the forests surrounding water bodies'. The operational definition of the query will be to find all polygons-type B, which share common arc with polygons-type A (Fig. 19.15).

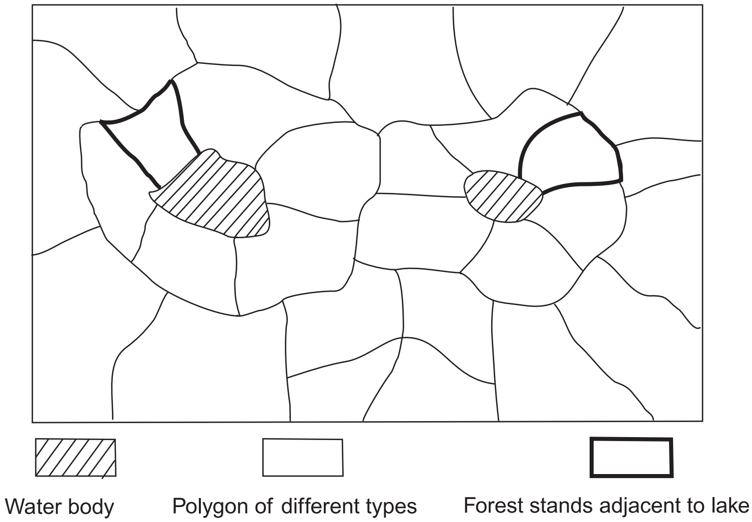

Fig. 19.15 *Adjacency of polygon type A to the polygon type B*

19.4.1.2 Polygon – Polygon (arc)

In stead of finding adjacent polygons, one can search for all arc that separate adjacent polygons. The query here is with regard to arc, for example, the initial query could be 'find forest type B adjoining the shore of the lake'. This is known as geographic duality and is depicted in Fig. 19.16.

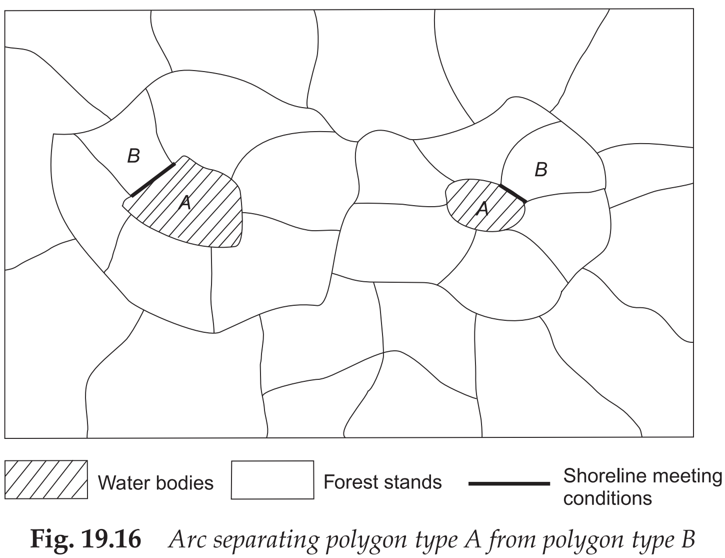

Fig. 19.16 *Arc separating polygon type A from polygon type B*

19.4.1.3 Polygon – Polygon (node)

Another type of adjacency is represented by three or more polygons sharing a common point in stead of a common arc (Fig. 19.17). The initial query will be 'find points where forest, meadow and lake meet'.

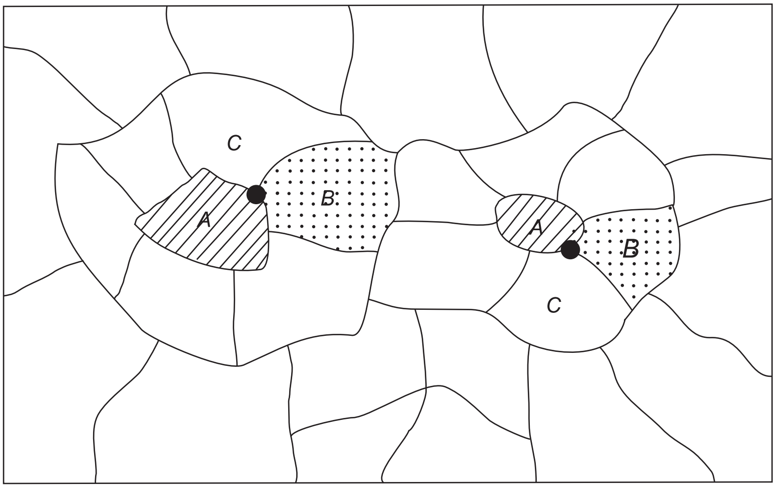

Fig. 19.17 *Nodes adjacent to polygon type A, type B and type C*

19.4.1.4 Line – Line

It is possible to find adjacency of lines (Fig. 19.18). It involves examination of arcs and nodes that form linear networks. The initial query could be 'find all 2nd order streams. The query will get translated into operational definition as to find all lines adjacent to line type-A.

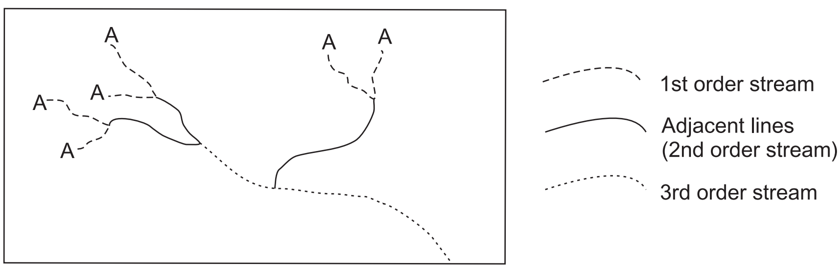

Fig. 19.18 *Lines adjacent to lines of type A*

19.4.1.5 Line – Node

The geographic duality of adjacent lines could be to ask as finding lines that are adjacent to a node (Fig. 19.19). The initial query will be 'find streams adjacent to a confluence'. This will be translated as 'find all lines adjacent to node-B.

