INPUT DEVICES

Human–computer interaction (HCI) is now a multidisciplinary area focusing on the interface and interactions between people and computer systems. Figure 1 presents a conceptual view of HCI: A user interacts with a system (typically a processor or device) using one or multiple input devices.

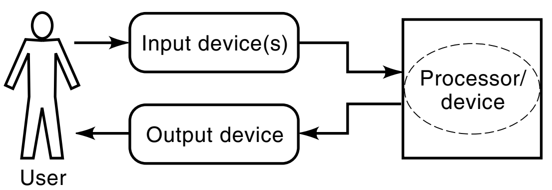

Figure 1. Fundamental human–computer interaction model.

Input devices convert some form of energy, most often kinetic or potential energy, to electric energy. In this article we consider analog and digital input devices. Analog input devices generate voltages that vary over a continuous range ($R = V_{max} - V_{min}$) of values and are converted to binary values by an analog-to-digital converter (ADC). Digital input devices are based on binary digits. An input device that generates logical 0's and 1's, on and off, respectively, is called a *binary switch.* A binary switch generates the binary digit 1 when the input voltage is equal to or greater than a specified threshold value and the binary digit 0 otherwise. A second type of digital input device approximates an analog signal and provides a binary stream. Thus, any device that produces an electrical signal or responds to an electrical signal can be used as an input device. Preprocessed analog (digitized) and digital signals generated by an input device are passed on to the processor/device for processing. Once processed, the processor/device may, and often does, generate a new signal or a series of signals. These signals can be used to trigger events on some attached output device.

Figure 2 shows examples of a signal produced by an analog input device. To be used with a digital computer, the analog signal can be processed to mimic an on/off switch or it can be digitized using an ADC. The performance of an ADC depends on its architecture. The more bits the ADC operates with, the better the resolution of the signal approximation.

Input devices can be further classified as acoustic, inertial, mechanical, magnetic, and optical input devices.

DEVICES

Based on their basic operation, input devices can be classified as 2-D, 3-D, 6-D, or *n*-D (degrees of freedom) input devices. Table 1 lists some of the most popular input devices and degrees of freedom associated with each. Many devices can fit in several categories. Also, as any device can emulate another, this table is to be used simply as a guide. Finally, there are other forms of input technologies that are described elsewhere in this encyclopedia.

Many of the aforementioned devices can be used in combinations with other input devices, thus providing the notion of either two-handed input or multimodal input. For example, the use of two data gloves is considered two-handed input, as is the use of a mouse along with a Spaceball, whereas the use of a mouse along with speech recognition is considered to be multimodal input.

COMMONLY USED INPUT DEVICES

Keyboard

The keyboard is now considered the most essential input device and is used with the majority of computers. Keyboards provide a number of keys (typically more than 100) labeled with a letter or a function that the key performs. Keyboards manufactured for use with notebooks and palm computers or those designed for users with special needs typically provide a reduced set of keys. Different alphabets require different characters to be mapped to each key on the keyboard (i.e., English QWERTY versus German QWERTZ keyboard). Such mappings are achieved by reprogramming the keyboard's in-

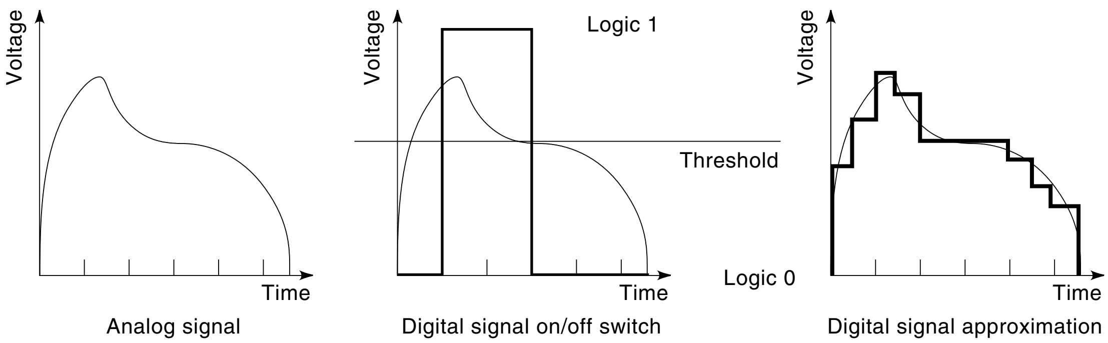

Figure 2. Input signals.

