TOUCH TECHNOLOGY ISSUE

Information DISPLAY

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March 2011
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The Evolution of Touch

A WIDER VIEW OF USER INTERFACES

CAMERA-BASED OPTICAL TECHNOLOGY

GROWTH CONTINUES IN THE TOUCH MARKETPLACE

PROJECTED CAPACITIVE CONTROLLERS: WHAT YOU SHOULD KNOW

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Journal of the SID March Contents

Information DISPLAY

MARCH 2011
VOL. 27, NO. 3

ON THE COVER: *The rate of growth as well as innovation in the touch industry continues to accelerate as is effidenced by projective-capacitance's surge to replace resistive as the dominate technology and the emphasis of optical touch from traditional IR to camera-based optical touch.*

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Display Week 2011 Preview / Cutting-Edge-Technology Issue

- SID 2011 Symposium Preview
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- Wireless Sources and Display Connectivity
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editorial

The Evolution of User Interfaces

by Stephen Atwood

I am not sure whether it happened after reading Daniel Wigdor's Enabling Technology article for this month, "The Breadth–Depth Dichotomy: Opportunities and Crises in Expanding Sensing Capabilities" or merely as the result of seeing so many new ideas for human–machine interfaces (HMIs), but at some recent point I realized that hardware will no longer define the scope of interaction between humans and computers. In his article, Daniel says, "A simple touch is not simple. What we think of as "touch" actually includes a variety of object-sensing technologies and an even wider variety of information that can be detected about the sensed objects." I am willing to say that this interaction is going to go beyond that to speech, facial expressions, tone of voice, and even, some day, to mood-interpretation.

IBM's new Watson computer project recently demonstrated for the record that computers running artificial-intelligence algorithms are capable of interpreting complex human speech and answering very abstract questions[1] – effectively performing vast queries of data based on clues as well as context. No, this is not the same as human thought, but it is a giant leap forward in the realm of interaction between humans and machines. The developers of Watson picked the TV quiz show *Jeopardy!* to show off their achievement because "The game of *Jeopardy!* makes great demands on its players – from the range of topical knowledge covered to the nuances in language employed in the clues," according to IBM's Web site and promotional materials.[2] In effect, what I think they really achieved was to prove the viability of a real speech input system for computers.

Touch screens and related interfaces have always represented a great advancement over keyboard or text-based computer interaction. Originally, we had to type the exact commands to the machine each and every time, even carrying the commands around in shoe boxes of punch cards. Later, with the aid of terminal displays, we were able to type commands in real time. The next big break came with the introduction of the graphical user interface (GUI) that is mainly credited to Xerox PARC and was adopted by both Apple and Microsoft. Now the computer could effectively give us a palette of options and could remember its own underlying commands, hidden behind icons and controls. Before this point, a touch screen would have had limited value. However, with the GUI, we could now design a wide array of choices and actions that could be intuitively selected by users simply by pointing at them. It is hard to overstate this monumental step and how much it bridged the gap between machines and the people who needed to use them.

As touch screens evolved, much of the focus was on the technology of the screens themselves and improving rather small details of the interaction such as whether the user could wear gloves or use a stylus. It was still primarily aimed at pointing and selecting predetermined icons and such. To me, the next small leap appears to have come with multi-touch interfaces, in which users could express their intentions with gestures instead of just choosing menus and icons. And now, a machine can interpret shades of gray in these gesture commands and respond in a similar, measured way. From here it is not much of a reach to see where you can go by recognizing hand and body movements with cameras (in the case of Microsoft's Kinect) or by measuring the momentum of a handheld wand and attempting to determine real intent (in the case of the Wii).

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industry news

Anti-Fingerprint Technology

One problem with touch technology, especially in today's germ-phobic society, is that the touch of the average human fingertip leaves a visible residue. Even recently cleaned hands exude perspiration and oil, due to oil-producing glands located in the fingertips. When fingers come into contact with any relatively smooth surface, such as a tablet screen, the friction releases the oil.

The issue is primarily aesthetic – most people do not like smudges on their personal devices. In the case of public touch screens – supermarket checkout monitors and the like – the sight of other people's fingerprints is a turn-off for many users. Beyond the aesthetics, fingerprint smudges can interfere with actual viewing under conditions such as bright sunlight. This problem is more significant when multi-layer optical coatings are applied to the touch screens, usually to enhance high-ambient-light readability. Then, the presence of fingerprints can cause unattractive bluish smudges that can make the device almost unreadable. For military or medical applications, fingerprints that affect readability in high ambient light are a serious concern.

"Anti-fingerprint technology is currently an interesting topic," says Jennifer Colegrove, a vice president with DisplaySearch, "because it is rumored that the iPad 2 will have it." And where Apple goes, continues Colegrove, other products are likely to follow.

It is possible to fingerprint-proof your personal mobile devices now – from phones to tablets to larger displays – with aftermarket films available from companies such as SGP Steinheil, UniPixel, Wrapsol, and ZAGG. A SGP Steinheil "ultra-oleophobic" screen protector for an iPhone 4 can be had for about $15 on Amazon. But in the future, according to Colegrove, expect to see more such protection built into device screens at the factory, especially if the iPad 2 rumor is true.

How effective or long-lasting the built-in anti-fingerprint technology will be is unknown. To date, most of the aftermarket films have a limited lifespan in terms of effectiveness, and many add a matte look and rougher texture to the display – a plus for some users and a negative for others.

The way most available anti-fingerprint technologies work is through surface tension that spreads the oily deposits on contact. Normally, these tiny drops of oil and water form spherical shapes that are apparent on the surface of screens. With anti-fingerprint technology, "The oil spreads out so you do not see it," says Colegrove – small comfort to the hygiene-obsessed, but a big step in terms of a nicer looking and more readable screen.

Another possible way to approach the fingerprint problem, notes Colegrove, is to remove the physical contact from the equation altogether with "touchless" touch technology such as that being developed by Microsoft or Elliptic Labs.

New Touch Products

Tyco Electronics recently introduced the Elo TouchSystems 2242L open-frame touch monitor, available with the company's IntelliTouch Plus Multi-Touch surface-acoustic-wave touch technology. It is Elo's newest monitor that is compatible with the Windows 7 operating system's additional qualifications (AQ) for multi-touch functionality. The wide-aspect-ratio display is designed to provide stable, "drift-free" operation with superior image clarity, resolution, and light transmission, as well as accurate touch response. Possible applications for the 2242L include point-of-sale (POS), point-of-service, digital signage, loyalty systems, kiosk information systems, light industrial shop-floor automation, and home control.

3M has extended its line of transparent conductors with the new 3M Patterned Transparent Conductors, designed for use in thinner, lighter consumer-electronic devices for a variety of applications including projected-capacitive touch sensing.

According to 3M, the conductors combine many of the advantages of glass-based projected-capacitive sensors, such as fine conductive feature width and low sheet resistance, with the thinness and weight advantages of a film-based material. The material supports curved and narrow bezel touch-sensor designs, increasing the effective display area of smartphones and tablet devices.

3M Transparent Conductors are also available as Unpatterned Transparent Conductors for EMI shielding applications.

– Jenny Donelan

guest editorial

Change Is the Only Constant

by Geoff Walker

As referred to in the title of this editorial,[1] the rate of change in the touch industry continues to accelerate. Projected-capacitive (pro-cap) touch technology is the ideal poster-child for this rapid change, going from less than $20 million in worldwide sales in 2006 to well over $2 billion in 2010. That's a 100x change, or 10,000% in 4 years! Even the name is changing from "projected capacitive" to just "capacitive" because surface-capacitive touch technology is rapidly becoming irrelevant (only single-touch, hard to integrate, expensive, *etc.*). Pro-cap is well on the way to displacing analog-resistive, which has been the dominant touch technology for over 30 years. In terms of growth in the overall touch industry, TPK Touch Solutions, a company founded in 2003 and a name that was unknown before 2007, is now the largest supplier of touch screens in the world, with 2010 revenues of over $2 billion (according to DigiTimes).

This issue includes a Frontline Technology article by Tim Wang and Tim Blankenship from Maxim on pro-cap with an emphasis on the importance of controller performance. Tim & Tim build on Gary Barrett and Ryomei Omote's article on pro-cap in the March 2010 issue of *Information Display*; that article (which is still worth reading if you never got around to it last year) was written primarily from the point of view of sensor design and performance.

The rise of high-volume consumer touch has split the industry into two types of companies: (1) high-volume, low-cost, low-margin, limited-product-line companies focused on consumer markets and (2) lower-volume, higher-cost, higher-margin broad-product-line companies focused on vertical markets. For all practical purposes, there are no significant players who compete in both markets. This is a big change from only 5–7 years ago, when the touch industry was far more homogenous.

This issue includes a Display Marketplace article by Duke Lee from Displaybank in Korea. Displaybank is one of the three primary market-research firms that cover the touch industry (the other two are DisplaySearch and iSuppli). Duke provides some interesting insight into the state of the touch industry, along with the expected update on the growth. Duke also points out that the total area (in m^2) of touch screens in tablets will exceed the area of touch screens in mobile phones by the end of 2012 – a very surprising forecast!

Multi-touch is yet another big source of change. It is now very rare to see any touch-technology development (new or enhancement) that is not closely tied to multi-touch in some way. Take the case of traditional infrared touch technology. It has been available for at least 30 years with single touch. In the last few years, a number of companies have launched two-touch versions, but I have yet to see one that is not plagued with severe ghost-touch problems. More recently, two companies (PQ Labs in California and Citron in Germany) have launched a new form of infrared that supports up to 32 touches. This technology breakthrough was developed by re-thinking and re-defining how a 30-year-old technology should work in order to meet today's need for multi-touch.

This issue includes an Enabling Technology article by Daniel Wigdor from the University of Toronto (he is also an ex-Microsoftie); his article includes the term "multi-touch" in the very first sentence. While the article concept started out as an overview of what's happening in multi-touch, it quickly turned into something more

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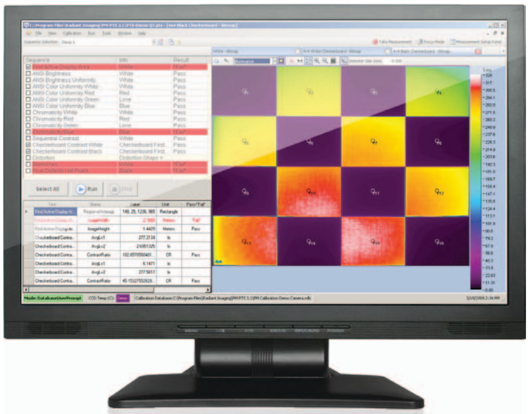

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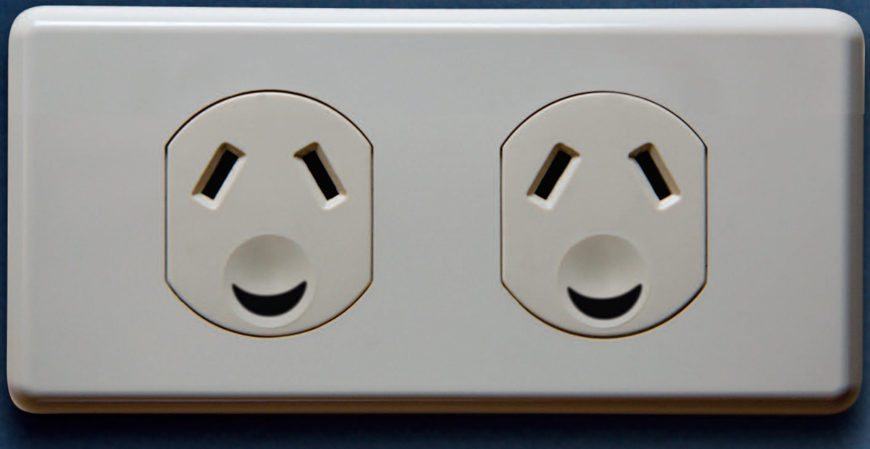

Projected-Capacitive Touch Systems from the Controller Point of View

Projected-capacitive touch has grown more than 100-fold in revenue since the iPhone was introduced in 2007, and it shows no signs of slowing down. This article describes many of the design and application challenges that must be faced when integrating projected-capacitive touch into a device, with a particular focus on the importance of the controller's signal-to-noise ratio.

by Tim Wang and Tim Blankenship

EVER SINCE the iPhone was introduced in 2007, projected-capacitive (pro-cap) touch-screen technology has been adopted in a growing range of applications. However, integrating a pro-cap touch sensor into a touch-screen device is still a challenging problem, especially with respect to the noise generated by the liquid-crystal display (LCD), peripherals, and environment. One of the most promising solutions is to make use of a high-signal-to-noise-ratio (SNR) touch-screen controller to combat the noise problem. A high-SNR controller also has a number of other benefits that will be explored here.

SNR is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal). If the signal and noise are measured across the same impedance, the SNR can be obtained by calculating the square of the root-mean-square (RMS) amplitude values. The numeric ratio of the power values (PS/PN) is often so large that it is best described using the logarithmic decibel (dB) scale. SNR can therefore be expressed as

$$\begin{aligned} SNR_{dB} &= 10\log_{10}(P_S/P_N) \\ &= 10\log_{10}(RMS_S/RMS_N)^2 \\ &= 20\log_{10}(RMS_S/RMS_N)\ . \end{aligned}$$

Higher SNR values represent higher signal strength measured relative to the background noise.

Overall Touch Performance

From a high-level view, there are two main components that determine overall touch performance: the touch-sensor design and the touch-controller design. Various projected-capacitive touch-sensor pattern designs exist, often referred to by names that are indicative of the shape or construction of the pattern, such as triangles, diamonds, snowflakes, streets and alleys, and telephone poles. For example, "diamond" is a grid of diamond-shaped (rhombus) structures, while "streets and alleys" is a grid of intersecting rows and columns that resembles a city layout. Some patterns use a single layer of ITO, while others require two or three layers, depending on the system performance desired and the architecture of the touch-controller integrated circuit.