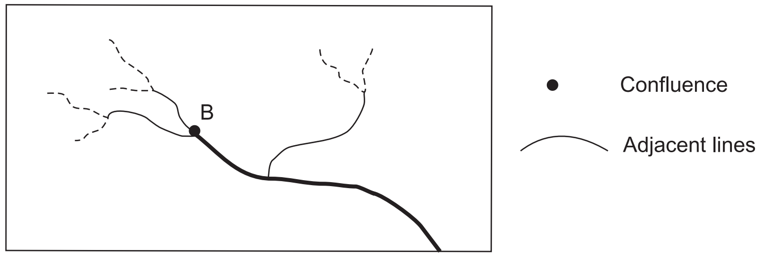

Fig. 19.19 *Line adjacent to a node*

19.4.1.6 Point–Point

The adjacency is not possible for points. It is replaced by near and nearest neighbor.

19.4.2 Connectivity

The idea of connectivity is most commonly realized in line coverage unlike the adjacency concept which is more apparent in polygon coverage. The containment concept pertains to "within" concept as such containment is also better realized in polygon coverage.

The topological property of connectivity acts on linear network, for example, the shortest path between two points say a child's house and his school can be answered through connectivity query. This is shown in Fig. 19.20. The query is resolved by seeking an optimum solution through the network by finding length of one arc to the next arc through an intervening node and comparing the cumulative lengths in alternative paths to find the minimum distance.

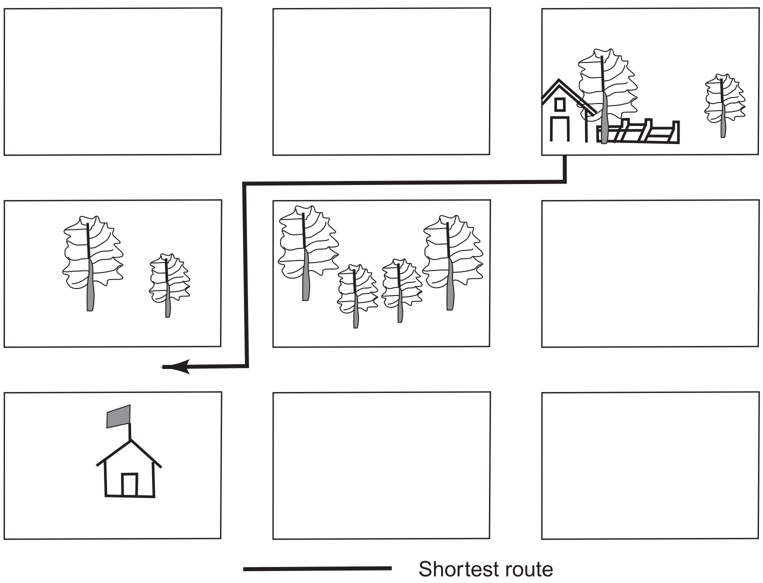

Fig. 19.20 *Connectivity: Road network to find shortest route (after Panda 2005)*

There can be a directional attribute added to linear relationship as happens in an electrical circuit (the current flows in a particular direction). If a device is failed in the circuitry system, the arc segment leading to the device can be traced, while those beyond that point (node) of failed device, having no electricity, can be traced separately. Thus, it is easy to find the affected parts in the circuit (Fig. 19.21).

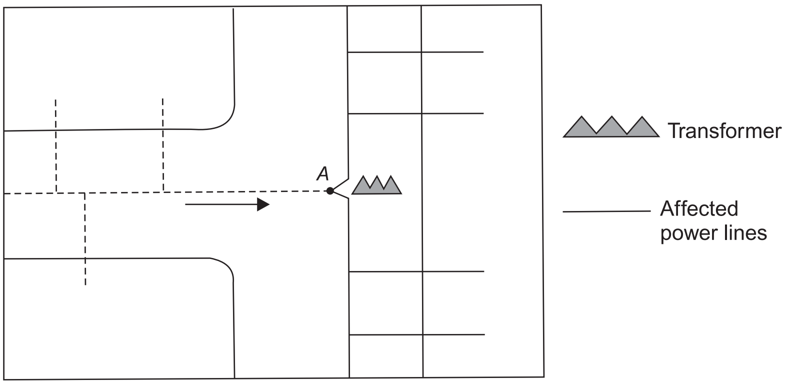

Fig. 19.21 *Connectivity in power line network*

The connectivity between polygons can be illustrated by different erosion patterns shown by a stream passing through a terrain having different lithology. The rock polygons will offer variable resistance to the flow of the stream.

19.4.3 Containment

Containment is indicated by the query "within". The following coverages may be considered in this regard.

19.4.3.1 Polygon-Polygon

A lake containing islands depicts this relationship best (Fig. 19.22). As the islands are completely surrounded by water, it may be expressed as the arc that separate land polygon from water polygon has a common node, the starting and end node of the islands, in this case. The geographic duality in this case may have two queries as:

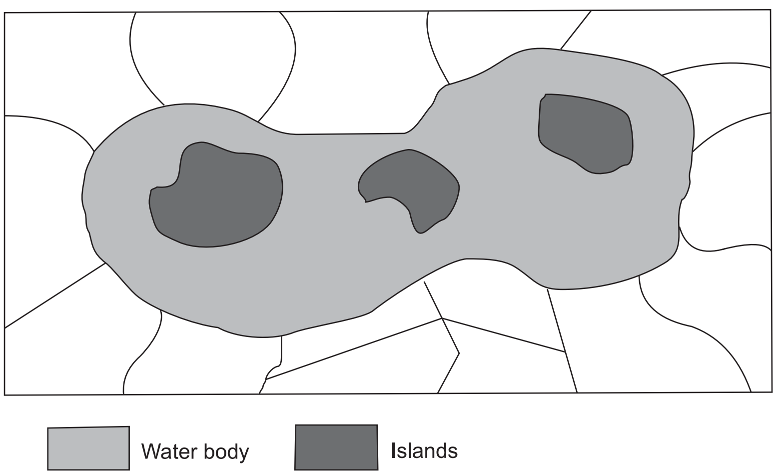

Fig. 19.22 *Containment: Polygon within polygon*

Identify land islands within the lake (water body), or

Identify the lake (water body) containing land islands

Both the questions will result in the same answer.