struction set. Certain keys (e.g., ALT, CTRL, and SHIFT) can be used in conjunction with other keys, thus permitting one key to map to several different functions.

Mouse

Since its creation at Xerox Palo Alto Research Center (PARC), the mouse has become the most popular 2-D input device and has a wide number of variants. Regardless of the variation, each mouse has one, two, or three buttons. For most mouses, the motion of a ball, located underneath the mouse, is converted to planar motion—a set of x and y values—using a photoelectric switch as an input transducer. The photoelectric switch contains a light-emitting diode as a source, a phototransistor as a sensor, and a circular perforated disk as a switch. When the light emitted from the diode reaches the sensor, a pulse (logic 1) is generated and passed on to the interface electronics. The frequency of pulses is interpreted as the velocity of the mouse. There are two such input transducers built in a mouse—one for the x and one for the y axis. Figure 3 shows the principle of motion-to-electric energy conversion.

The majority of mouses use this principle of motion conversion. Optical mouses take advantage of the reflective properties of mouse pads that have a grid of thin lines printed on their smooth and reflective surface. As the mouse passes across the line of a grid, a portion of the light emitted from the light-emitting diode is diffracted, resulting in a slight drop of a voltage on the sensor's side (Fig. 4). These drops of voltage are used to determine the direction and speed of movement of the mouse.

Table 1. Input Device Classes

Input Device	1-D	2-D	3-D	4-D	6-D	n-D
Data glove						X
Digitizer		X	X			
Eye tracker		X				
Graphic tablet		X				
Trackpoint device		X				
Joystick		X	X	X	X	
Lightpen		X				
Monkey						X
Mouse		X	X	X		
Position tracker	X	X	X	X	X	X
Scanner		X	X			
Slider	X	X				
Spaceball					X	
Touch screen		X				
Touchpad		X				
Trackball		X				

Trackball

A trackball can be described as an inverted mouse. To move a cursor on the screen, the user moves the ball in the desired direction. The motion of the ball is translated to electric signals using a set of perforated disks (one for the x and the other for the y direction). Trackballs, like mouses, are equipped with one or more buttons that are pressed to perform a desired operation. Many notebooks and portable computers provide built-in trackballs, as these require much less space than a mouse.

Joystick

The joystick made its first major appearance in arcade machines in the early 1980s. The basic joystick is a 2-D input device that allows users to move a cursor or an object in any direction on a plane. Typically, a joystick consists of two major parts—a vertical handle (the stick) and a base—each providing one or more buttons that can be used to trigger events. To move the cursor or an object, the stick is moved in the desired direction. Figure 5 shows a major limitation imposed by the resolution of a joystick. The resolution in this example joystick makes it impossible to move in the indicated direction (desired direction), making navigation a bit difficult.

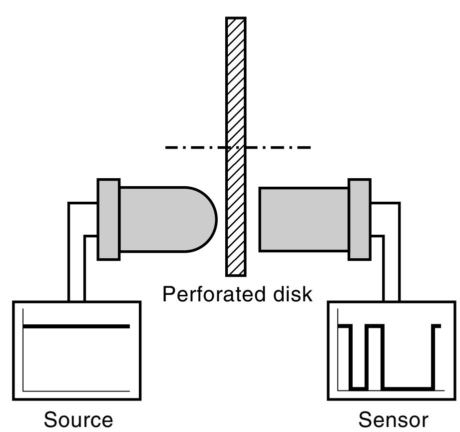

Figure 3. Motion to energy conversion.