Often, the touch-sensor pattern and layer structure ("stack-up") are tailored to the touch-controller architecture to maximize SNR. For example, in a single-layer mutual-capacitance diamond pattern with crossovers (shorting bridges), the distance from the touch surface to both the X and Y layers of ITO is the same. This reduces gain error and makes the SNR levels similar for rows and columns. However, this design may also require a shielding layer to prevent the sensor from picking up LCD noise. Using a touch-controller capable of high SNR can reduce the touch-sensor cost by relaxing the constraints on the design, enabling the use of a wider range of patterns and layer structures. As will be discussed later in this article, a high-SNR touch controller can also provide additional benefits such as making it easier to find a touch event's center of mass, reducing the touch screen's susceptibility to environmental noise and allowing the use of gloves and a small-tipped conductive stylus.

Controller Architecture

The two main competing pro-cap touch technologies are self-capacitance and mutual capacitance.[1] Self-capacitance is based on measuring the capacitance of a single electrode with respect to ground. When a finger is near the electrode, the human-body capacitance changes the self-capacitance of the electrode. Spatially separated electrodes

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are usually arranged in a single layer; each electrode is measured individually.

Mutual capacitance is based on measuring the capacitance between two electrodes. When a finger is near the electrode pair, the human-body capacitance changes the capacitance between the electrodes by "stealing" some of the charge. Electrodes are typically arranged in two spatially separated layers, usually in rows and columns; every intersection of every electrode is measured. A brief summary of the characteristics of self- and mutual capacitance follows.

Self Capacitance

- Early-generation pro-cap method still used today.
- Generally limited to one touch or two touches with ghosting (false touches positionally related to the intended touches).
- Diamond pattern is most common.
- Lower LCD noise immunity.
- Simpler, lower-cost controller.

Mutual Capacitance

- New-generation design gaining market share.
- True multi-touch with two or more unambiguous touches.
- Better touch accuracy.
- Allows more flexibility in the sensor pattern design, which can help maximize SNR.
- Better immunity to noise.
- More-complex higher-cost controller.

Many applications require only one or two touches and therefore a self-capacitance solution can be attractive, especially if the touch locations in the user interface can be controlled to eliminate ghosting. While a typical SNR of over 30 dB can be achieved with self-capacitance systems, this generally requires a shield layer between the LCD and the bottom touch layer of the sensor, which adds cost and reduces display brightness.

Other techniques can be applied to self-capacitance solutions to further increase SNR. These include (a) increasing the number of samples per channel; (b) increasing the sensor drive voltage, which increases signal amplitude in the presence of fixed background noise such as that from an LCD; and (c) sampling at various frequencies in order to avoid fixed-frequency interference such as at 60 Hz (this is known as "frequency dithering"). However, these techniques also typically reduce frame rate and increase power consumption, both of which are usually undesirable.

In order to maximize SNR and support two or more unambiguous touches, it is clear from the above that the most desirable touch-system architecture relies on mutual capacitance. The system block diagram in Fig. 1 illustrates a generalized mutual-capacitance implementation that applies an excitation signal to one of the touch-sensor capacitor plates. The other touch-sensor capacitor plate is connected to the analog front-end (AFE) of the touch controller. The AFE output is converted to digital form and further processed in a digital signal processor (DSP).

Design Challenges

There are many technical challenges when integrating a pro-cap touch sensor into a touch-screen-equipped device. The following paragraphs describe some of the most common situations that can benefit from a high-SNR touch controller.

Sensor stack-up: A wide range of touch-sensor layer structures exists in the touch industry today, driven by materials considerations, device-thickness goals, performance requirements, and cost targets. One example appears in Fig. 2. Single and multiple substrates, "face-up" and "face-down" structures, variations in the thickness of the X and Y sensor layers, variations in the thickness of optically clear adhesives (OCA), and other factors all affect the signal level produced by the sensor. A high-SNR touch controller can reduce the significance of these structural differences because it is able to handle a wider dynamic range of touch-sensor signals. This gives the designer more freedom in the design of the stack-up.

Thick cover lens: Some applications such as a bank ATM may require a thick cover lens to protect the display from vandalism. However, a thick cover lens reduces the signal strength of the finger touch detection and reduces the accuracy of the touch position because the finger is further away from the touch sensor.

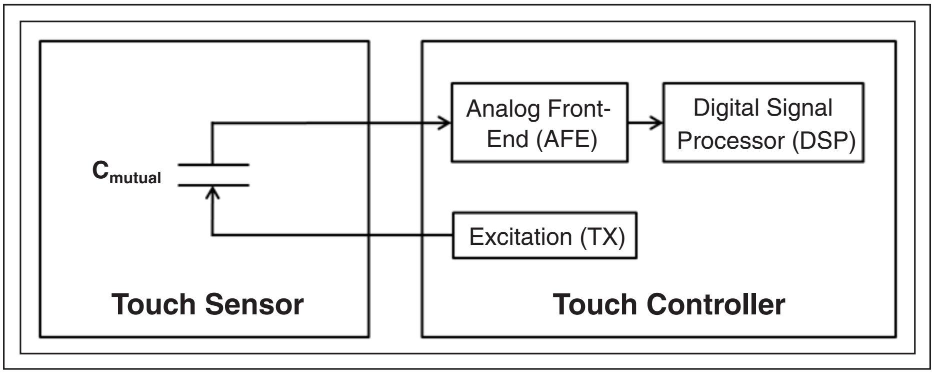

Fig. 1: *The relationship between touch sensor and controller is shown in a system block diagram of a generalized mutual-capacitance system. Source: Maxim.*

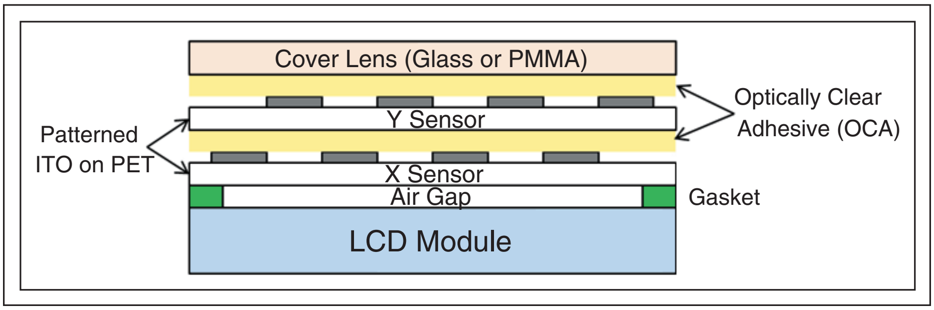

Fig. 2: *Shown is but one of many different mutual-capacitive touch-sensor stack-ups (not to scale). Source: Maxim.*

This "spreads out" the capacitance profile and reduces the peak, which makes it more difficult to determine the precise location of the intended touch. Gloved hands have a similar effect.

LCD V_{com} type: LCD V_{com} refers to "common voltage," the reference backplane voltage of a typical LCD. The technique of driving the backplane varies depending on the system requirements. Two common methods are AC V_{com} and DC V_{com}. AC V_{com} modulates the backplane between multiple voltage levels, while DC V_{com} maintains a constant voltage on the backplane. The former method produces more noise.

Air gap between touch sensor and cover lens: One of the most common problems reported by touch-screen-device end-users is a broken cover lens. To make a product thinner, a pro-cap touch sensor can be laminated to the back side of the cover lens. However, when replacing a broken cover lens, the touch sensor must also be replaced, which increases the cost of the repair. To avoid this cost – as well as the cost and lower yield of lamination – device manufacturers often separate the touch sensor and the cover lens with a thin gasket.

However, when an air gap is introduced between the touch sensor and the cover lens, it becomes more difficult for the touch sensor to detect a finger touch since the low dielectric constant of air reduces the signal strength from a finger touch. One way to solve this problem is to boost the touch system's sensitivity threshold, but this is a dangerous game since the sensor can then pick up unintentional signals such as LCD noise or other ambient noise from the environment, which makes it more difficult for the touch sensor to differentiate a touch from the noise.

Industrial design requirement: Some device manufacturers laminate the touch sensor directly onto the display in order to achieve an overall thinner design. But this also poses significant risk since the touch sensor is then located directly on top of a significant noise source. One solution is to add a shield layer between the touch sensor and the display. However, adding an extra ITO layer increases the overall material cost and has a negative effect on optical clarity.

On-cell touch sensor: In order to reduce the overall manufacturing cost, one approach increasingly being taken by LCD manufacturers is to locate the touch sensor directly on top of the color-filter glass under the polarizer. While this eliminates the need for an external sensor and lamination, the touch sensor is located even closer to the heart of the display, which increases the noise level seen by the sensor even further.

Touch-controller location: Pro-cap touch controllers are most commonly located on the touch-sensor cable (chip-on-flex or chip-on-PCB), or sometimes directly on the touch sensor (chip-on-glass). However, to make testing the touch sensor easier, some designs require the touch controller to be mounted on the system board. This approach may require a long flexible printed circuit (FPC) connecting the touch sensor to the touch controller. A long FPC can act as an antenna that readily picks up additional noise, making it more difficult for the touch controller to process the analog information from the touch sensor.

Other noise sources: The major sources of noise on a mobile device are from the LCD (or EPD), LCD inverter, WiFi antenna, GSM antenna, and various high-speed circuits within the device. Ambient noise can also have a significant impact on the touch system. Some AC power sources produce a high level of noise that is readily conducted through the device's AC adapter. Also, when a device is placed close to a strong source of noise such as a desktop fluorescent lamp, the touch system can misinterpret the noise as an intentional touch.

For a normal-sized finger (>7 mm) under normal conditions, a high-SNR controller may not have a significant advantage over a low-SNR controller. The advantage appears when a weak input signal, such as that created by a stylus or a small or gloved finger, is combined with a noisy environment. A low-SNR controller will not be able to differentiate the signal from the baseline noise in this situation. If the sensing threshold is lowered to increase the touch-detection sensitivity, the touch system can easily be triggered by noise, causing unintended activation. In real-world applications, unintended activation is absolutely not permitted.

Application Challenge

Touch accuracy: Touch accuracy is an important specification in touch-sensor design. For example, in a virtual keyboard application, the characters are tightly packed into a relatively small area. Precision response to a touch is critical to avoid mis-typed characters. One way to achieve high accuracy is to add more sensor channels in the controller to support a higher touch-sensor grid density. But this also comes with a cost penalty because more pins are needed on both the touch sensor and the touch controller. In addition, more sensor channels require more traces running along the border of the touch screen, which may increase the bezel width.

A high-SNR touch controller increases touch accuracy because it enables stronger signal readings from a touch and collects sample data from a larger surrounding area. The larger area provides more reference points from which the precise location of a touch can be calculated. Figure 3 illustrates the effect of the touch-controller SNR on line drawings made by a robot arm holding a 4-mm metal slug. The line drawn with a high-SNR controller is noticeably smoother than that drawn with a low-SNR controller. Note that these measurements were recorded with the same touch sensor and the same post-processing software to ensure the fairness of the comparison.

Stylus: Resistive touch-screen users have long been accustomed to using a fine-tipped stylus. A typical resistive touch-screen stylus has a tip diameter of less than 1 mm and is usually made of non-conductive plastic. It has been an extremely difficult challenge for pro-cap touch systems to detect such a small, non-conductive device, since its influence on the signal generated by the touch controller is so weak. Many of the existing touch systems on the market require a large-diameter stylus (3–9 mm), which is difficult to use for drawing and writing because the large tip obscures the digital ink being created.

A high-SNR touch controller can detect a stylus with a 1-mm-diameter tip, as long as the stylus is coated with a conductive material (a relatively small sacrifice). Figure 4 illustrates the effect of touch-controller SNR on the detection of a conductive stylus with a 2-mm tip. It is very difficult for a low-SNR controller to recognize the small stylus with a noisy background, particularly in the noisiest portion of the screen. Reducing the stylus to a 1-mm tip in the low-SNR case would result in the desired signal being buried in the background noise, rendering the stylus useless.

