how it works

THE HUMBLE STYLUS IS STAGING A COMEBACK.

Digitizing a natural interface

By Robert Cravotta, Technical Editor

THE STYLUS IS ONE of the most universally understood tools for drawing and pointing. As an intuitive extension of our fingers, it is one of the first tools a child ever plays with—as a crayon, a pencil, chalk, or even a stick to draw in the mud. We quickly learn the mechanics of using a stylus through years of repetitive use and refine our skill with it throughout childhood. The average child will wear down about 730 crayons by his 10th birthday, according to Crayola. With all this natural experience using styluslike tools, why do most desktop computers come with a mouse instead?

As with any pointing device, applicability to the task, cost, size, portability, precision, and ergonomics all play a role in which one you choose. As the cost difference among pointing devices shrinks, ergonomics; avoiding medical injuries, such as RSI (repetitive strain injury); and portability become more important (see **sidebar** "Ergonomics and other trade-offs" on the Web version of this article at www.edn.com). The mouse has proved cost-effective and precise enough for computing, but as computing becomes more portable and stylus-based devices begin to carry smaller price tags, the mouse may yet become a historical footnote for pointing devices.

The mouse began as part of a project aimed at augmenting human intellect. A set of experiments compared the mouse with a joystick, a Grafacon (a tablet input device), a knee control device, and a light pen (**Reference 1**). The experiments characterized the relative error rates of each device and the speed and accuracy with which a user could select material on the display screen. The results indicated that, for experienced users, a mouse is faster and more accurate than the other devices. Inexperienced users, however, perform better with a light pen.

Doug Engelbart, a research scientist at Stanford Research Institute (Stanford, CA), holds the patent for the "X-Y Position Indicator for a Display System," the basis of the computer mouse. In 1964, Bill English, who was then the chief engineer at Stanford Research Institute, built the first computer-mouse prototype. It was a carved block of wood with a single red button. A pair of wheels detected the motion of the mouse, which translated into cursor movement on the screen (**Figure 1**). Detecting and measuring mouse motion has evolved into optomechanical and optical implementations.

For optomechanical designs, a ball makes contact with the desktop surface and rotates two rollers, positioned 90° from each other, as the mouse moves. This type of mouse requires a surface, such as a mouse pad, that will roll the ball consistently at all points and in all directions. As each roller moves, it spins a disc with evenly spaced holes along its outer edge. An infrared sensor sees light pulses from the infrared LED on the other side of the disc as the holes pass in front of the sensor. Counting the pulses and applying acceleration and trajectory heuristics, determines how the mouse movement translates into cursor movement. The mouse has two sets of infrared LEDs and sensors for each disc—along with a piece of opaque plastic, located between the disc and each sensor at different heights. This difference in height allows the mouse software to infer the direction in which the disc is rotating, because there is a delay between when each sensors "sees" the light.

Early optical mouse implementations bounced light off a highly reflective mouse pad into a sensor. The mouse pad had a grid of dark lines that interrupted the

Figure 1 The underside of the mouse prototype shows the two wheels to detect motion. The wheels eventually moved inside the casing, where a ball acts upon them.

beam of light when the mouse moved, allowing the software to track the mouse movement. To use this type of optical mouse, you had to maintain the mouse at the right angle to ensure that the light beam and the sensor aligned. Losing or damaging the mouse pad rendered the mouse useless.

Contemporary optical mice do not require a mouse pad and can work on almost any surface. Optical mice reflect the light from a red LED and sample it with a CMOS sensor as many as 1500 times per second. A DSP performs signal processing on each sample to detect patterns in the desktop surface and to determine how those patterns have shifted since the mouse took the previous sample to determine the direction and amount of mouse movement.

AN ACTIVE STYLUS

The mouse was not the first digital computer-display pointing device. In 1963, Ivan Sutherland, then a graduate student at the Massachusetts Institute of Technology (Cambridge, MA), used a light pen to create engineering drawings directly on a TX-2 computer CRT monitor. A light pen is a stylus-type device that allows users to point and write directly on a display monitor. Light pens use a photocell that you place against the surface of a monitor to sense the CRT video-signal-refresh beam while it refreshes the display (**Figure 2**).

The CRT controller directs an electron gun to scan the display screen one line at a time—left to right and top to bottom. The electron gun is active while scanning left to right, exciting the phosphor to draw the displayed image. When it reaches the end of the monitor, the electron gun turns off, drops down one line, returns to the left edge of the monitor, turns on, and resumes drawing the next line from left to right. When the electron gun reaches the bottom of the display, it turns off and returns to the upper left corner to repeat this process and refresh the display image.