In ARC/INFO, polygon containment relationships are stored in the polygon arc list (PAL) file. This will facilitate measurement of perimeter and area of the polygons.

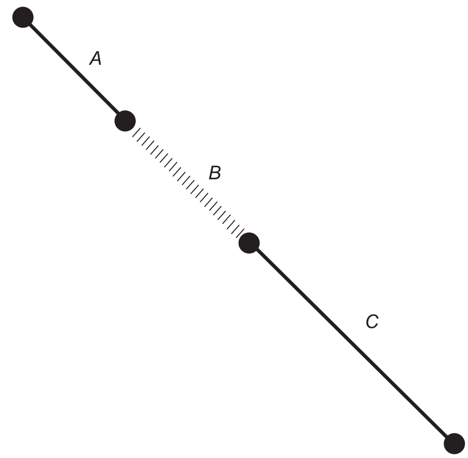

Fig. 19.23 *Line-line containment*

19.4.3.2 Line-Line

Figure 19.23 illustrates this relationship in line coverages. In the line segments A, B, C, the segment B may be contained, for example, if it represents a rail overhead bridge.

19.4.3.3 Pont-Line and Point/Line-Polygon

A point may be contained within a line as shown in Fig. 19.24. Similarly points and lines may be within a polygon (Fig. 19.24). In a multiple layer data system, different objects represented by point, line and polygon may reside in different layers. The containment relationship may be addressed after combining these layers. The query could be "which lines or points lie within an area?" This process is known as overlay analysis.

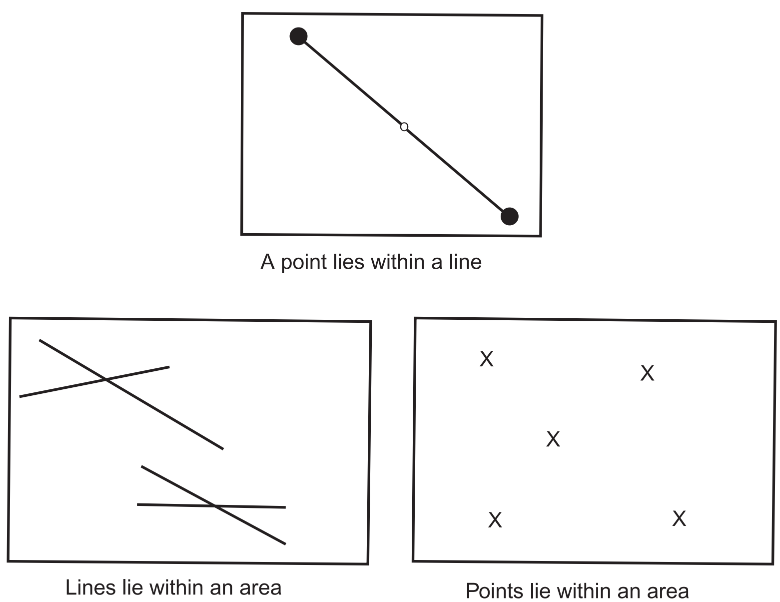

Fig. 19.24 *Different types of containment*

19.5 GIS FUNCTIONS

Various types of GIS functions are discussed below.

19.5.1 Data Input Functions

Functions under this category are required to convert the data from the existing form to the form suitable for use in GIS. For example a map, aerial photograph or satellite imagery provides georeferenced data with its associated attribute data. Figure 19.25 illustrates the process of converting the conventional data to GIS database. The maps convey location data by symbols (point, line and area) and attribute data by colour symbol or pattern. However, the GIS convey location by graphic symbols (point, line and polygon) and establish spatial relationships mathematically following the logic of topology.

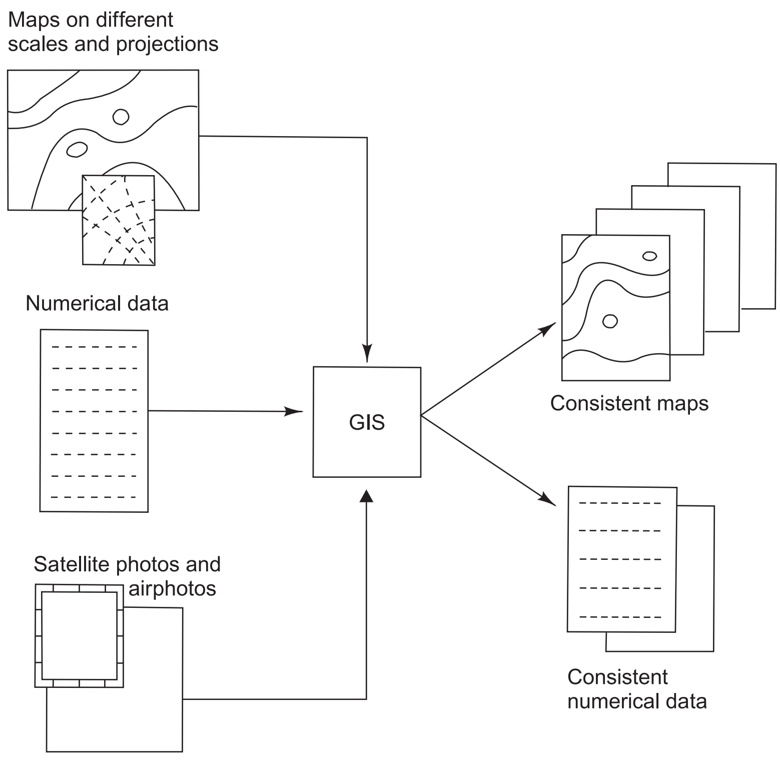

Fig. 19.25 *Integration of satellite data with maps and attribute data in GIS*

19.5.2 Data Management Functions

These functions include the storage and retrieval of data from the GIS database. The GIS is capable of reading the data in a logical manner, searching and identifying attributes, and displaying these in spatial context. Besides the other capabilities of GIS, the capacity to query, data retrieval and display functions make it more powerful and of practical value.

