Camera-Based Optical Touch Technology

Optical touch systems based on the use of CMOS cameras are typically characterized by a high degree of scalability, stylus independence, zero-force touch, high optical performance, object-size-recognition capability, and low cost.

by Geoff Walker

"OPTICAL TOUCH" can be an ambiguous term because there are several different methods of using light to detect touch. This article describes "camera-based optical touch," in which two or more CMOS infrared (IR) cameras are placed on top of a display, looking across the surface of the display in order to detect the presence of a touching object. Several other types of optical touch technology are described in the following paragraphs but not covered in detail here.

Traditional Infrared: Traditional infrared touch technology uses an array of infrared light-emitting diodes (LEDs) on two adjacent bezel edges of a display, with IR photosensors placed on the two opposite bezel edges. When a touching object interrupts the grid of IR light beams, a controller calculates the X-Y touch coordinates.

Waveguide Infrared: RPO's "Digital Waveguide Touch™" uses one or two IR LEDs to provide a planar sheet of IR light projected from two adjacent bezel edges, along with polymer optical waveguides at the opposite bezel edges to direct the light into 10-μm channels leading to a small photosensor array. As in traditional infrared, a touching object interrupts the light projected across the display and a controller calculates the X-Y touch coordinates.[1]

Vision-Based: Vision-based touch systems employ one or more IR imaging cameras positioned so that an image of the entire screen can be captured. Because this usually means that the camera must be located a significant distance away from the screen, most vision-based touch systems are therefore implemented with the detecting cameras located behind a projection-screen surface. After capture, screen images are deciphered by image-analysis software to determine the coordinates (and often the geometry) of touching objects.[2]

LCD In-Cell Optical: LCD in-cell optical touch, also called "in-cell light-sensing," functions by adding a photo-sensing transistor into some or all of an LCD's pixels (*i.e.*, in the TFT backplane). In its original concept, this technology used visible light, sensing either the shadow of the touching object from ambient light or the reflection from the backlight. Currently, the trend is toward the use of infrared light sourced by IR LEDs added to the LCD's backlight. In this configuration, IR photosensors receive light reflected by touching objects; a controller samples each photosensor and calculates the X-Y coordinates of touching objects from the light intensities.[3]

In the remainder of this article, "optical touch" refers only to camera-based optical touch.

History

Although optical touch only came to prominence in 2009 with the launch of Windows 7, the technology has existed for more than 30 years. In 1979, Sperry Rand Corp. was the first to patent the concept of using two infrared linear image sensors (they were CCDs at the time) to locate the position of a touch on the top surface of a display.[4] SMART Technologies in Calgary, Canada, and NextWindow in Auckland, New Zealand, both developed the first commercial CMOS-based optical touch systems independently early in the 2000s,[5,6] both in the large-format (over 30-in.) space.

Hewlett-Packard was the first to use optical touch in a desktop product, launching the first TouchSmart™ consumer all-in-one (AiO) computer in 2007 with NextWindow's multi-touch optical touch technology inside. Two years later, in October 2009, Microsoft released Windows 7 with built-in support for multi-touch. This opened the floodgates; within the next year, almost all of the major PC OEMs launched consumer AiO computers with optical touch, many using NextWindow's technology. In April of 2010, SMART Technologies acquired NextWindow; the combination of the two companies' IP portfolios gives SMART Technologies very broad coverage of the optical touch area.

Basic Principle

Most optical touch systems today use some form of backlighting. As shown in Fig. 1(a), light is emitted or reflected from the periphery of the display across the top surface. Cameras in two corners of the display also look across the top surface; when an IR-opaque object

Geoff Walker *is the Marketing Evangelist & Industry Guru at NextWindow, a leading supplier of optical touch screens. He is the Guest Editor for this issue of* Information Display *and a recognized touch-industry expert. He can be reached at 408/506-7556 or geoff@walkermobile.com.*