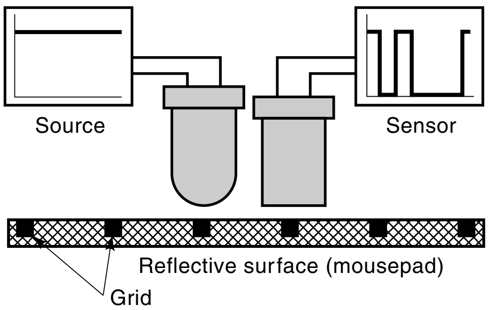

Figure 4. Optical mouse structure.

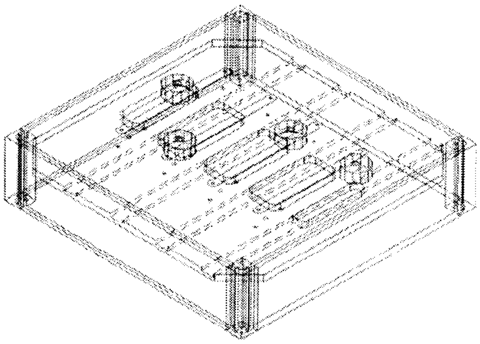

Figure 6. Slider box. (Image courtesy of Simulation Special Effect, LLC.)

There are two major types of joysticks—isotonic and isometric. *Isotonic* joysticks are precision position-sensitive devices, used in animation, special-effects development, and games. These joysticks are equipped with a set of springs, which return the joystick to the center position when released. A stream of x and y values is generated based on and proportional to the angle between the initial and the current position of the control stick. Some implementations of isotonic joysticks are insensitive to the angle α. These use switches to provide information on direction. *Isometric* joysticks provide no spring action—the control stick does not move. The x and y values generated by the joystick are proportional to the force applied to the control stick. Some newer joysticks also have been provided with tactile and force feedback.

Slider

A slider is a 1-D input device (Fig. 6). Although sliders are usually implemented in software as part of a graphical user interface (GUI), slider boxes are available as input devices in applications requiring a large number of independent parameters to be controlled [as in musical instrument digital interface (MIDI) applications requiring multiple channels to be manipulated independently]. Most windowing systems incorporate sliders to support panning of the window's content or for color scale value selections.

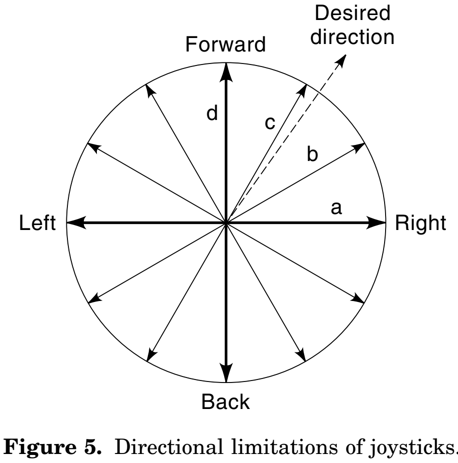

Figure 5. Directional limitations of joysticks.

Spaceball

The Spaceball is a 6-D input device used primarily in computer-aided design and engineering, animation, virtual reality, and computer games. It enables users to manipulate a 3-D model with 6-degrees-of-freedom control (simultaneous x, y, z, translations and rotations) and as easily as if they were holding it in their hands. A Spaceball is often used in conjuction with the mouse. Spaceballs made their appearances initially with high-end graphic workstations, but this is not the case anymore. As desktop computers have become more powerful, many applications make use of the Spaceball and its derivatives.

Touchpad

A touchpad is a 2-D input device developed for use in areas with limited space. Touchpads provide precise cursor control by using a fingertip moving on a rectangular area. Buttons located on the side of the rectangular input area can be programmed to perform specific operations as modifier keys on keyboards. Touchpads are usually located under the SPACE bar or the cursor keys, or they can be attached to a computer through a serial port.