19.5.3 Data Manipulation and Analysis Functions

These functions determine the information that can be generated by GIS. Some of the functions are described below.

19.5.3.1 Manipulation of Spatial Data

The available data sets are generally inconsistent in scale, projection, spatial accuracy, orientation and coverage. To bring these on to a common platform, the original data sets may need to be transformed by change of scale, removal of distortion, rotation or translation or change of projection through manipulations (Fig. 19.26).

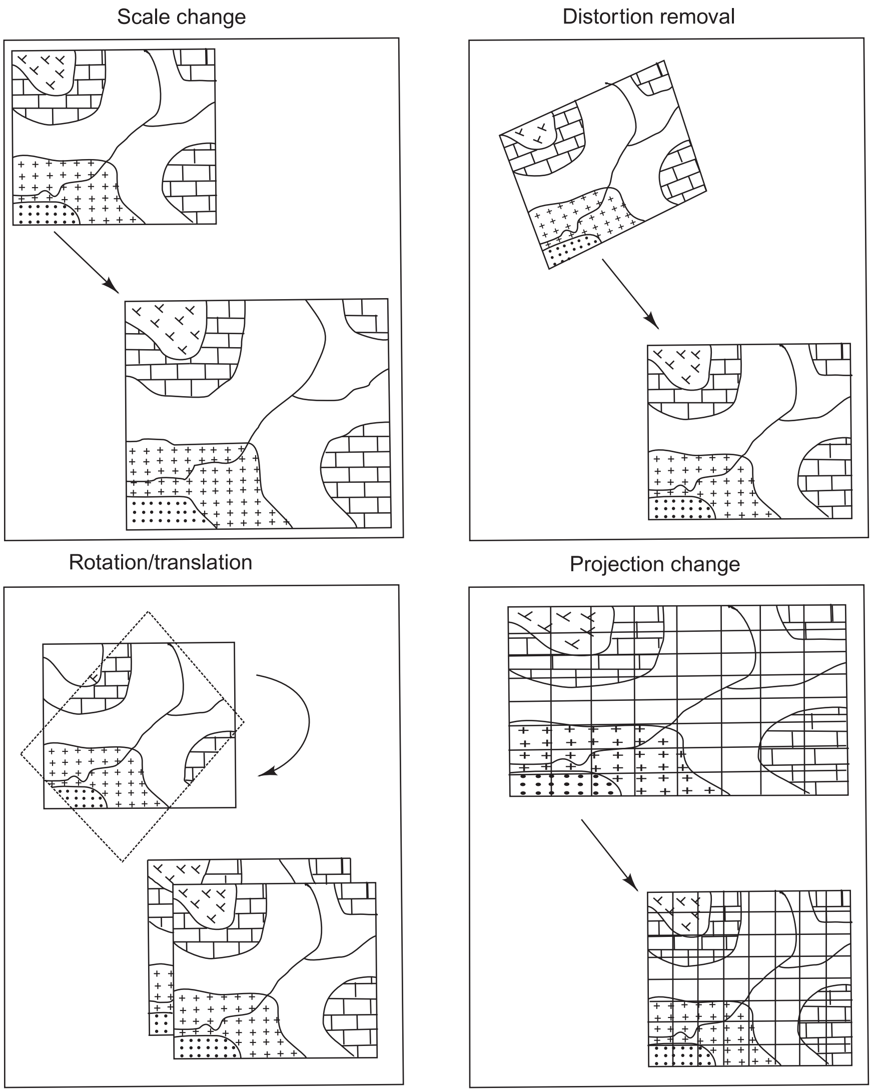

Fig. 19.26 *GIS functions: Some common manipulations (after Panda 2005)*

19.5.3.2 Map Overlays

Map overlay function creates new map layers with an existing one. The process facilitates creation of new features by intersection of features of each coverage. Attributes of input layers are also combined in the overlay process to describe new output features. The overlay function is illustrated in Figs 19.27 and 19.28, in which dominant mathematical operation is intersection and union.