Phosphor glows brightly when an electron beam strikes it and slowly dims after the beam moves on. The photocell in the light pen relies on this behavior to sense when the electron beam is scanning where the light pen is pointing. The CRT controller records the current X, Y position of the electron gun that it is controlling when it receives a signal from the light pen that it has sensed the electron beam. The application software can then use the stored X, Y position to indicate a selected screen location like any other pointing device.

Another contemporary pointing device of the mouse prototype was the Grafacon, originally manufactured by Data Equipment Co. The Grafacon was a tablet input device for curve tracing. It comprised an extensible arm connected to a linear potentiometer; the housing for the linear potentiometer pivoted on an angular potentiometer. The voltage outputs represented polar coordinates from the pivot point, but the software driver converted them to Cartesian coordinates.

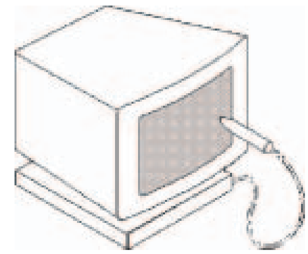


Figure 2

The light pen coordinates with the CRT controller to capture when the electron gun is refreshing the screen phosphor directly in front of the light pen's photocell.

Since then, digitizing-tablet implementations have used various methods to detect the position of the stylus on the tablet. Acoustic triangulation is a method in which sensors along the edges or corners of the active tablet space detect clicks that the tip of the stylus emits. The table can infer the stylus position by comparing the time difference between when each sensor detects the click. This method has the advantage of only needing a few active parts to cover a large area, but the stylus needs a power source, and the incessant clicking is a big drawback to the user.

Another method to detect the stylus position is to have the stylus transmit an electric field that acts on a grid of wires under the surface of the tablet. The tablet infers the stylus position by polling the horizontal and the vertical lines for the strongest signal. The stylus needs a power source, such as via a tether to the tablet or batteries in the stylus. Unfortunately, the tether can get in the way and restrict the stylus's movement. Also, batteries often need replacement and make the stylus bulkier than a regular pen.

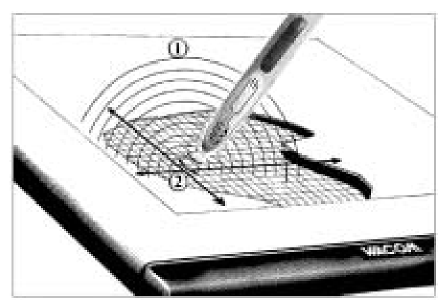


Figure 3

The graphic tablet alternates between transmit mode (1) and receive mode (2) to stimulate and detect the passive coil-and-capacitor-resonant circuit in the stylus device (courtesy Wacom).

A PASSIVE STYLUS

More recent tablet designs use a passive stylus that does not require a direct power source. Using optics to detect the stylus position places pairs of emitters and sensors along the edge of the active tablet area. The tablet infers the position of the stylus by determining where the light beam breaks along the horizontal and the vertical axes. This method allows anything, including a finger or a regular pen, to act as a stylus. However, it also means that the drawing or the pointing area must remain free of obstructions, such as those from users' hands; otherwise, ambiguous or erroneous position data could result.

Many of today's graphic tablets revisit the grid of wires under the surface of the tablet, as in an active-area approach, but use a passive stylus. During operation, the grid of wires under the tablet surface alternates between transmit mode and receive mode about every 20 msec (**Figure 3**). During transmit mode, the tablet's signal stimulates oscillation in the coil-and-capacitor-resonant circuit in the stylus. In receive mode, the tablet's antenna grid detects the energy of the resonant-circuit oscillations in the stylus to determine position and other information, including pressure. The stylus needs neither batteries nor a direct connection to a power supply, because the grid provides the power to the stylus through resonant coupling.

These alternating transmit and receive cycles work similarly to a tuning fork for tuning a piano. As you bring a tuning fork close to the appropriate vibrating piano string, it borrows energy from the vibrating string and resonates, generating a tone. Similarly, as the stylus comes close to the tablet surface, it resonates, generating its own frequency back to the tablet. The tablet triangulates the stylus's signal into location, tip-pressure, and stylus-tilt information by correlating the signal strength at each point on the grid.

TOUCH THE DISPLAY

The aforementioned graphic-tablet technology can coexist with tablet displays to allow users to work directly on display surfaces. Another point-and-select technology—the touchscreen—operates in a similar way but trades precision and extended functions, such as multiple buttons and tilt orientation, for lower cost. Touchscreens overlay display surfaces. Resistive touchscreens offer the best price with some image degradation, and capacitive ones offer the best durability and better image quality. Acoustic- and infrared-touchscreen implementations for high image clarity or large displays are also available.