Hover detection: Proximity detection is gradually being adopted in touch-screen applications. For example, by increasing the touch-system sensitivity while using an eReader application, the user can flip a page with a hand-gesture without physically touching the screen. However, a touch system with increased sensitivity can also be triggered by surrounding noise. It is a constant struggle for designers to find the optimum balance that maximizes proximity distance without causing accidental activation. Mitsubishi has done some interest-

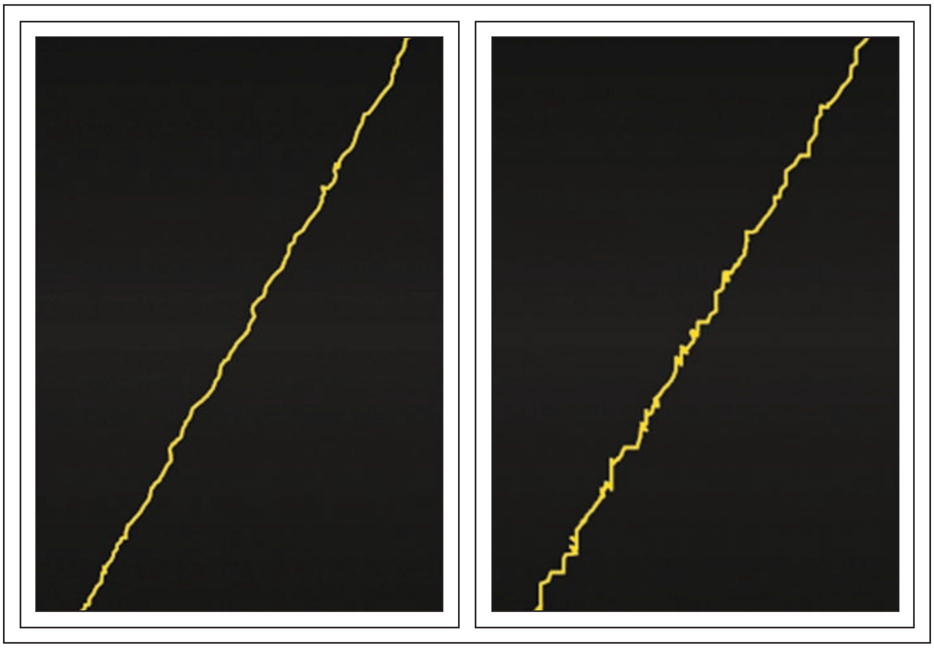

Fig. 3: These line drawings were made by a robot arm holding a 4-mm metal slug. The drawing on the left reflects the use of a high-SNR touch controller; the one on the right, a low-SNR touch controller. Source: Maxim.

ing research in this area in which it created a touch system that automatically adjusts its sensitivity based on whether a touching finger is hovering or actually touching.[2]

Glove operation: In medical applications, a touch screen should accommodate use with surgical gloves. Similarly, a touch-screen GPS device in a car should accommodate use with gloved hands in winter. Most winter gloves are made of a dielectric material that makes it difficult for the touch sensor to detect a touch. Increasing the touch controller's sensitivity may cause unintentional triggers when the user is not wearing gloves. Currently, the only solution on the market requires the application (or the user) to select different sensitivity levels based on use.

Conclusions

A high-SNR pro-cap touch controller brings many benefits. It can accommodate a wide range of design and application requirements such as a stylus, small fingers, and gloves. It can improve the accuracy of the reported touch position without requiring special ITO sensor patterns or adding more sensor channels. It can accommodate various display types with a variety of backlights while maintaining good touch performance. It offers greater flexibility in sensor design and manufacturing requirements. It can enable touch-system operation in a noisy environment and also has the capability to mitigate noise emitted from the device itself such as that from the LCD, WiFi antenna, GPS antenna, and AC adapter. It offers device OEMs the freedom to select from a broader range of components. Finally, from a performance point of view, it offers precise touch accuracy. In summary, a high-SNR touch controller enables a robust experience for end users.

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[1] G. Barrett and R. Omote, "Projected-Capacitive Touch Technology," *Information Display* **26**, No. 3 (March 2010).

[2] http://techon.nikkeibp.co.jp/english/NEWS_EN/20090310/166952/?P=1 ■

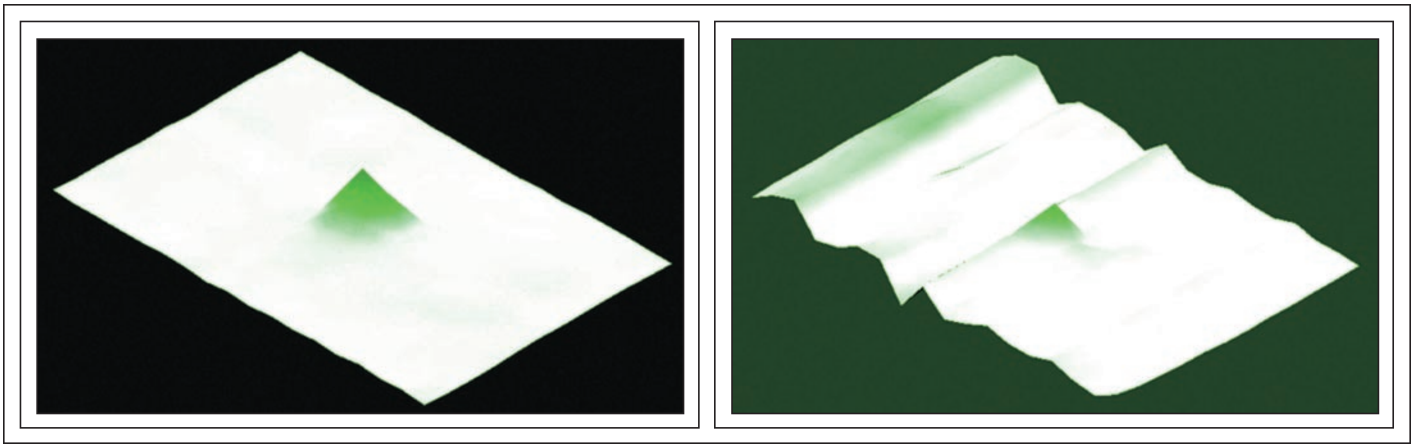

Fig. 4: In these capacitance profiles of a 2-mm conductive stylus on a 4-in. display, the profile on the left reflects the use of a high-SNR touch controller; the one on the right is a low-SNR touch controller. The stylus is positioned at the apex of the green cone; the height of the white surface represents the level of background noise across the display. A large increase in signal-to-noise ratio effectively reduces the peak-to-peak amplitude of the background noise, as shown in the profile on the left. If the stylus in the profile on the right were moved to the left edge of the screen, the signal would disappear into the noise and the stylus would cease to function. Source: Maxim.

The State of the Touch-Screen Panel Market in 2011

Each touch technology comes with its own strengths and weaknesses, a situation that is providing many differentiation elements for touch-screen panel makers. The cost competitiveness, profitability, and customer acceptance of the different technologies will become increasingly important as competition intensifies.

by Duke Lee

FOR the first 30-plus years of its existence, the touch-screen panel (TSP) industry was focused on specialized touch devices such as ATMs, kiosks, point-of-sales terminals, and industrial controls. In the early 2000s, when the industry first began expanding into consumer-electronic products such as personal digital assistants (PDAs) and personal navigation devices (PNDs), touch started attracting more attention. Growth prospects were diminished somewhat when the PDA market started to contract in 2003, but the TSP industry continued to grow while remaining focused mostly on small- and medium-sized niche markets.

As is well-known, the transformative event was the launch of the Apple iPhone in 2007. The iPhone's projected-capacitive (pro-cap) touch-screen panel drove the TSP industry to finally move beyond the application of traditional touch technologies in those small- and medium-sized markets. As global brands such as Samsung and LG Electronics radically expanded the use of touch in their products, the TSP industry began to be more investment-driven. And as market growth accelerated, a very high capability in touch technology came to be considered a basic competence. In addition, the ability to consistently supply very large quantities of touch-screen panels (ensured through the development of increasingly large manufacturing capacities) became important. These characteristics indicated that the industry was changing from technology-intensive to capital-intensive.

By 2009, supported by this market ambience, component subsidiaries of large corporations were fully participating in the TSP industry and LCD panel makers were suggesting roadmaps for the development of integrated touch technology. Together with first-tier and second-tier LCD panel makers, companies specializing in LCD color-filter manufacturing (suitable fabs for glass-based pro-cap sensors) were executing aggressive investment plans for TSP capacity expansion.

This extremely rapid TSP-industry ramp-up occurred because all three components of the mobile-handset value chain (hardware makers, communication service suppliers, and consumers) simultaneously showed a radical increase in recognition of the value of touch. The market grew rapidly because all three value-chain components were able to demonstrate the ability to add value through the inclusion of touch. This growth is expected to continue in the future.

Touch technology can be applied regardless of the size or type of display. Each touch technology (*e.g.*, resistive, capacitive, surface acoustic wave, infrared, camera-based optical, integrated, *etc.*) has its own strengths and weaknesses; this provides many variations and differentiation elements for TSP makers. The cost competitiveness, profitability, and customer acceptance of each touch technology will become increasingly important in markets with intensive competition. Since each technology has different strengths and weaknesses, it is likely that a hybrid or an entirely new type of touch technology will expand the market.

TSP Demand Forecast

Displaybank forecasts that the total TSP market will achieve a 36% CAGR (compound annual growth rate) in revenue and 42% CAGR in units through 2014. The total TSP market size of $4.58 billion in 2010 is expected to grow to $6.09 billion in 2011 and to $9.65 billion in 2014, as shown in Fig. 1(a). This revenue growth corresponds with unit growth from 494 million TSP units in 2010 to 665 million units in 2011 and to 1.35 billion units in 2014, as shown in Fig. 1(b). Clearly, the TSP market is expected to show continuous growth in revenue, units, and area. Displaybank sees the primary reason for the growth as the continuously increasing penetration of TSPs into smartphones, touch-enabled feature phones, netbooks, and tablets.

Major TSP Applications under 10 in.

Out of the total 1.36 billion mobile phones expected to be sold in 2011, 31% (420 million) are expected to be touch-enabled. Penetration is expected to grow to 50% in 2014 (800 million units out of 1.6 billion total). Figure 2(a) shows this forecast in more detail.

In scoping the universe of mobile devices under 10 in., Displaybank uses two main cate-

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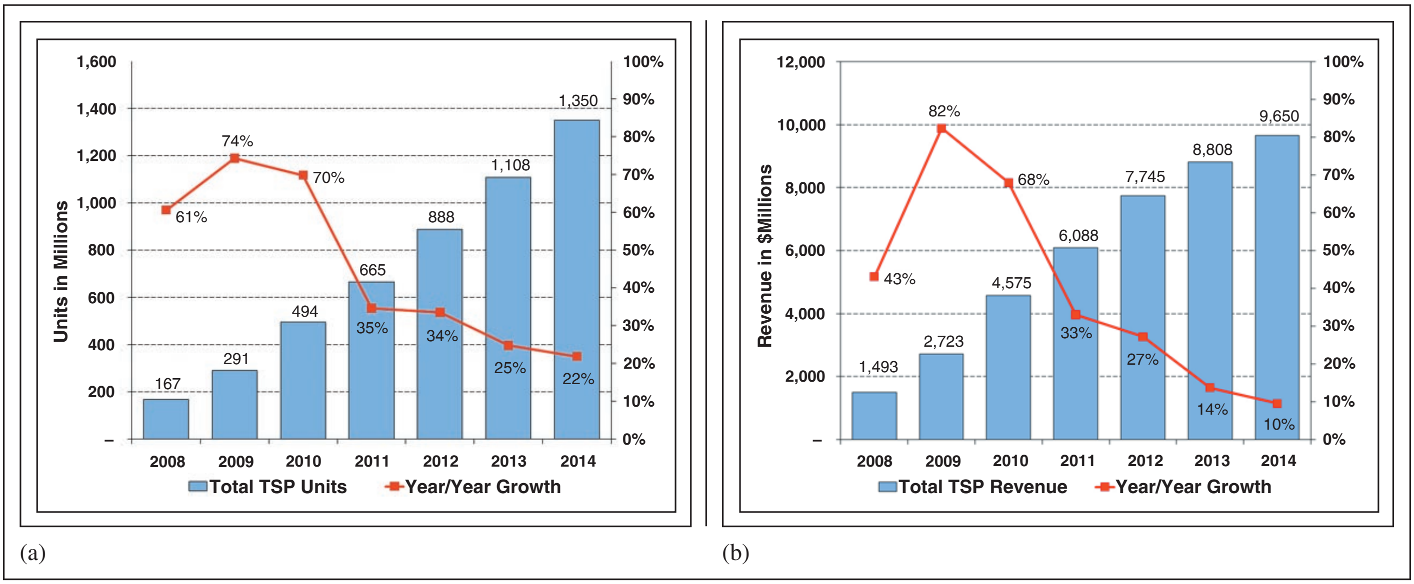

***Fig. 1:** Touch-screen-panel worldwide (a) units and (b) revenue are forecasted to show year-over-year growth from 2008 to 2014. Source: Displaybank* Touch-Screen Panel Market and Issue Analysis, *March 2011.*

gories: mobile phones and "smartbooks." The latter category is defined as a device with the functionality of a smartphone (*i.e.*, 3G, WiFi, GPS, instant-on, all-day battery life, *etc.*), a 5–10-in. screen, a clamshell or slate form factor, an ARM-class processor (not ×86), and a Linux- or Chrome-class operating system (not Windows). Smartbooks therefore include the majority of tablets likely to be launched in 2011 and most e-book readers, but not most netbooks, since they largely run Windows.

In 2011, Displaybank expects total smartbook shipments to be 84 million units. Out of this total, about 66 million smartbooks (80%) are expected to include touch. Figure 2(b) shows this forecast in more detail. Even though the total number of units with touch is much greater in mobile phones (420 million), the average screen area of a smartbook is more than four times larger than that of a mobile phone. As a result, 2012 will be the year that the total area of smartbook TSPs will exceed that of mobile phone TSPs, as shown in Fig. 3.