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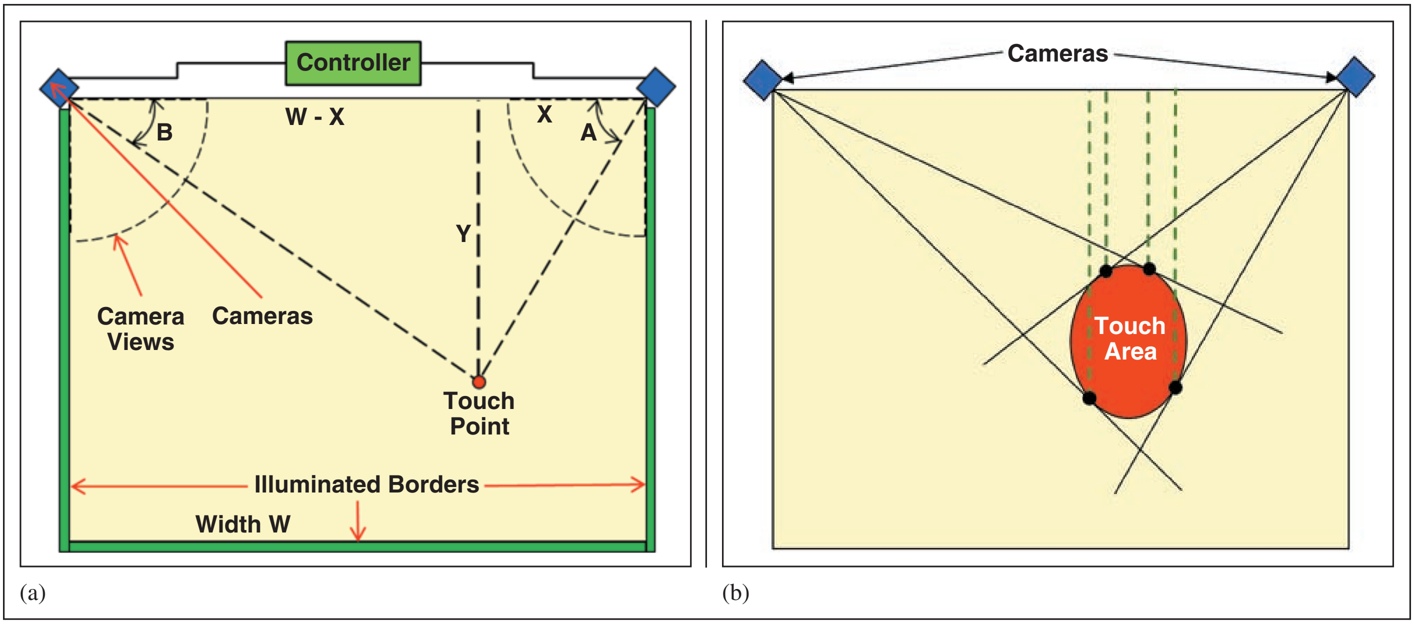

Fig. 1: *(a) The basic elements that comprise a camera-based optical touch screen are two cameras, a distributed light source around the periphery, and a controller. (b) When possible, triangulation is accomplished using the sides of the touching object, producing four sets of coordinates for each object.*

such as a finger touches the surface of the display, it interrupts the light and creates a shadow that is seen by the cameras. Because the touching object can be anything that blocks IR, optical touch systems are stylus independent.

The location of the touch can be calculated using mathematical techniques based on principles of triangulation, as also shown in Fig. 1(a). The angles A and B between the top of the screen and the touch point are found by analyzing each camera's output and determining the pixel location of the shadow. The distance W between the cameras is fixed, so the X-Y location of the touch point can be calculated using the tangents of angles A and B. Note that this is an intentionally over-simplified explanation; real-world calculations are much more sophisticated, taking into account factors such as lens distortion and sensor skew.

When possible, the location of a touching object is calculated from the sides of the object, as shown in Fig. 1(b). The resulting four sets of coordinates can be used to calculate both an approximate bounding box (which can be used in object-size recognition) and the approximate centroid (center of mass) of the touching object. Figures 1(a) and 1(b) also illustrate one of the basic limitations of a two-camera optical touch system: lower positional accuracy at the top center of the screen. When a touching object is very close to the top edge of the screen, angles A and B are very small; in the worst case, triangulation can only be done using one side of the object. Accuracy at the top of the screen can be improved by locating the cameras slightly above the top edge, thus ensuring that angles A and B are always non-zero, but this increases the top bezel width.