Input Tablet

An input tablet is a variation of a touchpad. It is larger than a touchpad, and instead of a finger, a penlike device with a button to perform specific operations is used. A coil in the pen generates a magnetic field, and a wire grid in the tablet transmits the signal to the tablet's microprocessor. The output data include the pen's location, the pressure of the pen on the tablet, and the tilt of the pen in relation to tablet. Input tablets are mostly used in the design arts and in mechanical and engineering computer-aided design.

Integrated Pointing Device—Stick

A 2-D integrated pointing device, called a stick, is a miniature isometric joystick embedded between the keys on the keyboard. To move the cursor, the user pushes or pulls the stick in desired direction. The buttons associated with the stick are located under the SPACE bar on the keyboard.

Lightpen

A lightpen is a penlike 2-D device attached to a computer through one of the communications ports or through a dedicated controller board. It is used to draw or select objects directly on the screen. Lightpens may be optically or pressure driven. An optically driven lightpen receives light from the refresh update on the screen; the x, y position of the refreshed pixel is then available for processing. A pressure-driven lightpen is triggered by pressing the lightpen on the screen or by pushing a button.

Touch Screen

A touch screen is a special type of a 2-D hybrid device because it can both display and acquire information at the same time. On the input side, a touch screen contains a set of sensors in the x and y directions. These sensors may be magnetic, optical, or pressure. Users simply touch the screen, and the sensors in both x and y directions detect an event at some x and y coordinate. Since users tend to use a finger to interact with the touch screen, the resolution of the input device is not fully utilized. In fact, it is often limited to the size of a fingertip. Touch screens are very popular in menu-driven environments such as information booths, fast-food restaurants, and control rooms.

Scanner

A scanner is a 2-D input device used to capture pictures, drawings, or text. Images, color or black and white, can be captured and stored in digital form for analysis, manipulation, or future retrieval. Associated application software is typically bundled with scanners. This includes imaging software, photo manipulation software, vector graphics conversion software, or text creation (using optical character recognition) software. Three major scanners are available: handheld, flatbed, and sheet scanners. Handheld scanners are suitable for small-scale scanning, flatbed scanners usually handle up to legal-size documents, and sheet scanners usually handle documents of fixed width but arbitrary length. Some engineering firms and geographers use special large-scale scanners for digitizing blueprints and maps.

Digitizer

A digitizer can be considered either a 2-D or a 3-D input device. There are numerous kinds of digitizers available. Many older and less expensive systems require a great deal of manual work to acquire the data points. For example, the user may need to draw a grid on the object to be digitized to enable the acquisition of coordinates for every point on that grid. This is both time consuming and error prone.

3-D Laser Digitizers

Nonmanual digitizers can automate several parts of the digitization process. These are primarily laser-based scanners. An object is positioned on a podium and the scanner rotates the podium while the digitization takes place. Some digitizers revolve around the object when the object is too big or to heavy to be rotated easily around its axes. Such scanners project a beam of laser light onto the model. The intersection of the laser beam and the surface of the object creates a contour of the model captured by a camera and displayed on the screen. This can be done in real time, and a color camera can be used to generate a color model. Most laser scanners use laser triangulation to reconstruct the object.

Position Trackers

Position trackers are used to detect motion and are often attached to objects or body parts. Trackers perform reasonably well. Newer trackers have removed the tethering limitation of older trackers. Newer technologies are also solving the line-of-sight problem (the receiver's requiring an unobstructed view of the sensors). Some trackers need to be recalibrated often to maintain a high degree of accuracy.

Mechanical. Mechanical position trackers use a rigid jointed structure with a known geometry. Such a structure has one fixed and one active end, with the position of the active and available in real time. Mechanical tracking devices are very fast (less than 5 ms response time) and very accurate. The accuracy depends on the accuracy of joint angle encoders. A tracker with a full-color head-coupled stereoscopic display can provide high-quality, full-color stereoscopic images and full 6 degrees of freedom (translation along x, y, and z as well as roll, pitch, yaw).