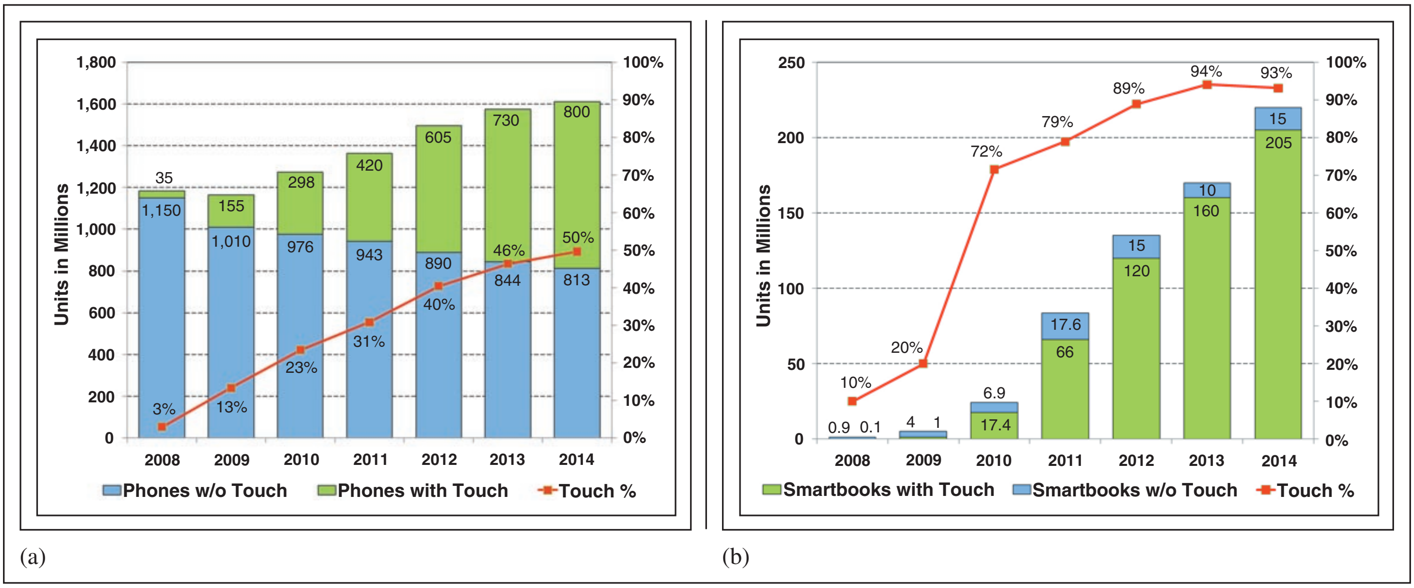

***Fig. 2:** (a) Mobile-phone and (b) smartbook market sizes are shown in units, with touch penetration shown in both units and the percentage for the period 2008–2014. Source: Displaybank, op. cit.*

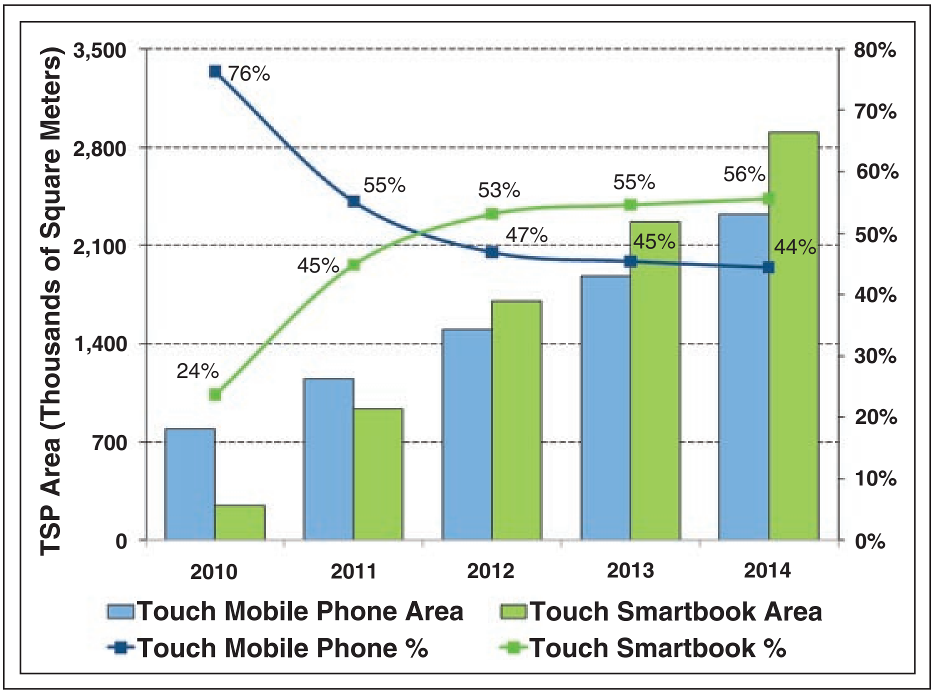

Fig. 3: This comparison of touch-screen-panel areas in thousands of square meters of touch-equipped mobile phones and smartbooks (2010–2014) shows the crossover point where the latter exceeds the former in 2012. Source: Displaybank, op. cit.

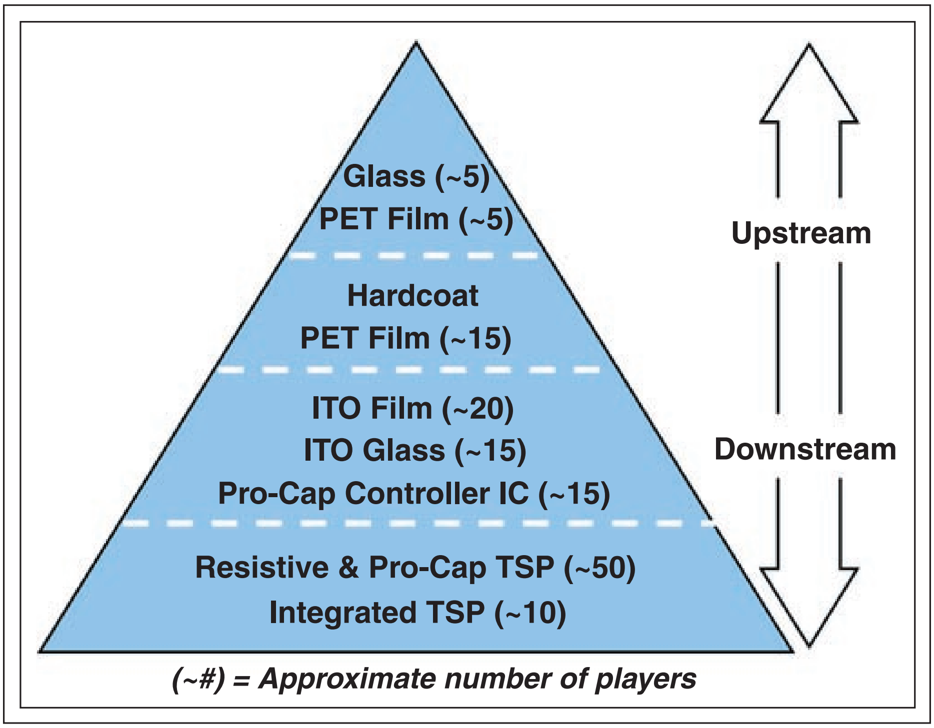

Fig. 4: TSP-industry structure and number of players. Source: Displaybank, op. cit.

Glass-Type *vs.* Film-Type Pro-Cap

The iPhone in 2007 was the first consumer product to use a pro-cap TSP with indium tin oxide (ITO), a transparent conductor, deposited on glass. The other popular TSP structure that is common in mobile phones is film-type, in which ITO is deposited on one or more film layers that are subsequently laminated to a plastic or glass cover lens. Taiwanese and Korean TSP suppliers are seeing substantial growth in film-type TSP; Displaybank expects film-type TSP to achieve a 54% share in 2011. As the size of a TSP increases, it becomes increasingly difficult to achieve good performance with ITO on film, so Displaybank expects that film-type TSPs will not generally be able to replace glass-type TSPs.

In a comparison between ITO on film and ITO on glass, ITO on film has advantages in safety (it is shatterproof), thinness, lightness, and ease of process. ITO on glass has advantages in cost, optical performance, durability, and narrow bezel. Because the advantages of each type are quite distinct, device OEMs typically select a type by focusing on structural design, usage characteristics, and cost-reduction curves rather than an expectation that one type will survive in the market over the other.

In Taiwan, many companies are building a glass-type TSP infrastructure by transforming existing small- and medium-sized color-filter or STN-LCD production lines. But in the case of Korea, where there are few of either type of production lines, film-type TSPs are dominant in the pro-cap market. Glass-type TSPs have an advantage when a single product is manufactured in high volume, such as in the case of Apple, but film-type TSPs have an advantage for Korean companies, which need to develop a variety of lower-quantity products with quick time-to-market.

Mobile-Device TSP Trends

While there are more than a dozen touch technologies in existence, resistive and projective capacitive are the dominant ones applied in mobile products, which are currently leading the TSP industry. Resistive touch technology works by sensing a contact between two ITO films with a small gap between them, while pro-cap touch technology works by using human-body capacity to change the internal capacitance of the TSP. Because a finger has to touch the surface of a pro-cap TSP, it is desirable to treat the surface with an anti-fingerprint or anti-corruption coating. The top layer of glass-type TSPs is often made of tempered glass in order to increase durability and provide improved touch sensing. While the usage of tempered glass is increasing, there are a limited number of suppliers, so cost pressure is driving a trend of increased internalization at many TSP suppliers. Pro-cap TSPs have many superior aspects compared with resistive TSPs, not only in their very light touch and multi-touch capability, but also in terms of layer structure, transparency, and durability. For these reasons, pro-cap TSPs are beginning to be more common than resistive TSPs in mobile devices.

In 2009, the market share of resistive TSPs was 72% because pro-cap TSPs were only applied in a few segments of the mobile-phone market. However with the rapidly growing market for smartphones and smartbooks, Displaybank expects the market share of pro-cap TSPs to increase to 51.4% in 2011. Considering only the mobile-phone application, pro-cap's market share has already exceeded that of resistive, with the 2011 share expected to be about 70%. In smartbooks, pro-cap is expected to be used in most cases except in a few models and in e-book readers. The reasons behind the sharp growth of pro-cap are primarily its use in mobile phones (driven by its gesture, multi-touch, and light-touch capabilities), and its growing use with larger display sizes such as 7, 9, and 10.1 in. Resistive touch technology is expected to continue its presence in game devices that require precise touch, as well as in commercial applications, medical applications, and wherever low cost is the primary requirement.

Current Market Issues

The iPhone/iPad Effect: The iPhone's user interface changed the perception of the value of touch, a value that had been reflected in applications such as printing a boarding pass at an airport check-in kiosk. This gave way to an entirely new way of interacting with devices. In the past, mobile-device touch applications were mostly the province of small- and medium-sized companies such as makers of GPS and game players. Once global powerhouses with superior capital and technological edge such as Samsung, LG, Nokia, and Apple successfully drove touch into mobile-phone applications, interest in the touch industry rose to a new high.

The same effect is happening with the iPad, where the tablet PC market has flipped virtually 180° from its previous state with the coming competition of global makers in the tablet world. Displaybank's 2011 update of the TSP market report includes more discussion of the impact of tablets on the overall touch industry.

Windows 7 Effect: Unlike Windows Vista, Windows 7 has superior basic performance and major upgraded elements such as the support of multi-touch throughout the OS. Because of this, TSPs are generally expected to expand into Windows applications such as monitors and notebooks. Monitors and notebooks with integrated TSPs have relatively higher price ranges than conventional products without touch integration. However, expansion of TSPs into these applications seems very likely, since both major brands and consumers recognize touch technology as one of the key functional aspects of Windows 7.

TSP-Industry Structure Issues

Unlike other industries, the TSP industry is currently booming with many high added-value activities. TSP materials (e.g., PET/glass combinations, hardcoated PET, ITO film, and controller ICs) all have relatively high added-value. An example of added-value in both the resistive and pro-cap TSP industries can be seen in the decorated "touch windows" (cover lenses with printing, silk-screened designs, logos, and other embellishments) sometimes used in mobile devices. As the importance of light touch and multi-touch continues to increase, the expansion of pro-cap capacity progresses. As part of the pro-cap market expansion, controller IC makers

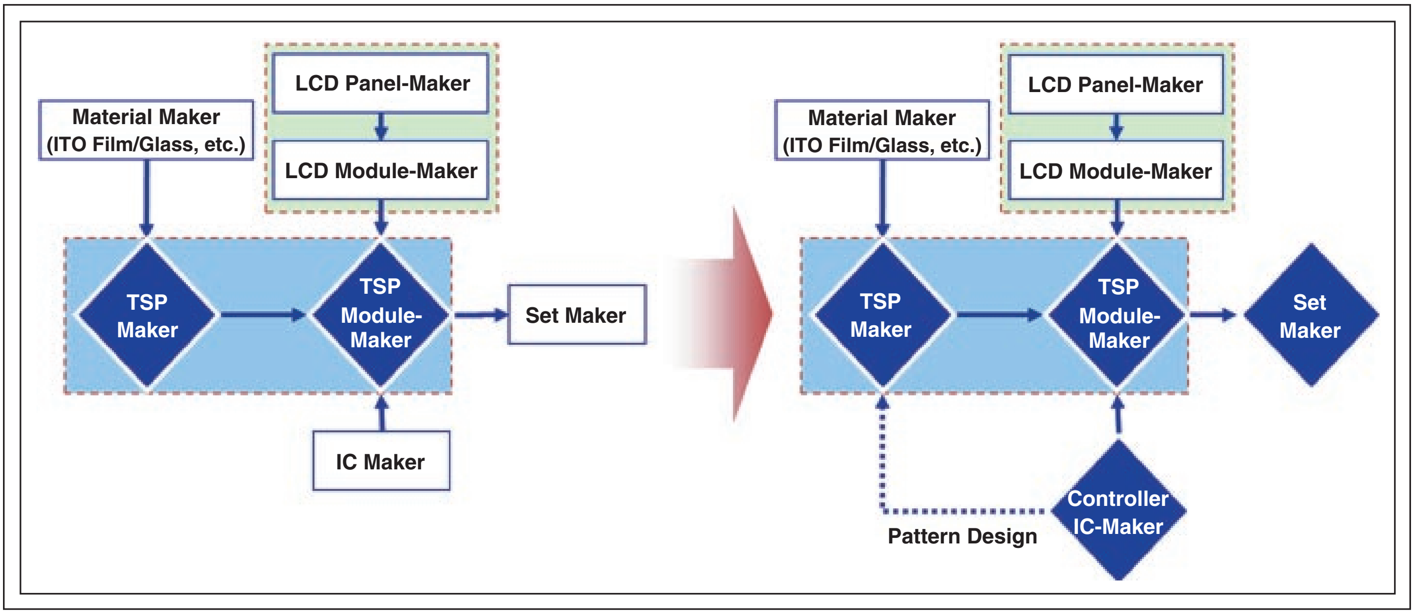

Fig. 5: *The hegemony change in the TSP industry is shown from left to right. Diamonds indicate key collaborators, while rectangles indicate other players. Source: Displaybank, op.cit.*