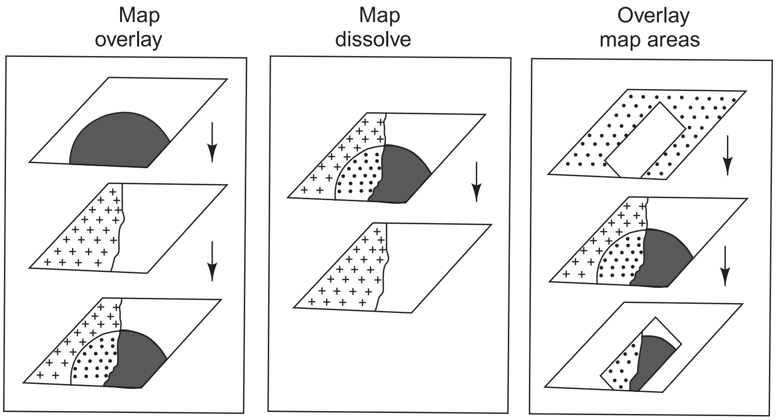

Fig. 19.27 *Map overlay and dissolve (after Panda 2005)*

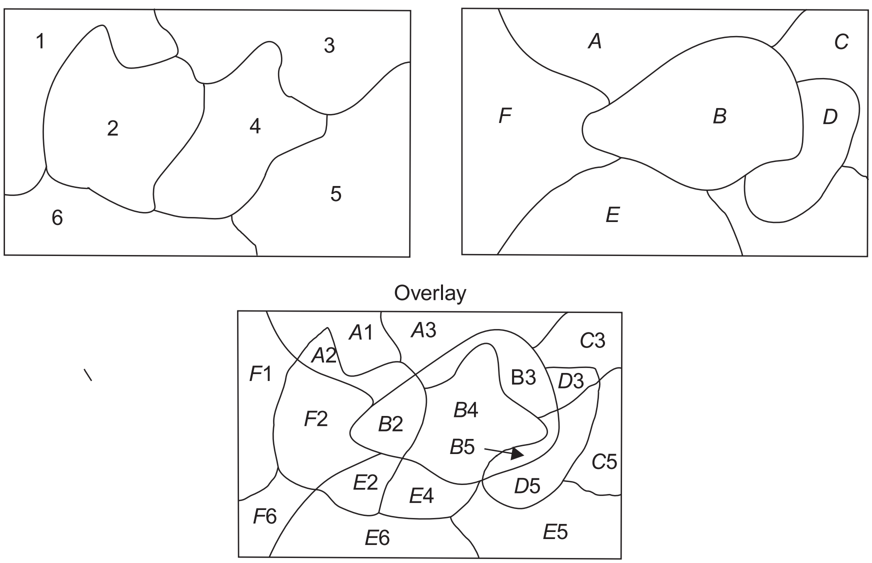

Fig. 19.28 *Overlay of soil and vegetation maps*

19.5.3.3 Map Dissolve

The dissolve function deletes the boundaries between adjacent polygons having same attribute values for a specified feature. Dissolve operation also retains only the required features by clipping the unwanted polygons from the map. This is especially useful in retaining the details within a district or block boundary (Fig. 19.27).

19.5.3.4 Buffer

Buffers are polygons created around point, line or polygon. These are illustrated in Fig. 19.29. The buffers are used for various purposes including zoning and impact assessment. For example a 5 km buffer around a primary health centre (a point) may indicate the population benefited by it. Likewise, A 1 km buffer along a canal (a line) may indicate waterlogged areas. Two kilometer zone around an open cast mine (a polygon) may indicate environmentally polluted zone due to mining activity.

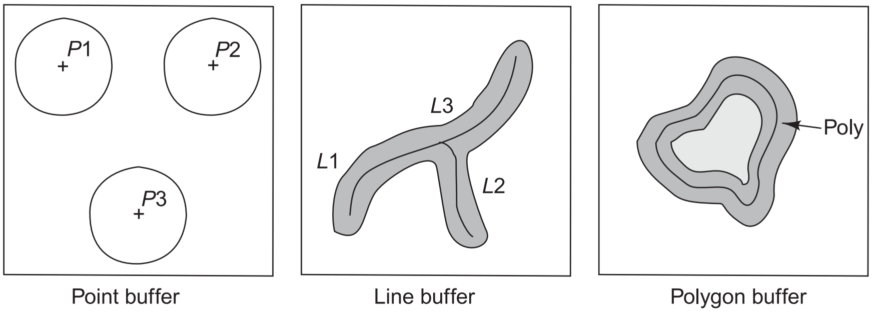

Fig. 19.29 *Buffers around points, lines and polygons*

19.5.4 Data Output Functions

The emphasis of GIS output functions are required for better quality, accuracy and user friendly operations. The GIS output functions are shown in Fig. 19.30. The outputs may be in the form of display on the monitor, listing in tabular or text form, print out as a single layer map or multilayer coloured maps, data files in hard copy or on tape, disks and other modes of electronic storage.

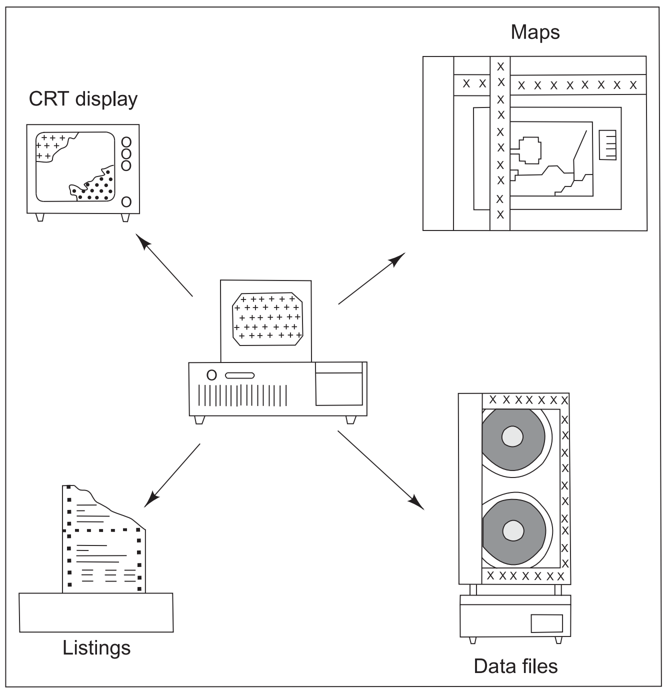

Fig. 19.30 *GIS outputs*

19.6 REMOTE SENSING AND GIS

By definition, Remote Sensing is the science and art of obtaining useful information about an object or phenomenon without coming in contact with it. Geographical Information System (GIS) represents hardware and software systems, designed to capture, store, manipulate and display spatial information and related attributes. Thus the two are complementary to each other, in solving large number of complex problems of the society at operational levels. With better resolution of remote sensing sensors to sub meter levels (QuickBird, Ikonos, GeoEye and Cartosat), it is possible to tackle practical problems of any desired scale with the help of GIS.