Cameras and Sensors

The term "camera" is used in optical touch to designate an assembly that typically includes a housing, image sensor, cable, lens, and IR filter. Depending on the system architecture, a camera may also include an IR light source (for retro-reflective systems) and an image processor.

Two different types of CMOS infrared image sensors are used in optical touch today: line-scan sensors and area sensors. Line-scan sensors, often used in applications such as flat-bed scanners and barcode scanners, output a single row of pixels. Because the sensor must ensure coverage of the full screen, some pixels at each edge of the sensor are typically dedicated to "margin," reducing the number of pixels actually available for use in determining touch location. However, because the output of a sensor is interpolated down to a small fraction of a pixel, the physical resolution of an optical touch system is typically limited by system noise rather than by the number of pixels in the image sensor. The difficulty of defining the actual resolution is why most optical touch companies specify controller resolution (*e.g.*, 32K × 32K points) rather than physical resolution.

Area sensors, commonly used in imaging applications such as webcams, output multiple rows of pixels. Area sensors used in optical-touch applications are generally in the range of 512–1024 pixels horizontally, with 20–64 pixels vertically. A standard webcam-resolution image sensor (640 × 480 pixels) can be used inefficiently in optical touch systems if the output of most of the rows is ignored. The tradeoff between line-scan and area sensors is mainly one of cost. Producing and processing the output of additional pixels costs more, and low cost is essential in consumer electronics. For more sophisticated applications, area sensors can identify the type of object touching the screen, not just the location, and they can distinctly recognize hover separate from contact.

Lighting

As mentioned previously, optical touch systems can use either direct (active light emitters) or reflected light. In the desktop size range (15–30 in.) and in much of the large-format-sized range, reflected light is most commonly used today. The light source is typically one or two IR LEDs that are integrated into each camera assembly. The light from the LEDs is reflected by a retro-reflector surrounding the periphery of the display; a retro-reflector is a material that sends light back in the direction from which it came, regardless of the angle of incidence. The use of retro-reflectors is the foundation of optical touch's high degree of scalability because no additional components are required as the size of an optical touch screen increases.

The height of the retro-reflector determines the amount of illumination that the image sensor receives. For this reason, as the diagonal size of an optical touch screen increases, the height of the retro-reflector also typically increases. The height and efficiency of the retro-reflector also limits the maximum aspect ratio of an optical touch screen for the same reason. The primary advantage of using reflected light is the low cost of the retro-reflective material compared with active light-emitting components; the primary negative is that retro-reflectors are very sensitive to water droplets due to their refractive effect. This is true even if the retro-reflector is behind a window in the bezel, which means that retro-reflector based systems are generally not suitable for outdoor use.

Active lighting systems are most commonly constructed from an array of infrared LEDs surrounding the periphery of the display. The density of the LED array can be quite a bit lower than that in traditional infrared touch systems (1–2 LEDs/in. *vs.* up to 6 LEDs/in.), and active lighting systems are typically much less sensitive to water droplets. However, the cost of surrounding the display with a printed circuit board containing multiple components, as well as the power consumption of those components, is significant. To counter this, at least one optical touch supplier uses a light-emitting light pipe along three sides of the display with an LED directed into each end of each light-pipe segment. While this is more complex to manufacture, it has the advantage of maintaining a low profile height as the size of the touch screen increases.

Substrate

Most optical touch screens are constructed on top of a sheet of glass because it is usually necessary to provide protection for the surface of the display. However, protective glass is not actually required for optical touch; the cameras and light sources can be placed directly on top of a display if the surface is hard enough to withstand repeated touches. Thus far, very few commercial products with optical touch have gone "glassless" because in most cases the hardness of an LCD's top polarizer is insufficient. Even when hardness is not an issue, the "pooling" of the liquid-crystal material when the surface of some unprotected LCDs is touched can be quite distracting.

Hardness is not the only requirement for a touch surface; flatness can also be an issue, particularly in large-format displays with line-scan sensors. Cameras and light sources must be as close to the touch surface as possible for two reasons: (1) low bezel height is highly desirable and (2) minimizing pre-touch (registering a touch before the touching object actually contacts the display) is very important. Since light travels only in a straight line, locating light emitters and sensors very close to the surface results in a low tolerance for bow and warp in the substrate.