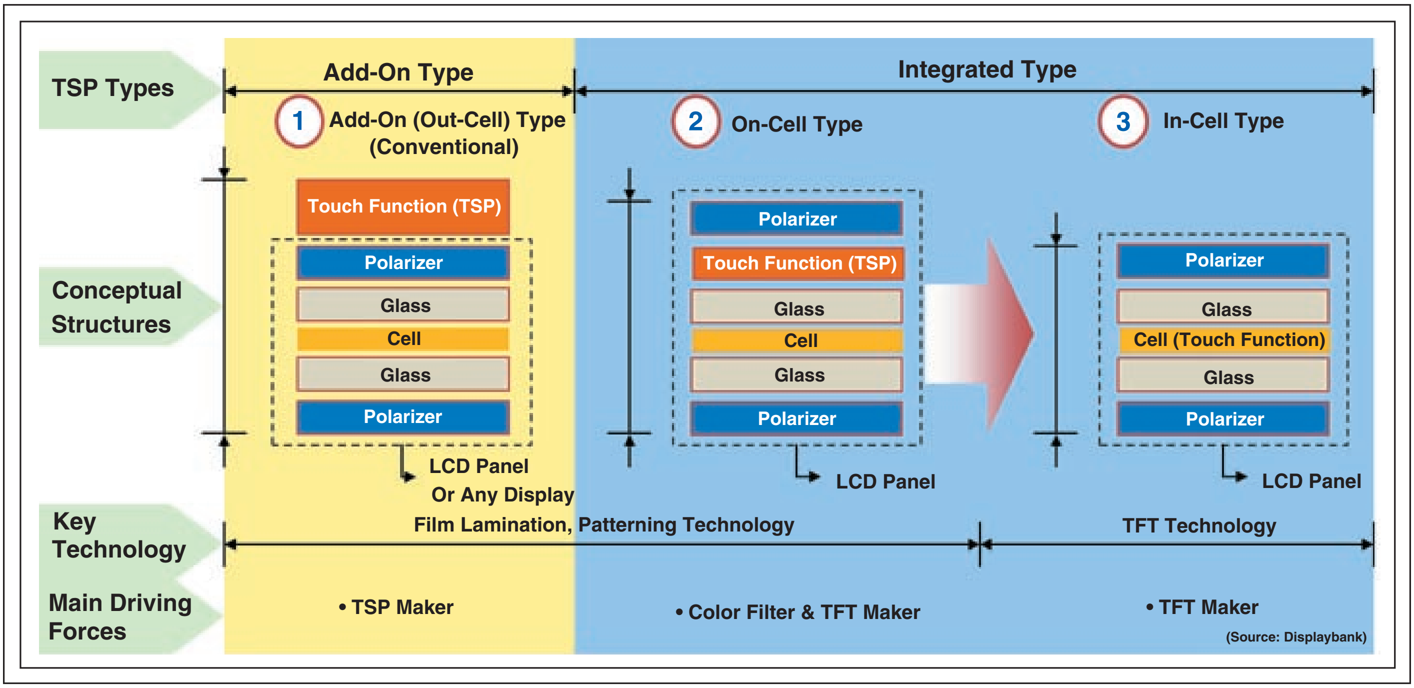

Fig. 6: This comparison shows the conceptual structures, key technology, and main driving forces of conventional TSPs vs. integrated TSPs. Source: Displaybank, op. cit.

with patent barriers show expansion in their significance and control. Encouraged by the introduction and expansion of Windows 7, LCD panel makers intend to aggressively develop and produce integrated TSP technology. Figure 4 shows the TSP industry structure and approximate number of players.

Hegemony Change: Due to the importance of pro-cap, the connections between TSP sensor and module makers, set makers (device OEMs/ODMs), and pro-cap controller-IC makers are having a more significant effect on the supply chain. The industry, once led solely by TSP makers, is now moving to a structure of three collaborators (TSP – Set – Controller). Other TSP material suppliers are also finding the strategic connection with TSP makers and set makers to be important. Figure 5 illustrates this change graphically.

Integrated TSPs: The conventional TSP-industry infrastructure and the integrated TSP infrastructure are different (Fig. 6). The integrated TSP industry is led by LCD panel makers and competes against the conventional TSP industry. The current integrated TSP technology still needs to be verified for mass production, and its effect is not yet significant in light of the TSP industry's rapid overall growth.

Summary

Because of its ability to add value to mobile phones and smartbooks, touch is expected to continue growing in the future. Currently, the dominant touch technologies are resistive and pro-cap; in the latter, both film-type and glass-type are common and are expected to continue. However, the cost competitiveness, profitability, and customer acceptance of each technology will become increasingly important in markets with intensive competition. Pro-cap is currently winning; Displaybank forecasts that pro-cap's market share in 2011 will be about 70% in touch mobile phones and about 50% in the overall touch market. ■

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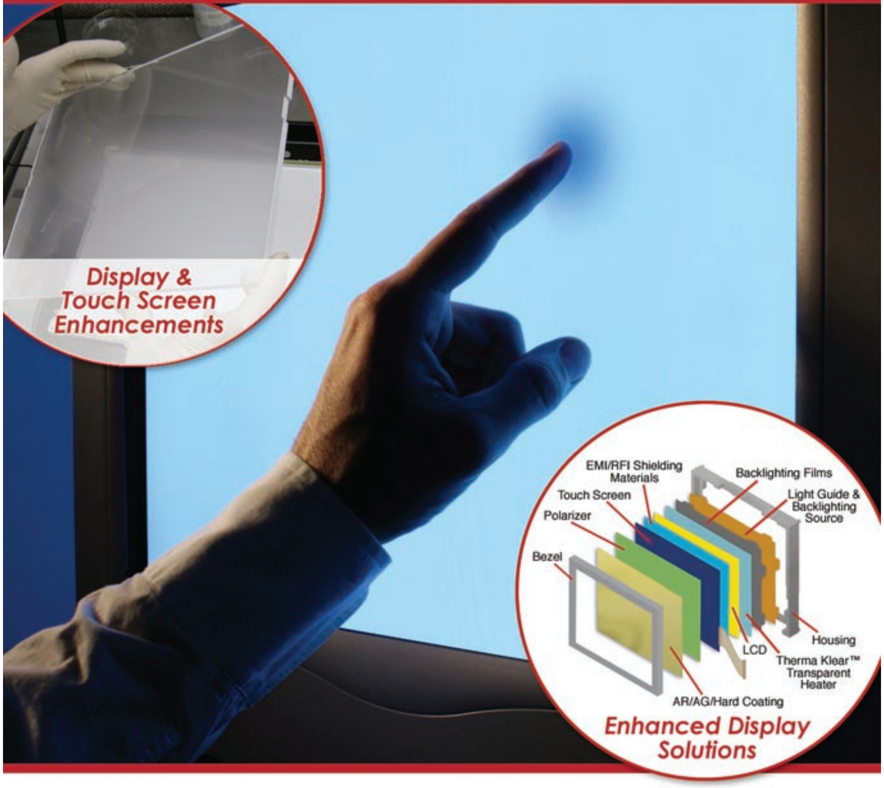

The Breadth–Depth Dichotomy: Opportunities and Crises in Expanding Sensing Capabilities

A simple touch is not simple. What we think of as "touch" actually includes a variety of object-sensing technologies and an even wider variety of information that can be detected about the sensed objects. This wide range of capabilities forces developers to choose between designing once for a "lowest-common-denominator" platform (breadth) or significantly redesigning their software for each hardware capability (depth). This dichotomy threatens the future of touch computing as a platform for innovation.

by Daniel Wigdor

THERE is no such thing as "touch." It is a vast category of sensors varying from fingertip location to object tracking. This wide range of sensors forces developers to choose between designing once for a "lowest-common denominator" platform (breadth) or significantly redesigning their software for each hardware capability (depth). This dichotomy threatens the future of touch computing as a platform for innovation.

The number of simultaneous touch points that a technology must detect in order to be termed "multi-touch" is not yet an agreed upon standard in the touch industry. While this is an interesting issue, a more pressing one for content developers is the guaranteed minimum number of contact points a hardware device will support if it is running a given platform. In the case of Android, it is one. In Windows Phone 7, it is four and in iOS 4, it is five. If a design team sets out to create a touch-based application, should they design it for a single touch point so that it will work on all of these platforms? Or should they design a different version of their application for each platform?

The pressure for software to be highly tailored to a device comes from designing for a good user experience. The more software is tailored to a given form factor, the better the experience can be, and the more highly differentiated the software will be. The pressure for homogenization comes from what might seem to be good business sense. The less tailored a piece of software is, the easier it is to distribute across multiple platforms.

How these choices are already being made on the iOS platform is illustrative. The author selected two-dozen iOS applications at random and compared their iPhone versions with their "designed for the iPad" versions. None of the applications had significant differences in the design for the two devices, despite a larger screen and the ability to give two-handed input on the iPad. The business arguments seem to be winning out; the iPhone was successful and the iPad is (so far) unproven, so content producers hedge their bets by releasing content designed for the iPhone with only minor changes (if any) for the iPad. If the availability of content to a new platform is oxygen, then the iPad might be having trouble breathing.

The Breadth–Depth Dichotomy

This phenomenon is not unique to touch computing. It is common to witness an explosion of variations of that technology with each laying claim to some unique property that supposedly makes it superior to the alternatives, especially in the early days of a technology's penetration into the marketplace. Direct current worked better with batteries, but alternating current could more easily be converted to different voltages. Wax-based phonographs could more accurately record sound, but flat gramophone records could be more easily mass-produced. Projective-capacitive touch screens can be better tuned to detect the first moment of a touch, but vision-based touch screens can identify objects and shapes.

The dangers of the breadth–depth dichotomy, whether to design a less robust platform that works across a broad range of applications or a more powerful one that works only in a particular and deep niche, are found in instances where technology differences require content producers to make

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choices that fundamentally affect content. Consider the choice faced by filmmakers regarding the framing decision. Should they frame their movies for the aspect ratio of standard television (1.33:1 = 4:3), widescreen television (1.78:1 = 16:9), or movie theaters (1.85:1 or 2.40:1) or should they produce three different films, each designed for a different venue? One solution for content intended mainly for television is to frame by using the 14:9 "action-safe area," a compromise between 16:9 and 4:3. For content intended for all three venues, the aspect ratios are so different that framing for the 14:9 action-safe area results in a significant compromise in the movie cinematographers' ability to express their vision. This is the heart of the breadth–depth dichotomy, where content producers are forced to choose between developing a single, watered-down design for multiple platforms (breadth), thus accessing more markets for a lesser cost or taking full advantage of the available technology to produce an ideal experience for each platform (depth).

In the case of input technologies, it is easy to see that variation can also affect content. This is because the content itself – the game, application, and even software platform – is fundamentally different depending on which sensing capabilities are targeted and leveraged. As will be shown, more than a dozen technologies all claim the ambiguous category of "touch," and content producers are already being forced to make choices between compromising content or missing certain markets.

Nintendo and the Dichotomy

To understand the dangers of the breadth–depth dichotomy in input devices, it is worth considering Nintendo's history of innovation with technologies. Nintendo's Wii has been a wild success, in no small part due to the deep game designs created to take advantage of its innovative input technology. The success of the Wii may lead one to forget several failed bets the company made in user-interface technology. One such bet was the Power Glove.

The Power Glove was worn by the user, and its position was tracked in three dimensions, as well as its roll, pitch, and yaw and the degree to which each finger was "curled." It could, in a technical sense, detect many of the sorts of gestures now made popular by the Microsoft Kinect gaming device. Although there were issues with the technology, that is not where the device failed. Instead, the source of the problem was that the makers of the glove emphasized breadth over depth by enabling the glove to control old games designed for the Nintendo controller. For the vast majority of the users, the Power Glove was simply emulating the controller they previously used to play their games. Designers of these experiences were retroactively disempowered, in that they had no opportunity to design, build, or test their game designs for use with the Power Glove. Reviewers and gamers alike agreed that the experience was terrible, and the glove was a business failure. However, it is striking that the Wii's success followed an almost identical technological path as the Power Glove, *i.e.*, leveraging cutting-edge sensors to provide game makers with additional input channels. This newfound success with innovative technology is in no small part due to Nintendo's decision to emphasize depth over breadth; rather than enable the control of content designed for a different input device, Wii games are designed for this new platform.

Nintendo had the luxury of emphasizing depth over breadth in the Wii in part because of its business relationships with content producers and a history as a platform producer. For hardware companies, depth can be an unaffordable luxury. Instead, they typically call on platform makers such as Microsoft and Google to create technologies that enable developers to strike a balance between breadth and depth. Unfortunately, in the case of touch computing, this call has gone largely unanswered.

To understand the scale of this problem, it is important to realize that touch technologies are already coming to be differentiated by far more than the number of simultaneous touch points they are able to detect. By relying on research systems as a guide, it can be predicted that at least seven types of capabilities will soon come to define touch technologies. The number of touch points sensed is just one of these seven.