Although remote sensing and GIS technologies are involved in the analysis of phenomena which have spatial significance, the GIS requires accurate, digital, polygonal or point network data sets as its input for further processing. On the other hand remote sensing presents raw data, which needs to be classified into meaningful polygons through digital image processing and transformed to vector format, acceptable by the GIS as layers of spatial information for further processing.

Both the technologies have evolved rapidly. Their evolution was along separate paths. These paths are now converging since GIS technology is ideally suited to the analysis of spatial phenomena and remote sensing is the most common source of spatially continuous data. Remote sensing data analysis requires collateral data for improvement of its classification schemes. These valuable information is usually available in GIS as attribute data. Thus substantial improvement in the accuracy of classification and interpretation of satellite imagery can be made. Together these technologies offer the most promising and practical means of monitoring and managing our natural resources.

The realization that there is no difficulty in the data flow either way of the two systems, the future development is towards a hybrid image based information system (IBIS), having twin capabilities of image processing system and GIS.

19.7 GIS APPLICATIONS AND STATUS IN INDIA

GIS is being used in number of fields at individual, institutional, industry and governmental levels, for planning and development activities. The GIS applications can be divided into three categories on the basis of geographic phenomena studied, which is either manmade or natural or both. Setting up cadastral information system or using GIS for urban planning purposes involve study of man-made things mostly: the parcels, roads, sidewalks, suburbs and transport routes. These entities mostly have clear-cut boundaries.

On the other hand, geomorphologists, ecologists often have natural phenomena as their study objects. They may be looking at rock formations, plate tectonics, distribution of natural vegetation or soil units. Often these entities do not have clear-cut boundaries and there exist transition zones.

Many times we find GIS applications doing a bit of both. Examples are common in areas where we study the effect of human activity on the environment. Construction of Rail-road may be an example of this type, where parcels involved in the project area are to be reclaimed from the Government. It involves assessing of environmental impact within inclination extremes in the hilly terrain and avoiding active flood planes of the streams *en route*.

There are research projects using GIS applications with well defined time duration; while in an Institution, use of GIS applications has no time duration. Their goal is to provide basic data to others. Example of this category are: monitoring systems of flood, water scarcity, snow cover melt or systems that keep track of weather patterns. National topographic or thematic surveys, cadastral organizations and national census bureaus keep their data up-to-date and provide data to others either in form of printed material, such as maps, or in form of digital data.

Within the ambit of state governments, there are two major areas of applications of the spatial/cartographic information viz. (i) cadastral map available with the land records and (ii) detailed ward-wise maps with the municipal bodies. At National level, all mapping organizations use GIS effectively and data sharing among the users is the key to the success stories. National Spatial Data Infrastructure (NSDI) is one such common platform available in India, just like other countries have their own SDIs.

19.7.1 NSDI

The idea of spatial data infrastructure was mooted at the ISPRS Congress in Amsterdam in 2000. Soon after a task force was constituted by Department of Science and Technology (DST), Government of India, which included representatives of various national mapping organizations, like Survey of India (SOI), Geological Survey of India (GSI), Forest Survey of India (FSI), Indian Meteorological Department (IMD) National Remote Sensing Agency (now NRS Centre), National Informatics Centre (NIC), Central Water Commission (CWC), Central Ground Water Board (CGWB), etc. It gradually evolved strategies for technical, institutional, financial and revenue modalities for Indian NSDI.

In view of India's strength in IT and Geospatial technologies and rich tradition in spatial data collection (SOI, established in 1767 and GSI in 1851 are the oldest organizations) it was chosen to become founding member of Global SDI (GSDI), in 2001. GSDI-6 conference at Budapest, Hungary, in 2002, was attended by members of ISRO, NIC, GSI and SOI. Dr. Mukund Rao of ISRO was elected Vice President of GSDI. He was elected President subsequently. This gave boost to the activities of NSDI. A formal approval for NSDI was given by Government of India on 2nd June, 2006.

The International Standards Organization (ISO), Technical Committee 211 brought out the ISO19115 for Metadata. Subsequently, NSDI Metadata Standard Version 2.0 was released in 2009, which is in tune with ISO19115.

All these efforts lead to building a consensus amongst all the spatial data processing agencies. Now they are willing to participate and share their data assets on a common platform of NSDI. The Open Map Policy of 2005 was the result of sustained discussions during the evolving stage of NSDI. It is hoped that, by 2020, the participating agencies will own NSDI and Government's role will become as a facilitator. The NSDI movement has contributed significantly in making people aware of GIS as a tool and mechanism for growth.

19.7.2 NTDB

Survey of India has created National Topographic Data Base (NTDB), where topographic data is available in the National Standard Exchange format. NTDB deals with the task of digitization of maps on 1: 25,000, 1: 50,000 and 1: 250,000 scales, as the topographic information forms the base for other spatial information. Users would be able to obtain data pertaining to any part of the country without any restriction.

19.7.3 NRDMS

Natural Resources Data Management System (NRDMS) is a multi-disciplinary and multi-institutional programme launched by Department of Science and Technology (DST) for developing a scientific database approach for operationalising the concept of micro level planning. Major objectives of the programme include *inter alia* development of integrated district level resource databases on natural resources and allied sectors for use in local level planning and rural development.

NRDMS has initiated various R and D seed projects to nurture spatial data, technology and applications. It also supports the Advanced Research Laboratory (ARL) at IIT Mumbai, which developed, a low cost indigenous GIS software package, GRAM++, for academic and research purposes. The use of spatial data and tools/technologies like GIS, GPS and Remote Sensing, at different level of planning, will improve the quality of resource management decisions/strategies. Spatial Decision Support Systems in the sectors of water management, energy budgeting, landuse planning and location allocation of facilities (roads, hospitals, fair price shops, etc.) have been tested and demonstrated to user agencies. Modeling/application studies have been launched in the sectors of hydrology, ecological biodiversity, sustainable agriculture and landslides, to better address the user's information needs.