Magnetic. Magnetic trackers use a source that generates three fields of known strength. Detectors are attached to the object to be tracked and measure the magnetic field strengths at a given point. These values are used to determine 6 degrees of freedom in space. Magnetic trackers do not experience any line-of-sight problems and are scalable to many detectors. However, the amount of wiring increases as the number of detectors increases. Magnetic trackers do not operate well around ferrous materials.

Ultrasonic. Ultrasonic trackers are often attached to a virtual reality (VR) headset. The tracker consists of three receivers and three transmitters. The position and orientation of the object is calculated based on the time required for each transmitted signal to reach a receiver. Ferrous materials do not affect such trackers. However, ultrasonic trackers are affected by the line-of-sight problem and may be affected by other sources of ultrasonic harmonics.

High-Speed Video. High-speed video along with fiducial markings on a tracked object is used to determine the location of an object in space. A single picture or a series of pictures are acquired and later processed using image-processing techniques. Fiducial markings can also be located in the space (i.e., scene or walls) and the camera can be attached to the object itself. Such device can then be used to control the navigation of a robot between two given locations. High-speed video is used for work in a large space because no extra wiring is necessary. Video is unaffected by ferrous and other metals, ultrasonic sound, and light. However, the line of sight problem does affect video-tracking systems.

Inertial. Inertial position trackers are used to measure orientation and velocity. They are untethered and are not limited by the range or the size of the volume they operate in. Inertial position trackers provide almost complete environmental immunity. Such trackers are sensitive to vibrations and can thus result in inaccurate readings.

Biological. Eye tracking is a relatively old technology although not in common use. Eye tracking can be used for control or monitoring. For example, a pilot can control various instruments by simply looking at them. A low-powered infrared (IR) beam is used to illuminate the eye, which in turn is captured using a small camera. The image is processed to track pupil and corneal reflection. Today's eye tracking devices operate at one degree of resolution. It takes approximately one-third of a second to select, acquire, and fix on an image. Modern applications of eye tracking include its use as an input device for the disabled.

Digital Whiteboard

A digital whiteboard is a 2-D input device designed to replace traditional blackboards and whiteboards. Everything written on the digital whiteboard with a standard dry-erase marker can be transmitted to a computer. That information can then be used by any application, such as e-mail, fax, or teleconferencing.

Data Glove

A data glove is an input device that uses properties of leaky fiber-optic cables or resistive strain gauges to determine the amount of movement of fingers and wrists. Leaky fiber-optic cables provide good data, but it is the resistive strain-based input gloves that provide more accurate data. Each data glove is often combined with a 3-D tracker and with 10 strain gauges—at least one for each finger joint—which provides a very high degree of freedom. The latest data gloves also have been extended to provide tactile/force feedback using pneumatic pistons and air bladders. Data gloves can be used along with gestures to manipulate virtual objects or to perform other tasks.

Microphone/Speech Recognition and Understanding

The microphone has proved to be one of the most useful input devices for digitizing voice and sound input or for issuing short commands that need to be recognized by a computer. Longer commands cannot be handled by simple recognition. Most sophisticated systems available today still cannot guarantee 100% understanding of human speech.

Monkeys or Mannequins

The first monkeys were humanlike input devices with a skeleton and precision rheostats at the joints to provide joint angles. Monkeys can be used to set up and capture humanlike motions and offer much better degree-of-freedom match than other devices. Since the first monkeys, a series of animal-like input devices and building blocks have been created that allow users to create their own creatures.

Game Input Devices

There are a number of other specialized input devices designed to make playing games a more exciting and more realistic experience. Most of these input devices offer additional degrees of freedom and can be used along with other input devices.

CONCLUSIONS

There are a large number of input devices, and the technology is rapidly changing. It is expected that speech recognition and command interpretation, gesture recognition for highly interactive environments (game and virtual), and real-time imaging will become more prominent in the next decade. These will increase the level of human participation in applications and the bandwidth of the data transferred.

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