A Taxonomy of Sensing Capabilities

To understand how deeply the breadth–depth dichotomy affects touch computing, it is essential to understand that touch itself is already fragmented in terms of the capabilities of each touch technology and that the fragmentation will only increase as more promising technologies make the transition from the research lab to consumer device. As shown in Fig. 1, these capabilities can be categorized into two high-level areas: (a) *sensed objects* (the types of objects which can be sensed), and (b) *sensed information* (the details which can be detected about the sensed objects).

Sensed Objects

The types of objects that can be sensed and the nature of the sensing have perhaps the most immediate effect on the user experience. The taxonomy defines three types of object sensing: *touch*, *stylus*, and *imagery*.

Touch: The number of touch points that a technology can detect is critical in differentiating a user experience. A technology might detect only a single touch (*single touch*) or it might provide sufficient contacts to sense a single user giving gestural input (*single-user gestural*) or multiple users giving gestural input simultaneously (*collocated gestural*). The related differences between a single-touch device, a single-user device that can accept multi-finger gestures, and multiple users on a large display are substantial.

Stylus: Pen computing has long occupied the niche of design professionals. Although the transition of pen computing to the consumer space has been bumpy, the recent popularity of the tablet form factor and touch's weakness in content production point to its likely return. Some touch technologies cannot detect a stylus at all (*none*). Others can detect a stylus, but cannot differentiate it from touch input (*recognized*). The most promising technologies are able to make that differentiation, enabling a user to use their fingers to manipulate the user interface, then seamlessly switch to a pen to draw, take notes, or annotate content.[1]

Imagery: Capturing imagery of objects in contact with the surface has been demonstrated to enable new interaction methods. Very few commercial technologies are able to provide applications with photographic imagery of what is in contact with the display. The detection of *text and graphics* enables scenarios where users can easily scan content in real time (imagine sharing a magazine article with a remote collaborator just by holding it up to the screen or producing a sketch on paper and animating it with the computer). Finer imagery detection can detect *fingerprints*, which would enable a degree of instant customization and access to online identities, and also address mundane but important issues such as dramatically increasing the precision of touch input.[2]

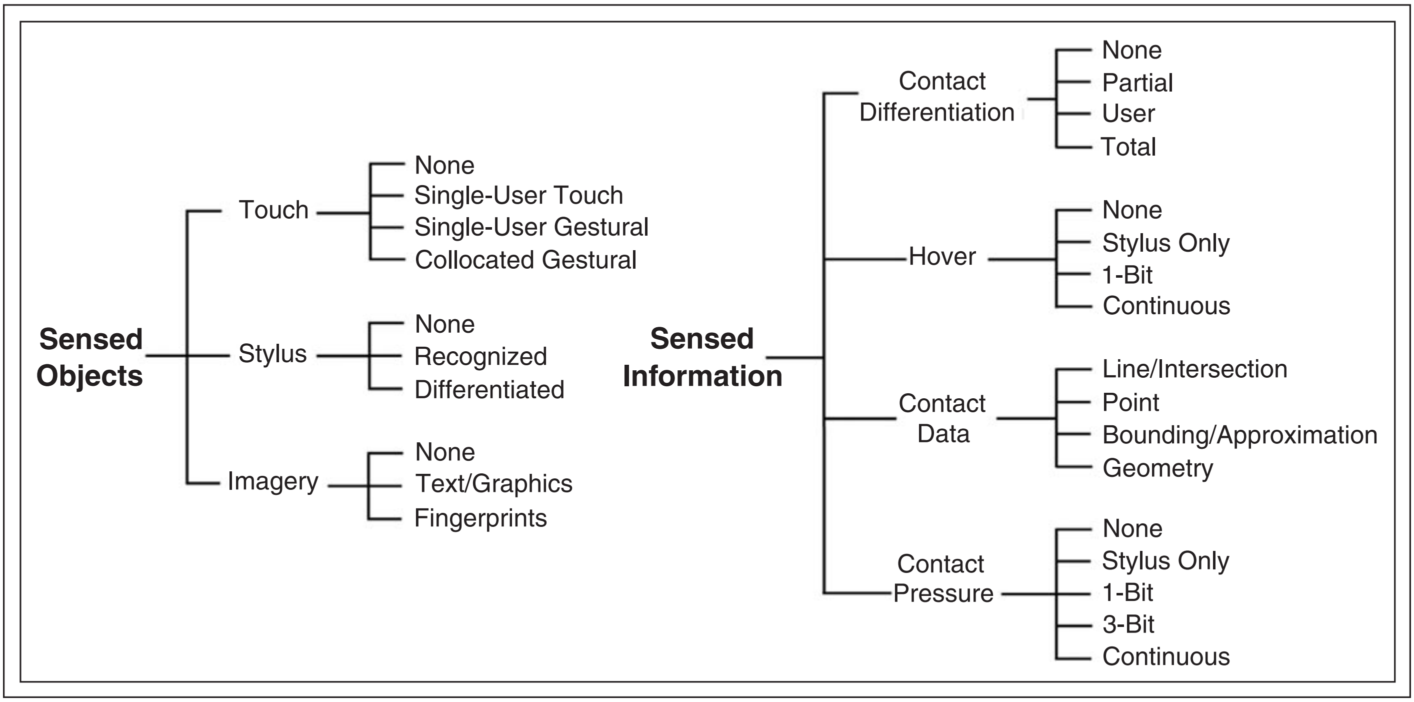

Fig. 1: A taxonomy of sensing capabilities for touch computing helps show that the use of the generic term "touch" is clearly inadequate in the face of such a broad range of capabilities.

Sensed Information

While the types of objects that can be sensed are an obviously important technological differentiator, the details of those sensed objects are equally important. Technologies have been demonstrated that are capable of four types of information sensing: *contact differentiation*, *hover*, *contact data*, and *contact pressure* (see Fig. 1). Just as the ability to detect and differentiate a stylus enables a clearly different user experience, these capabilities also create a need for additional depth of design, thus further reinforcing the dichotomy of breadth and depth.

Contact Differentiation: Contact differentiation refers to the ability to differentiate between contacts that are produced by different parts of the body or by different users. Systems capable of *partial-user* differentiation can successfully identify whether two contacts are coming from the same or different hands. For multi-user systems, the ability to differentiate between *users* is an absolute necessity. Basic user-interface elements such as paint canvases do not work with multiple users unless differentiation is present (*e.g.*, it is impossible for two users to paint in two different colors at the same time without being able to tie each user's color selection to their ink strokes).[3] Finally, *total* differentiation allows designers to identify each contact by the body part making that contact.

Hover: If a system is able to detect the presence of a touch object above the display and detect when that object touches the surface of the display, it is said to support hover. Hover can improve touch accuracy and can enable previews of actions that will occur when the surface is touched by highlighting objects or displaying. In the keyboard and mouse world, hover is emulated as "mouseover," *i.e.*, moving the mouse without clicking. Some technologies can sense hover only for the stylus (*stylus only*), while others can detect hovering fingers or other objects as well. Two types of hover detection have been demonstrated: *1 bit*, in which the system can differentiate between a hovering and a touching finger, and *continuous*, which can provide the height of a finger above the display. The ability to hover can also enable increased precision, for example, by enlarging the area beneath a hovering finger, as has been described by Autodesk Research.[4]

Contact Data: Little attention has been paid in the touch world to the type of information that is known about each contact. The majority of touch technologies reduce the entire contact area to a single x-y coordinate (*point*). Some technologies are limited to detecting only the column and row location of touches (**line/intersection**), which produces ambiguities when more than one contact is touching the device. Others are able to approximate the size of a contact with a bounding rectangle or other shape (*bounding/approximation*). Finally, the most advanced technologies are able to provide full *geometry* of a contact area. Knowing this geometry can enable advanced gestural inputs such as the "Rock and Rails" language shown in Fig. 2, in which the user can change system modes by touching the device with different postures.[5]

Contact Pressure: Some technologies are able to detect the force with which the user is touching the display. This data can be used to differentiate input (*e.g.*, a light touch can preview a rectangle, while a forceful touch places it on the canvas), as well as to vary continuous input (*e.g.*, control the size of the brush in a paint application). There are five different types of pressure sensing. Projected-capacitive devices such as the iPad cannot detect pressure (*none*). Some others are able to detect

Fig. 2: *Rock and Rails augments conventional direct-manipulation gestures (e.g., shown in the first photo) with independently recognized hand postures used to restrict manipulations conducted with the other hand (e.g., rotate, resize, and one-dimension scale, shown in the remaining three photos). This allows for fluid selection of degrees of freedom and thus rapid, high-precision manipulation of on-screen content.*

the pressure only of an active stylus (*stylus only*). The remaining technologies can detect pressure with varying fidelity. Apple trackpads detect *1 bit* of pressure via a switch beneath the touch area, *3-bit* pressure is sufficient to enable the full range of human-discernable pressure levels, and continuous pressure can be used to create 3D-like experiences such as those in Perceptive Pixel's demonstration of easy stacking of objects in a scene by "pressing" them deeper.

Hardware and Software Support

This vast array of different capabilities, each laying ambiguous claim to the category of "touch," creates the challenge faced by content producers. Should they design their software so that it takes advantage of these capabilities, knowing that it will no longer function on some devices or should they defeature their user experience to enable it to run across platforms? To facilitate this decision, it is important to know which touch-sensing technologies have been demonstrated to offer which sensing capabilities. Table 1 shows the various maximum capabilities that have been demonstrated using a given technology, usually in a research lab. It is worth noting that there is no commercial touch technology that is capable of everything shown in the table.

It is also worth noting that although individual technologies support various levels of sensing, the software platforms for which content producers most often develop their products are actually much more limited in their capabilities. Table 2 shows the levels of taxonomic properties that are supported by five common software platforms. Given this startling lack of support, one might conclude that breadth is the only option because none of the platforms presently supports much depth.

Table 1: Different sensing technologies appear with the levels of taxonomic properties they have been shown to support. Each technology is shown with an example product (in parentheses) that uses that technology. Note that these example products do not all meet the maximum capabilities that have been demonstrated in research labs.

	Analog Resistive **(ATM Machines)**	***Analog & Digital Multi-Touch Resistive*** **(NYU/TouchCo UnMouse Pad)**	***Direct Illumination*** **(Microsoft Surface, v1)**	***Frustrated Total Internal Reflection*** **(Perceptive Pixel Magic Wall)**	***Projected Capacitance*** **(iPad, iPhone)**	***Capacitive Coupling*** **(Circle Twelve DiamondTouch)**
Sensed Objects						
Touch	Single User Gestural	Collocated Gestural	Collocated Gestural	Collocated Gestural	Collocated Gestural	Collocated Gestural
Stylus	Recognized	Recognized	Differentiated	Recognized	Recognized	Differentiated
Imagery	None	None	Fingerprints	Fingerprints	None	None
Sensed Information						
Contact Differentiation	None	None	Partial	None	None	User
Hover	None	None	Continuous	None	None	None
Contact Data	Point	Geometry	Geometry	Geometry	Geometry	Geometry
Contact Pressure	None	Continuous	None	Continuous	None	None

Table 2: Five common software platforms are shown along with their capacity for conveying sensed information to applications.

	Windows 7	iOS 4	OSX	Android	Microsoft Surface, v1
Sensed Objects					
Touch	Collocated Gestural	Collocated Gestural	Collocated Gestural	Collocated Gestural	Collocated Gestural
Stylus	Differentiated	Recognized	Recognized	Recognized	Recognized
Imagery	None	None	None	None	Text/Graphics
Sensed Information					
Contact Differentiation	None	None	None	None	None
Hover	Stylus Only	None	None	None	None
Contact Data	Bounding/ Approximation	Point	Point	Bounding/ Approximation	Bounding/ Approximation
Touch Pressure	Stylus Only	None	None	Continuous	None

However, this would be short-sighted because the march of progress will undoubtedly increase the fidelity and range of information supported by these platforms.

Overcoming the Dichotomy: An Unmet Challenge

Several attempts have been made to alleviate the pressures associated with the breadth–depth dichotomy. Three such solutions are as follows: (1) finding a lowest-common denominator, (2) separating content from presentation, and (3) providing a level of abstraction for sensing capabilities. Unfortunately, none of these approaches has yet met the challenge, but in their attempts we can see the promise of potential solutions.

The lowest-common-denominator approach is simple. By using it, a designer surveys the capabilities of all target platforms and designs the application such that it requires only the minimum available capability across those platforms. This is the approach that guarantees the greatest breadth, thus also guaranteeing the least depth of design. This is also the most common approach to the dichotomy – it is the Power Glove's approach, and the approach of most applications developed for iOS thus far. It is highly dangerous to innovation because it guarantees that new sensors and capabilities are always ignored in favor of the status quo.

The second approach is to attempt to separate content from presentation. A good example of this approach can be found in HTML, which allows content designers to have tight control over the presentation form while still maintaining an abstraction. This approach has enabled Web sites to easily produce content for both desktop and mobile-phone browsers. It has also enabled the differentiation of input type in order to produce different controls (*e.g.*, the iPhone's method for selecting objects from a list is distinctly different from the method of making the same selection on a desktop). While this enables some opportunity for depth, it fails to provide a solution to the dichotomy because it imposes an assumed interaction model on a device. For example, the iPhone's list selector is a great touch interface, but should users really ever be forced to choose from a linear list on a touch device? This approach provides insufficient granularity to fundamentally alter interaction for a given technology and context.

The third approach is executed at a lower level by providing an abstraction of input capabilities. This approach allows applications to query the capabilities of a particular device and deliver a modified version of the application based on the results. This is the approach taken by Java Platform Micro Edition (J2ME), a less-powerful alternative to Android. This is the solution that enables the greatest depth for every application because it forces the content producer to consider each capability, alone and in combination, and design the best possible solution in a given context. The limitations of this approach are immediately apparent because the number of possible combinations makes the development of truly deep applications prohibitively expensive. In the taxonomy shown in Fig. 1, there are seven categories, each with 3–5 levels. Designing a deep application for every combination in this space would require 11,520 different designs.