NRDMS data centers, operating in over 60 districts in the country, have helped in evolving NSDI. Karnataka Geoportal of the province of Karnataka and India Geoportal (launched on 22nd Dec., 2008) have come up after sustained efforts of NRDMS and NSDI.

19.7.4 NNRMS

National Natural Resources Management System (NNRMS) was initiated by Department of Space (DOS) for generating a proper and systematic inventory of natural resources, adopting various advanced technologies such as Remote Sensing, GIS, GPS, database and networking infrastructure and advanced ground-based survey techniques. Over the years, NNRMS has provided impetus to use data from Indian Remote Sensing Satellites (IRS) series and has generated large spatial database through national mapping missions.

NNRMS developed a Metadata Standard in 2002-03. Metadata, which is the first element and interface of the user to a repository, enables a user to find, on-line, spatial data that is available with NNRMS. It was this Metadata Standard that defined the schema and design for the NSDI Metadata.

19.7.5 NRIS

In 1998, NNRMS took a major leap in defining GIS standards for the project National Resources Information System (NRIS). It enabled the availability of a national inventory of natural resources information in spatial formats and with proper linkages to other socio-economic data within the framework. NRIS is visualized to be a network of GIS based nodes covering data for districts, states and even the entire country. NRIS will later become a part of NSDI, enabling a national network of GIS-based information systems at local, state and national level on key parameters of natural resource management.

19.7.6 Bhuvan

Yet another initiative taken up by ISRO/DOS has been the designing, development and launching (2010) of 'Bhuvan', the image and map data visualization in 2-D and 3-D. *Bhuvan*, in Sanskrit, means Globe, which this portal displays with its distinctive visualization capabilities by porting entire geospatial raster and vector databases. This application demonstrates India's imaging capabilities by providing seamless viewing of coarse resolution to high resolution raster images, database cataloguing services, varieties of value-added services in 2-D/3-D, vector services, user-friendly interactive services, etc.

This facility enables large number of users, within and outside the country, to utilize the services concurrently for such viewing through the portal. It will further enable ISRO to keep portraying current events as well as newer value-added services on a regular basis on a near real time basis, for the benefit of the public at large.

19.7.7 National Informatics Center (NIC)

NIC, under the Department of Information Technology, Government of India, is dedicated to active promotion and implementation of information and communication technology (ICT) solutions in the government. NIC leveraged ICT to provide a robust communication backbone and effective support for e-governance to the Central, State governments, UT Administration, district and other government bodies. It offers a wide range of ICT services. This includes NICNET, a nationwide communication network with gateway nodes at about 53 departments of the Government of India (GOI), 35 State/UT Secretariats and 603 district collectorates to service ICT applications. One of the milestones of NIC, India Image Portal, is a gateway to Indian government information with a mission to extend comprehensive World Wide Web services to ministries and departments. Under this project, over 5000 GOI websites are being hosted.

Suggestions for Further Reading

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Frequently Asked Questions

1. Describe different components of Geographical Information System (GIS).
2. Write short notes on: Raster data; Vector data; Spatial Data Capture; Adjacency; Connectivity; Containment; Map Dissolve; Buffer.
3. Write about Spatial data as Coverage and Spatial Objects.
4. Describe various relationships of spatial objects.
5. What are different GIS functions? Illustrate in detail about Data Manipulation and Analysis functions.
6. How Remote Sensing is related to GIS?
7. Write about the status of GIS applications in India.

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ABOUT THE AUTHOR

Born on 8th February, 1943, Dr. G.S. Srivastava has his early education in Rae Bareli district of Uttar Pradesh. He was a meritorious student all along He graduated with Honours from University of Lucknow in 1961 and did his M.Sc. in Geology, in 1963. Soon, he joined Oil and Natural Gas Corporation, in 1964.

After a brief stint in Ankleshwar oil field of Gujarat, he got selected through Geologists' Examination of UPSC and joined Geological Survey of India, in 1966 as Geologist. His initial years were devoted to eological mapping in high altitudes of Himalayas and mineral investigations in J & K state. He joined Indian Institute of Remote Sensing, Dehradun in 1972 for pursuing Diploma course, where he topped his batch with Honours grade. He was appointed as Professor (Reseach) in IIRS and was awarded Dutch fellowship for completing M.Sc. degree in Remote Sensing from ITC, The Netherlands.

On his return in 1975, he was made Officer-in-charge of Advanced Course in Photogeology and Remote Sensing, in the GSI Training Institute, Hyderabad, where he conducted several courses for GSI officers. Using Remote Sensing technique, he carried our many investigations covering geological and geomorphological mapping, snow cover assessment, mineral exploration, IRS utilization programme, etc.

He joined Remote Sensing Application Center, U.P., as Scientist E, on deputation for two years (1983-85), where he helped in establishing the Center and headed its Earth Resources Division.

He was promoted as Director in 1992 and supervised the activities of PGRS and Environmental Geology Divisions of Western Region of GSI. He initiated Database management and actively collaborated with BRGM, France, in establishing Geoscientific Data Centers in GSI. He was also closely associated with National Spacial Data Infrastructure (NSDI) activities and was a member of Indian delegation to the VI Global Conference on GSDI, at Budapest, Hungary, in 2002.

As the Deputy Director General of Op: U.P. and Uttaranchal, he supported clearance of Tehri Dam Project. He contributed significantly in the River Linking Project for the nation. After his superannuation in 2003, he joined the University of Lucknow and completed his Ph. D. degree in 2009, on the problem of Vedic Saraswati River, in Punjab-Haryana Plain, under the guidance of Prof. I. B. Singh, FNA. He has published about 50 research papers in national and international journals and submitted as many technical reports to the GSI.