Resistive touchscreens are the oldest and most widespread approach. You commonly use them with LCDs, especially on handheld devices. Users can employ a stylus or a finger—even a gloved one—to interact with the touchscreen. Resistive touchscreens comprise several thin layers laid over the display surface. Beneath a protective layer, such as polyester, electrically conductive and resistive layers sandwich a layer of invisible separator dots (**Figure 4**). All of these layers reside over a layer of glass or plastic that covers the CRT or the LCD. The separator dots normally prevent the conductive and resistive layers from making contact with each other. When a user touches the screen, the conductive and resistive layers make contact that alters the uniform flow of electricity in the conductive layer and allows the touchscreen driver to detect and infer the point of contact.

Capacitive touchscreens rely on a layer of capacitive (charge-storing) material, such as indium tin oxide, coated on or sandwiched between sheets of glass. Electrodes connected to oscillator circuits in each corner of the display convey a consistent amount of voltage across the capacitive layer. When a conductive object, such as a finger, touches the screen, it draws current to itself that causes the oscillator circuits to vary their electrical frequencies. The touchscreen controller can compare the fluctuations between the four corners to detect and infer the point of contact. A plastic stylus does not work with a capacitive touchscreen, because it can detect contact only with conductive objects.

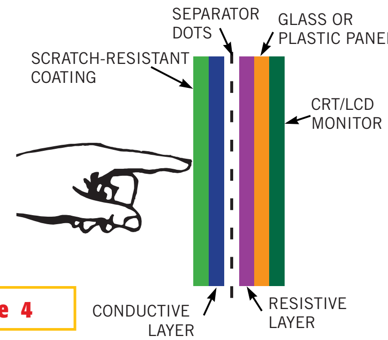


Figure 4

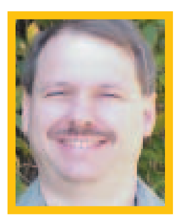
Pressure from a finger or stylus causes contact between the conductive and resistive layers of a resistive touchscreen.

No single type of pointing device excels in all features and constraints facing today's applications, but they have all evolved to be more natural to use, with better precision, less strain on the user, and lower cost. Tomorrow's pointing devices will have to continue evolve to handle even more challenges, such as wall-sized displays or flexible displays.□

Reference

1. English, William K, Douglas C Engelbart, and Melvyn L Berman, "Display-Selection Techniques for Text Manipulation," IEEE Transactions on Human Factors in Electronics, March 1967, Volume HFE-8, No. 1, pg 5.

Author's biography



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ERGONOMICS AND OTHER TRADE-OFFS

You can choose from a variety of pointing devices that trade off ease of use, range of control, cost, size, portability, precision, and ergonomics. Mice, trackballs, joysticks, and keypads are common pointing options. Touchscreens, light pens, glide pads, and digitizer tablets are examples of finger- or stylus-pointing options.

Advanced drivers with acceleration and trajectory heuristics make a mouse one of the fastest ways to direct the cursor around the screen. However, for many tasks, you must move your hand between the mouse and the keyboard. Mouse devices contribute to RSI (repetitive-strain injury) because many users incorrectly use their wrists to direct the mouse. Using a trackball reduces the wrist motion that mice require by allowing users to directly manipulate a ball instead of moving the whole device. RSI can still occur with trackballs, because poor posture can still strain the wrists.

Joysticks and keypads typically employ a vertical stick or directional buttons to control the cursor. Some laptop keyboards integrate a joystick as a mouse replacement. These pointing devices avoid many of the fatigue and RSI issues of mice and trackballs, but they are generally slower for pointing unless you are performing a task optimized for these types of devices.

Finger- and stylus-based pointing devices avoid many of the wrist-strain and fatigue issues of the other pointing devices, because you tend to move your fingers and arm rather than your wrist to point with these devices. Some people believe these devices are good alternatives to mice, especially for those recovering from or hoping to avoid RSI symptoms. However, finger- and stylus-pointing devices are more expensive.

Glide pads and digitizer tablets are similar to mice in that you indirectly control the cursor with your finger or a stylus from a surface other than the display. Glide pads are smaller than mouse pads and can work well in tight configurations. Digitizer tablets can support high-precision pointing, even for large surfaces, but this precision comes with a hefty price tag.

Light pens and touchscreens are the most intuitive pointing devices because you need to reach out only with your finger or a stylus to directly select and manipulate objects on the display. Light pens are good for industrial environments and are less expensive than large touchscreens, but they require a special "pen" connected to the CRT controller.

Touchscreens offer the ultimate portability support; they require no obvious device to manipulate, because a touchscreen overlays a display. Touchscreens support finger and stylus touch and are strong for handheld devices with small graphical displays, such as PDAs. Text entry with touchscreens is slower and more cumbersome and requires users to learn how to write for the driver, train the driver software to learn how he or she writes, or both.