Conclusions

The breadth–depth dichotomy is a challenge that must be met as the sensing capability of touch devices explodes. The pressure of business to favor breadth over depth is a crushing force on innovation that has often extinguished the fires of exciting new technologies. The pressure of design in favor of depth is also clearly untenable – creating a perfect design for every sensing profile is prohibitively expensive. Finding a way forward is the only hope the touch-computing industry has of achieving its promise of fundamentally changing the way users interact with computers.

Acknowledgments

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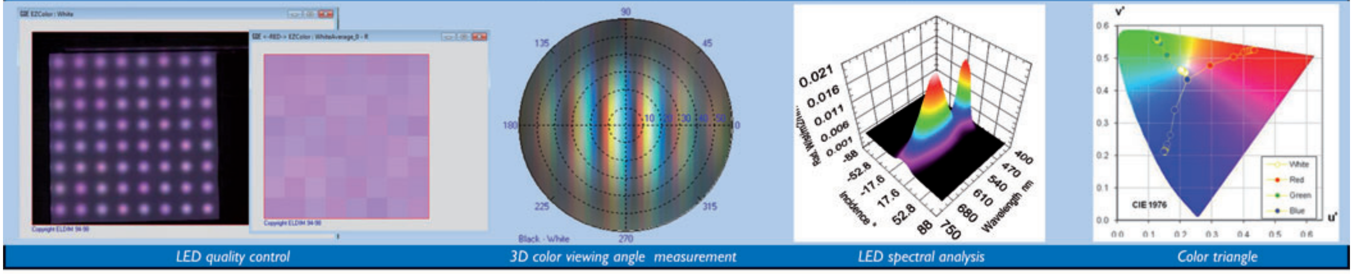
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3D color viewing angle measurement
LED spectral analysis
Color triangle
CIE 1976
White
Red
Green
Blue
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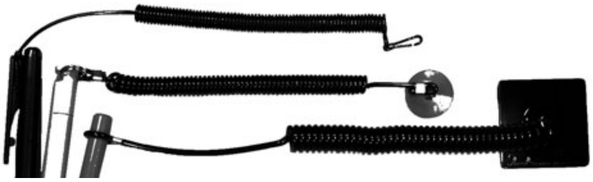


the Magic of
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“In-Touch” with Display Technology

By Joe Fijak, Vice President, Strategic Business Development, Avnet Embedded

Touch screen technology emerged from corporate research labs as early as the 1940s. Today, most individuals encounter some kind of “visual performance” display device, LCD or touch screen during any given day. These interactive products include ATMs, DVD rental kiosks, Blackberrys, iPhones, iPads and a variety of other cell phones, PDAs and GPS devices. The iPhone, which is perhaps the most recognized visual performance display product on the market today and utilizes a projective capacitive touch screen, has helped drive visual performance technology in other smart phones. In fact, by year end various manufacturers will introduce over 100 new cell phone/PDA models that utilize some form of a touch screen; and, there may be over 500 million total units by 2012. But touch screen technology is not only limited to the consumer application market, it has burgeoned in the industrial marketplace as well.

Recognizing the industrial marketplace as a key segment, Avnet Embedded, a division of Avnet Electronics Marketing, has positioned itself as the number one provider for the forth year in a row in N. America for display and touch screen technology — LCD, graphic and character modules. We are pleased to offer displays from some of the world’s leading technology providers such as AUO, NEC LCD Technologies, Optrex, Samsung, Sharp and Toshiba. And, our touch screen portfolio includes products from 3M Touch Systems, AMTouch, Elo Touch Systems, Fujitsu, Panjit and Wacom.

The following is an in-depth matrix offering an overview of the variety of popular touch screen products available through Avnet.

AVNET EMBEDDED TOUCH SCREEN PERFORMANCE MATRIX

Touch Feature and Performance Attribute	4 Wire Resistive	5 Wire Resistive	7 Wire Resistive	8 Wire Resistive	Surface Capacitive	Projected Capacitive	SAW (Surface Acoustic Wave)	IR (Infrared)	APR (Acoustic Pulse Recognition - ELO)	DST (Dispersive Signal Technology - 3M)
Cost	Low	Low-Med	Low	Low	Low-Med	High	Medium	High	Med-High	Med-High
Light Transmissivity	75-85%	75-85%	75-85%	75-85%	85-93%	90-95%	90-95%	up to 100%	92%	92%
Number of Touches	1M	35-50M	10M	3-5M	50-100M	Unlimited	100M	Unlimited	50M+	50M+
Durability	Low	Medium	Medium	Medium	Med-High	High	Med-High	High	High	High
Bare Finger Activation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gloved Finger Activation	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Pen/Stylus Activation	Yes	Yes	Yes	Yes	Tether	Tether	Some	Yes	Yes	Yes
Sealability	High	High	High	High	High	High	Low	Medium	High	High
Shock and Vibration	High	High	High	High	Moderate	High	High	High	Medium	Med-High
Chemical Resistance	Low	Low	Low	Low	Med-High	High	High	High	High	High
Scratch Resistance	Low	Low	Low	Low	Med-High	High	High	High	High	High
Surface Debris Resistance	Medium	Medium	Medium	Medium	Medium	High	Low	Low	High	High
Multi-Touch	No	No	No	No	No	Yes	No	Yes	Yes	Yes
Ease of Integration	High	High	High	High	Medium	Low-Med	Medium	Low-Med	Low	Low

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In addition to our vast portfolio of display and touch screen products, Avnet offers value-added services to assist our customers in creating unique projects with an interactive combination of display and touch screens. Our 228,000 sq. ft. state-of-the-art integration facility in Chandler, Arizona provides services such as touch screen enhancements on various displays and assistance with resistive, surface mount capacitive, projective capacitive, surface acoustic wave, infrared and DST touch screen technologies. This facility, along with several others worldwide, offers the following certifications: ISO: 9001-2000, 13485:2003 Medical and ISO: 140001 Environmental. In addition, it is ISO 14644-6 Clean Room compliant and features cellular manufacturing processes that utilize lean initiatives. And for breakthrough advances, it also offers continuous improvement methodology using frequent Kaizen events.

Touch Screen Controller Boards & Device Options

Touch systems function similar to a computer mouse. Touch screen controllers and software drivers, along with the desired sensor (touch screen), make up the touch solution. Controllers are PCB modules that connect the sensor to the computer source. Though typical interfaces include USB or serial, on occasion touch controllers are available on-board embedded computers.

The controller takes information from the touch screen and translates it into understandable information. Software drivers not only allow the computer operating system and the controller to communicate, but they also help the controller recognize input. The X/Y location of the touch point of contact is calculated by the controller and transmitted to the computer.

Calibrating the sensor, drivers and controller enables full and accurate functionality. It is critical to think of the touch sensor as a complete and inter-dependent solution. When selecting a sensor for your application it is critical to research appropriate controllers and compatible drivers specific to the desired touch screen technology and interface requirements.

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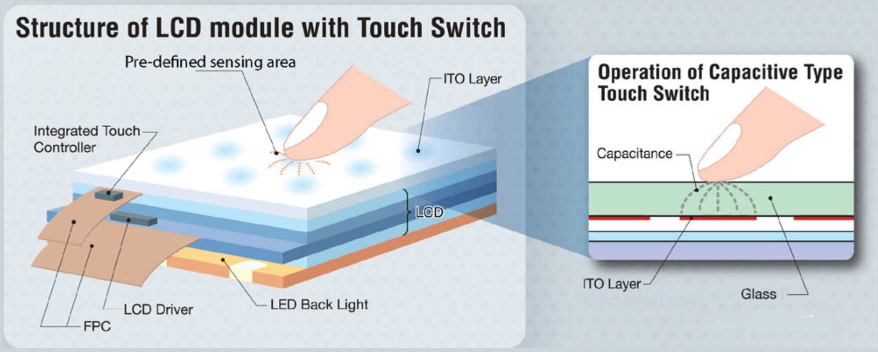
Features:

- High Transparency (95%)
- Glass bonding to eliminate air gap
- High visibility for outdoor environment

Advantage:

- Support multiple touches
- High sensitivity and high durability
- Simple design and easy calibration



Applications:

- Hand held terminal
- Medical Equipment
- Mobile & Gaming

Products Available:

Size	Part number	Resolution	Display Type	Brightness	Contrast Ratio	Interface
3.0”	T-55149GD030J-MLW-AJN	240 x 400	Transflective	400 Cd/m2	105:1	18-bit RGB
3.5”	T-51963GD035J-MLW-ALN	240 x 320	Transflective	150 Cd/m2	70:1	18-bit RGB
3.5”	T-55343GD035JY-LW-AFN	320 x 240	Transmissive	360 Cd/m2	700:1	24-bit RGB

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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

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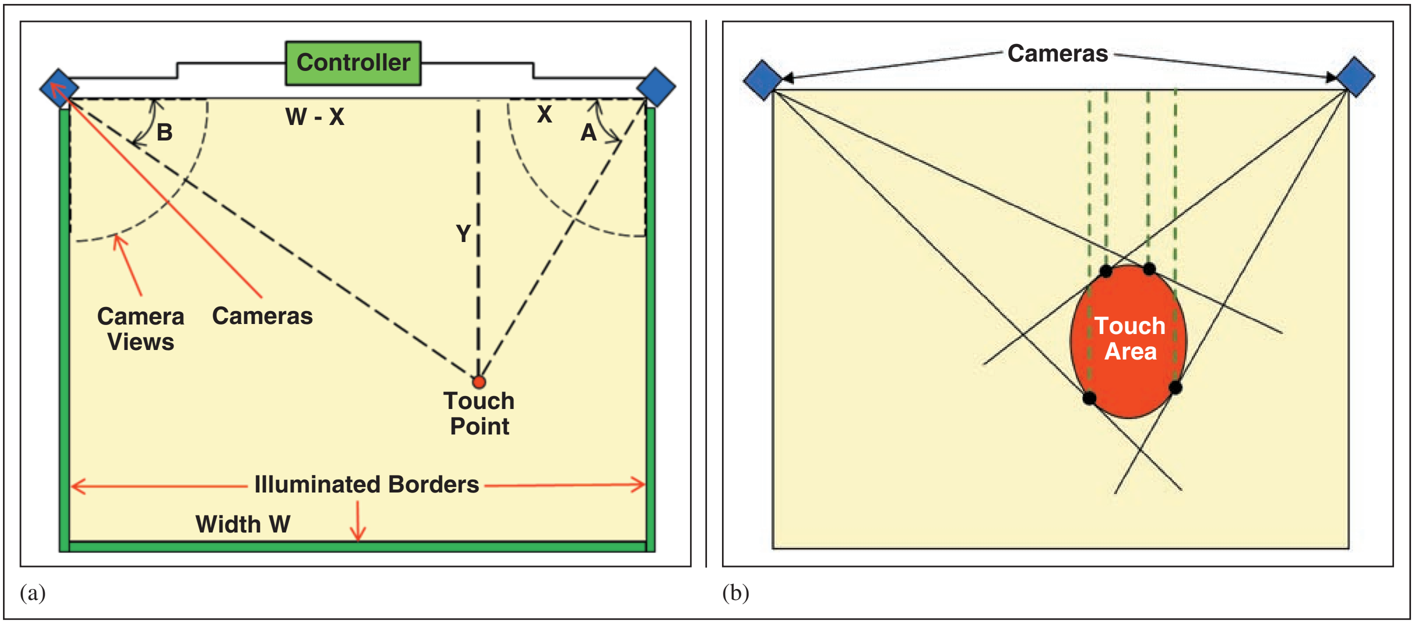

Fig. 1: *(a) The basic elements that comprise a camera-based optical touch screen are two cameras, a distributed light source around the periphery, and a controller. (b) When possible, triangulation is accomplished using the sides of the touching object, producing four sets of coordinates for each object.*

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 oversimplified 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]

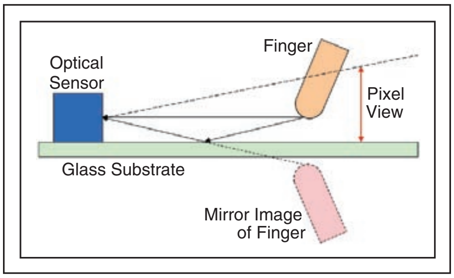

Fig. 2: *The "wedge view" of an optical sensor's pixels and the high reflectivity of glass when viewed at an oblique angle allow sensing light from both an actual object and its mirror image as the object approaches a glass substrate.*

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

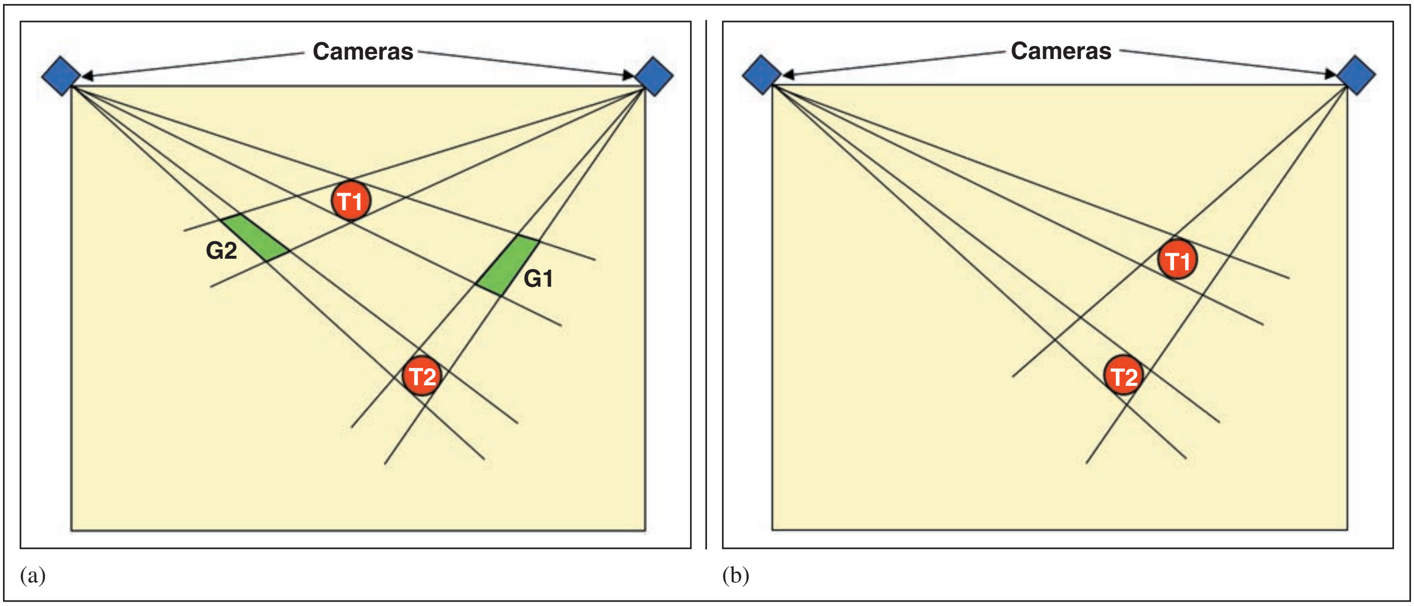

Fig. 3: *(a) In the case of two touch points (T1 and T2) where both cameras see distinct shadows of each point, "ghost" points (G1 & G2) are created. (b) With two touch points, where one camera has an occluded view, the measurement of the fourth edge on T1 & T2 is obscured.*

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.