Another substrate characteristic of interest is reflectivity. When light hits glass at a very oblique angle, the surface of the glass becomes an almost perfect mirror. (This is true even if the glass has an anti-glare coating, although in that case the reflectivity is somewhat lower.) This means that as a touching object approaches the surface, a mirror image of the object comes into view (see Fig. 2). Because the pixels in the image sensor see a "wedge view," the sensor can see both the actual object and its mirror image. This can actually double the total light received by the sensor, which effectively increases the sensitivity of the system and enables lower retro-reflector height.[7]

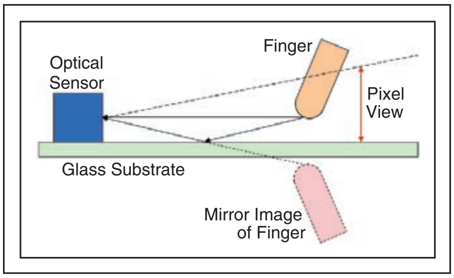

Fig. 2: *The "wedge view" of an optical sensor's pixels and the high reflectivity of glass when viewed at an oblique angle allow sensing light from both an actual object and its mirror image as the object approaches a glass substrate.*

Controller

The controller for an optical touch system that uses line-scan sensors is relatively simple, especially when compared to that for a vision-based touch system that requires intensive image-processing activity. The basic function of the controller is to process the analog information from the image sensors, make the triangulation calculation, and output the touch coordinates, usually in USB human-interface device (HID) format.

The main variation in controller structure is how the processing is distributed. In some cases, the image processing is performed in a chip in the camera electronics, and a small central processor combines the data and calculates the touch location. More commonly, all the processing (including the USB HID conversion) is done in a larger CPU in the controller. Such controllers are "plug-and-play" because no driver is required on the host computer. This is an advantage when the touch screen is in a monitor that can be connected to any type of computer. However, in the case of an all-in-one computer with an internal (dedicated) touch screen, plug-and-play makes the controller unnecessarily expensive. In this situation it is more cost-effective to split the processing between the touch-screen controller and the host computer, resulting in a "driver-based" touch-screen controller.

Multi-Touch

The ability to recognize two or more simultaneous touches has become a widespread market requirement, largely as a result of the success of the iPhone and lately the iPad. The triangulation example in Fig. 1(a) showed that information (angles, derived from shadow locations) from two cameras is required in order to calculate the X and Y coordinates of a single touch point. If two simultaneous touch points can be seen by both cameras (*i.e.*, each camera sees two distinct shadows), then there are four potential touch points – two real touch points and two "ghost" touch points, as shown in Fig. 3(a). Ghost points are false touches positionally related to real touches; determining which are the real touch points requires the application of sophisticated algorithms.[8] Another situation in which advanced algorithms are important is when