He is a Life Member of Indian Society of Remote Sensing and Indian Society of Geomatics, Indian Society of Glaciological Sciences and Lucknow Management Association. He was elected as Fellow of ISRS in 1999 and was Vice-President of the ISRS for couple of terms. He was Chairman of Lucknow Chapter of ISRS for several terms. He has been Visiting Professor for many universities for teaching Geoinformatics including Remote Sensing, Photogrammetry, GIS and GPS, and is continuing till date. He is presently a Member of Research Advisory Committee of Wadia Institute of Himalayan Geology, Executive Committee of ISRS Lucknow Chapter and various UGC Committees.

Dr. G.S. Srivastava
Former Deputy Director General, Geological Survey of India

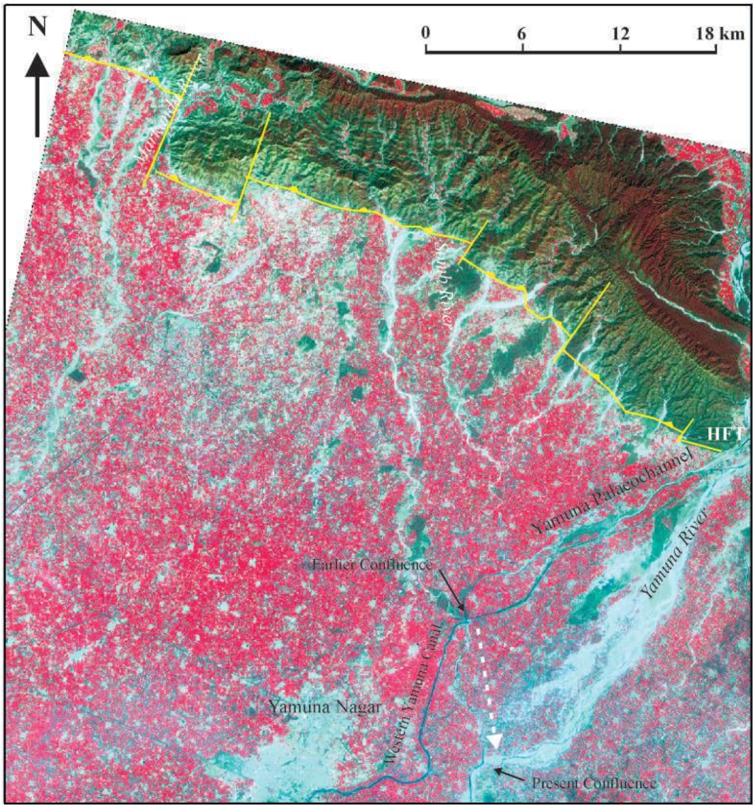

Fig. 12.5 *Neotectonic activity in foothills of the Himalayas*

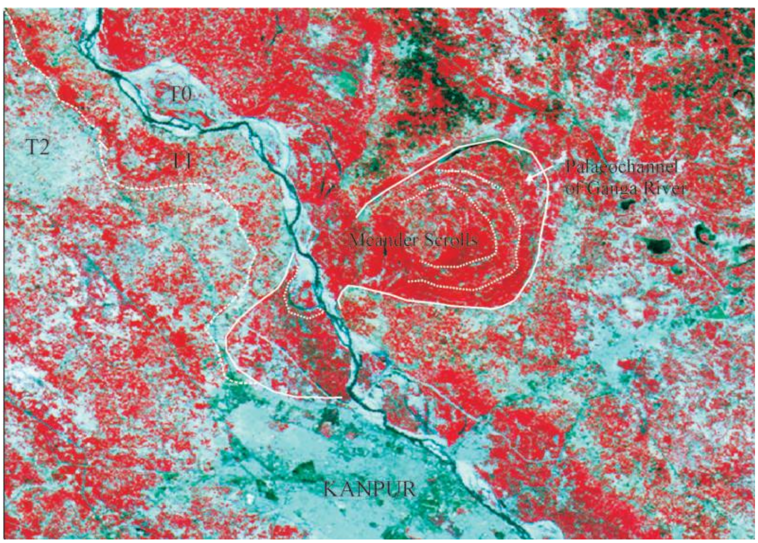

Fig. 12.6 *Palaeochannel of Ganga river*

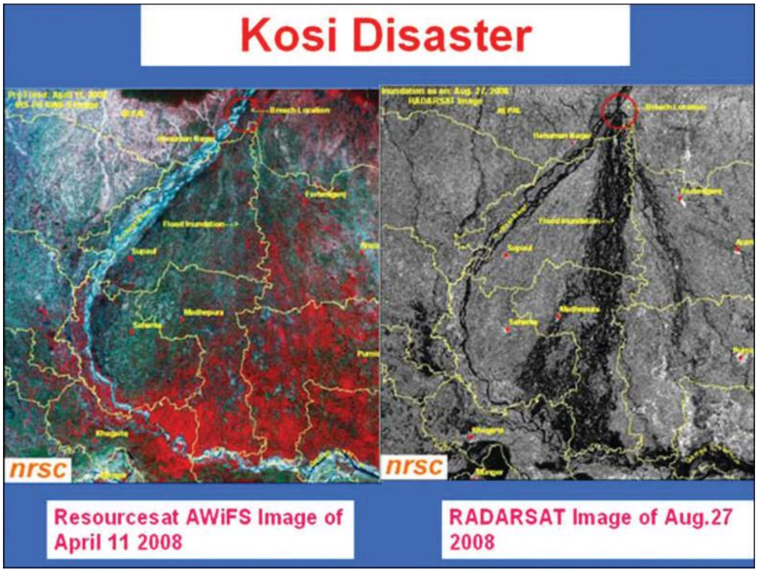

Fig. 12.7 *Kosi disaster (Courtesy: NRSC, Hyderabad)*

Fig. 15.5 *Total station*