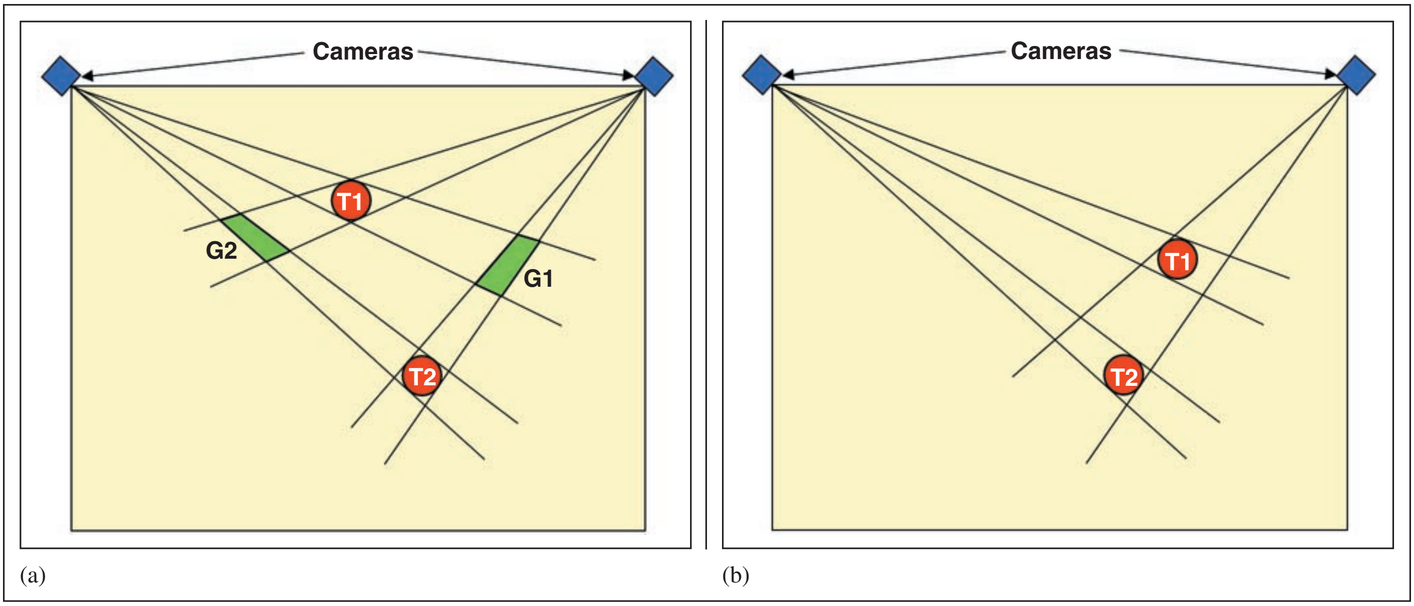

Fig. 3: (a) In the case of two touch points (T1 and T2) where both cameras see distinct shadows of each point, "ghost" points (G1 & G2) are created. (b) With two touch points, where one camera has an occluded view, the measurement of the fourth edge on T1 & T2 is obscured.

the position of the two simultaneous points is such that one of the cameras cannot distinguish between them [*i.e.*, one point occludes the other, as shown in Fig. 3(b)]. Much of a controller's processing time in a two-camera optical touch system is used for running algorithms to eliminate ghost points and compensate for occlusion. In fact, the quality of the multi-touch experience in a two-camera optical touch system depends largely on the sophistication of the algorithms.

Multiple Cameras

The two basic reasons for using more than two cameras in an optical touch system are (1) to achieve a higher-quality, more-robust touch experience or (2) to support more than two touches. Adding a third camera reduces occlusion problems somewhat because it provides an additional viewpoint. However, two touches on the line connecting two diagonally opposed cameras still create a problem because one touch occludes the other for both cameras. Triangulation using two diagonally opposed cameras is also problematic because tangents go asymptotically to infinity as they approach 180°. Hands-on testing performed by the author on two recently launched desktop products with three-camera touch screens seems to indicate that the degree of improvement in the quality of the touch experience resulting from three cameras may not be very significant.

It is possible to add two "virtual" cameras without adding any real cameras by replacing the retro-reflector opposite the two real cameras with a mirror and adding a retro-reflector on the top edge. As shown in Fig. 4, the mirror multiplies the cameras, touch points, and edges. The intent of this configuration is to gain the performance advantage of four cameras without the additional cost. However, the actual performance is less than that of a four-camera system for the following reasons:

- The virtual touch image is smaller in the real cameras, producing less information for object selection.
- The distance between the real and virtual cameras is doubled, which increases the magnitude of triangulation errors.
- With two touches, each camera sees four touch objects, which increases the number of triangulations by up to a factor of four; this increases the amount of processing power required in the controller.
- The doubled number of object edges increases the likelihood of occlusions and ghost touches.
- As the cost of real cameras declines, it is not obvious that there are actually any substantial cost savings, given the added processing required.

Increasing the number of cameras to four eliminates essentially all occlusion problems with two touches, since there are always two cameras with a clear view of both touches. However, there are no four-camera products currently on the market in the desktop-sized range. The reason is that because all two-camera systems pass the Windows touch logo and because cost almost always trumps performance in mainstream consumer-electronics products, there is insufficient motivation for the PC OEMs to move to four cameras. In other words, in the desktop world, two are "good enough" and three do not provide sufficient improvement.

The situation is different in the large-format space, where there are several four-camera products on the market. Some of the products (*e.g.*, the 800-series interactive whiteboard from SMART Technologies)[9] use four cameras to achieve excellent two-touch and object recognition, while others (*e.g.*, Crystal Touch from Lumio)[10] use four cameras to support four touches with performance comparable to two touches in a two-camera system. At the present time, the main factor that is driving demand for more than two touches in the large-format space is a desire to support multiple users, but technology to identify which touch belongs to which user is still very young.

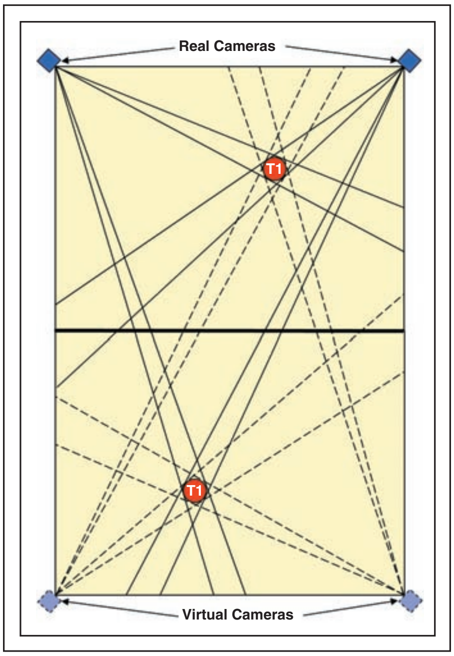

Fig. 4: Shown is a configuration with two cameras and a mirror. The black line in the center of the figure is the mirror; the lower half of the figure is the "virtual" touch space. A single touch (T1) is shown in red; the location of the touch is calculated by four triangulations – two from real cameras and two from virtual cameras.

To the author's knowledge, there are currently no optical touch products on the market that use more than four cameras. However, given the declining cost of image sensors and the ever-increasing market interest in multi-touch, it is the author's opinion that it is only a matter of time until products that use more than four cameras appear on the market.

Applications and Competitive Technologies

Optical touch's strongest penetration has been in the Windows 7 desktop space, where it is used in the great majority of AiO touch computers and touch monitors. Competitive touch technologies in this space are surface acoustic wave (SAW) and analog multi-touch resistive (AMR). Neither of these technologies currently has more than a few percent market share in the desktop space. Projected capacitive, the newest entry in the desktop space, entered the market in the second half of 2010.

Optical touch's applications in the large-format space are found in four main applications as follows:

- Interactive information kiosks, such as wayfinders and directories.
- Digital signage, in both commerce and branding environments.
- Interactive whiteboards in education and training, in both schools and businesses.
- Conference rooms.

The primary competitive touch technology in the large-format space is traditional infrared. The market shares of the two technologies are roughly equal, although iSuppli forecasts that optical touch's penetration in large-format applications will be almost double (187%) that of traditional infrared by 2013.[11] Other competitive touch technologies include film-based projected capacitive and 3M's Dispersive Signal Technology (DST).

References

[1]I. Maxwell, "An Overview of Optical Touch Technologies," *Information Display* **23**, No. 12 (2007).
[2]G. Walker and M. Fihn, "Beneath the Surface," *Information Display* **26**, No. 3 (2010).
[3]G. Walker, "In-Cell LCD Touch," *Information Display* **26**, No. 3 (2010).
[4]U.S. Patent 4,144,449 (1979).
[5]SMART Technologies, "DViT – Digital Vision Touch Technology," White Paper (2003). (Widely referenced but no longer available at http://www.smarttech.com/dvit/).
[6]NextWindow, "An Overview of NextWindow Optical Imaging Touch Technology," White Paper (2003). (http://www.idt.com.au/NextWindow/Optical_imaging_technology_overview_whitepaper.pdf).
[7]U.S. Patent 7,629,967 (2009).
[8]U.S. Patent Application 2009/0278816 (2009).
[9]http://downloads.smarttech.com/media/sitecore/en/pdf/brochures/sbiw/sb_800_series_fact_sheet_edu.pdf
[10]http://www.zinniatech.com/LUMIO/Lumio_multi_user_datasheet_-_1-10.pdf
[11]iSuppli, "Touch Screen Interfaces Continue to Drive Growth in Signage and Professional Applications" (2009). ■