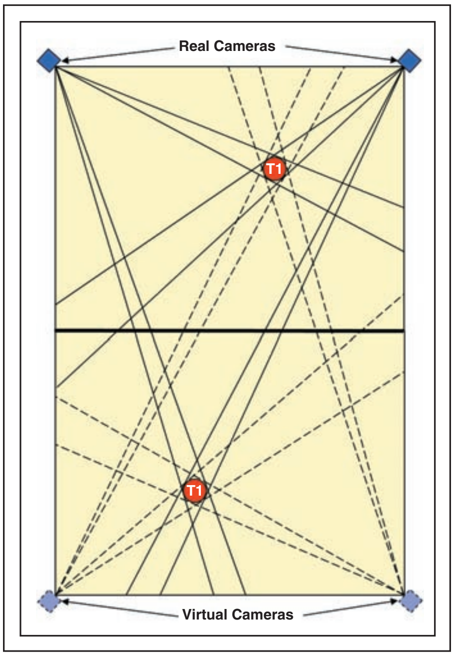

Fig. 4: Shown is a configuration with two cameras and a mirror. The black line in the center of the figure is the mirror; the lower half of the figure is the "virtual" touch space. A single touch (T1) is shown in red; the location of the touch is calculated by four triangulations – two from real cameras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

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First Look

Society for Information Display
SID INTERNATIONAL SYMPOSIUM
SEMINAR, AND EXHIBITION

DISPLAY WEEK 2011

May 15–20, 2011
Los Angeles Convention Center, Los Angeles, California, USA

www.sid2011.org

Announcing Special Topics of Interest on

- 3D
- Solid-State Lighting
- Green Manufacturing
- Flexible Displays
- Touch Technologies

Join us at Display Week 2011 to see what new technologies are shaping our future.

SID DISPLAY WEEK
Los Angeles
2011

Visit www.sid2011.org for the latest updates

A Look into the Future of Displays

Electronic displays touch nearly all aspects of modern life. Display Week's 2011 Keynote addresses will provide a vision for how new display technology and products will be shaping the future of entertainment, communications, and energy efficiency.

Keynote Speakers

Phil "Captain 3D" McNally, *Stereoscopic Supervisor at DreamWorks Animation*

While 3D technology continues to evolve, the focus of the entertainment industry is centered on how best to deploy 3D capabilities to mass audiences. *Phil McNally* will provide both his vision for 3D media and a personal history of his entry into the field. Mr. McNally is credited for the visual effects in 17 3D productions, including *Meet the Robinsons, The Nightmare Before Christmas, Chicken Little, Kung Fu Panda,* and *Monsters and Aliens.*

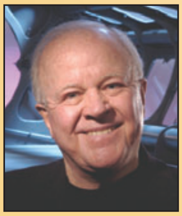
Yasuhiro Koike, *Professor at Keio University and Director of the Keio Photonics Research Institute*

Much of the demand for improved display technology is tied to the availability of high-quality telecommunications networks, and there are some amazing new capabilities in network technology under development. Professor Koike will share his vision of breathtakingly realistic face-to-face communications through the use of 3D and super-high-resolution 4K real-time video imaging. Professor Koike will provide an overview of the enabling technologies that could revolutionize both optical fibers and displays. Professor Koike is the inventor of the Graded-Index Polymer Optical Fiber (GI POF) technology and recipient of numerous awards, including the International Engineering and Technology Award and the Metal with Purple Ribbon from the Japanese government.

Shuji Nakamura, *Professor in the Materials Department at the University of Santa Barbara*

The development of high-brightness and short-wavelength LEDs has enabled the proliferation of new products ranging from Blu-ray players to energy-efficient lighting. Professor Nakamura will discuss how the development of high-brightness LEDs and visible laser diodes has led to new display application areas such as LED-backlit TVs, projection TVs, and DVD Blue-ray players. Professor Nakamura's first breakthrough was the development of the first group-III nitride-based blue/green LEDs in 1989, and he later developed the first group-III nitride-based violet laser diodes in 1995. His talk will review that work and describe the prospects for future breakthroughs in LED technology and applications. Professor Nakamura is the recipient of numerous international awards, including the Harvey Prize (Israel), Prince of Asturias Award (Spain), Millennium Technology Prize (Finland), and Braun Prize (SID), among others.

Awards Luncheon Address: "Immersive Cinema Technology"



The interplay of technology, the artist, and production is a critical aspect in the evolution of modern cinema. ***Douglas Trumbull*** will present his thoughts on current trends in motion-picture and television production and exhibition technologies, with a focus on 3D, high frame rates, and large-screen presentations. He will also describe how these technologies relate to the creative process of writing, producing, directing, photographing, and exhibiting science fiction and fantasy films. A legendary filmmaker and visual effects pioneer, Mr. Trumbull was one of the Special Photographic Effects Supervisors for *2001: A Space Odyssey.* He went on to become the Visual Effects Supervisor for such classics as *Close Encounters of the Third Kind, Star Trek: The Motion Picture,* and *Blade Runner,* each of which earned him an Academy Award nomination for Best Visual Effects.

2011 SID Technical Program to Include Special Technology Tracks

The Society for Information Display's annual Symposium at Display Week 2011offers a selection of presentations on display technology that simply cannot be found anywhere else. This year's program consists of 71 technical sessions with a total of 265 oral presentations and an additional 200 papers to be presented in the Thursday afternoon Poster Session. Please join us in Los Angeles (Tuesday, May 17 – Friday, May 20) to share the latest research and developments of the display industry. Among our special areas of focus are 3D, touch technologies, flexible displays, green technology, and solid-state lighting. Here is just a sample of the innovations you can expect to find at this year's Symposium.

3D

Possibly the biggest commercial story in displays last year was the arrival of 3D-ready TVs. Now that they have arrived, however, the story is far from over. Researchers continue to pursue the different approaches of active-shutter vs. passive glasses technology, and glasses-free viewing is a major challenge that many experts believe must be met in order to make 3D displays truly successful. This year's presentations also cover topics such as holographic displays, crosstalk reduction, measurements for 3D performance, and numerous other issues related to both OLED 3D and LCD 3D displays. Also, do not miss the 3D Cinema event happening on Tuesday evening, May 17, where 3D film shorts will be projected stereoscopically on a special 30-ft. silver screen and 3D filmmakers as well as other members of the rapidly growing industry will be making brief presentations.

Touch Technologies

Since the launch of touch-enabled mobile devices several years ago, touch has become an increasingly crucial component for numerous display products. Yet, the industry has not found the ideal touch technology solution. Touch is in an evolutionary phase now, and this year's papers reflect the diversity of approaches: projective-capacitive, optical, and many more. Which touch technologies hold the most promise and what is the next application or technology on the horizon? Make sure you attend the touch sessions at Display Week to find out.

Flexible Displays

Flexible displays offer the promise of ultra-thin robust displays that will fit into compact form factors, enabling new devices and applications previously envisioned only in movies and dreams. In particular, flexible OLEDs and electronic paper have the potential to open up completely new markets. Come learn about novel backplane materials, flexible electronics, and innovative processing techniques that are enabling this new class of displays.

Green Technologies

Display technology continually advances to provide higher resolution, larger size, and better performance – all at a lower cost. At the same time, however, environmental, social, and legislative forces are combining to ensure that manufacturers use the greenest-possible processes to create the most energy-efficient displays. What are the anticipated production and end-of-life issues for the display industry and how can they be addressed?

Solid-State Lighting

Solid-State lighting has begun to fulfill its promise with regard to saving energy and providing design flexibility. However, LEDs have made more commercial inroads in this area than just OLEDs, which are currently available only in high-end architectural applications. OLED papers therefore form the bulk of this year's solid-state-lighting sessions, as the industry pushes to develop higher-efficiency higher-performing OLED panels. Other solid-state-lighting papers will focus on trends in LED illumination.

The topics described above are only a portion of the wealth of information you will discover at this year's Symposium. Visit www.sid2011.org to view the Advance Program. No one involved in the display industry can afford to miss this event. Please join us this May and prepare to engage, learn, and discover what you need to know about the innovations occurring right now in the display industry.

Market Focus Conferences

After a very successful debut in 2010, the Market Focus Conferences will once again be held in conjunction with Display Week on Wednesday and Thursday, May 18 and 19, 2011. They will cover the following three topics:

- **Innovations in Touch** (Wednesday, May 18)
- **Green Displays** (Wednesday, May 18)
- **eBook/Tablet Market Evolution** (Thursday, May 19)

Each Market Focus Conference will concentrate on the critical market development issues facing each of these technologies. Developed in collaboration with IMS Research, each conference will feature presentations and panel sessions with executives throughout the display supply chain. Conference fees include a continental breakfast, lunch, refreshments, access to the Exhibit Hall and to the Symposium Keynote Session on Tuesday morning, and electronic copies of the presentation material. Market Focus Conference registration does not require a current SID membership.

Innovations in Touch: This conference will build on the success of Display Week 2010's Future of Touch & Interactivity Conference. Touch technology is ubiquitous in today's digital world and this event will play host to the who's who of the touch industry. The objective of this unique event is to provide an international forum for senior executives, technical managers, and marketing personnel from leading companies involved in touch technology to meet with other industry players to examine the market potential, technical barriers, and new opportunities that next-generation touch and interactivity technologies bring.

Green Displays: With increasing legislation and environmental awareness, the need for low-power displays has become a very hot topic. The Green Displays Conference at Display Week 2011 will look at issues such as green-display legislation and its impact on display manufacturers, the transition to LED-backlit displays to reduce power consumption, power semiconductor initiatives that reduce power consumption, innovations in fully recyclable displays with non-toxic components, and new technologies for reducing power consumption.

eBook & Tablet Market Evolution: With the rapid growth of the Amazon Kindle and the Apple iPad, the eBook reader and tablet markets are two of the fastest growing in displays. How might this change in the future? Will they remain distinct markets or will they collide? If so, when? This conference will examine the outlook for each of these markets and how their displays are likely to evolve, in terms of size, form factor, and much more.

For further updates visit www.imsconferences.com/displayweek2011.html.

Business Conference — The Ever-Evolving Display Supply Chain

DisplaySearch will once again organize this year's Business Conference to be held during Display Week 2011 in Los Angeles, California, Monday, May 16. This year's Business Conference will feature presentations from top executives of leading companies throughout the display supply chain. Each session will be anchored by DisplaySearch analysts presenting in-depth market and technology analysis and the latest forecasts. The SID/DisplaySearch Business Conference will feature in-depth analysis of key global markets, as well as display-supply-chain issues, including:

Economic Issues and Consumer Trends: What is the outlook for the global economy, and which are the fast- and slow-growing regions?

Equipment and Manufacturing: What is the state of the art in flat-panel manufacturing equipment, materials, and manufacturing processes?

Panel Production and Technology, including Regional Trends: How rapidly will panel production grow in China? Which regions will lose market share as China gains?

Set-Making and Applications: How are the value chains for TVs, monitors and notebook PCs, mobile devices, and other display systems shifting? How are devices like e-book readers and tablet PCs changing demand?

Emerging Technologies and Applications: What are the most promising new display technologies? How is TFT-LCD technology improving to meet the challenge of other technologies such as OLED and reflective technologies?

For further updates visit www.displaysearch.com/SID

Investors Conference

Co-sponsored by Cowen & Co., LLC, a securities and investment banking firm, this Conference will feature company presentations from leading public and private display companies, intended to appeal primarily to securities analysts, portfolio managers, investors, M&A specialists, and display company executives.

For further updates visit www.cowen.com

2011 SID Seminar Series

Sunday May 15 Short Courses

The Society for Information Display presents four 4-hour short courses on diverse topics related to information display. The tutorials are characterized by technical depth and small class size. The four-hour classes covering the fundamentals of electronic information displays will be held on the morning and afternoon of the Sunday preceding the Symposium. Full-color tutorial notes will be distributed to all participants and are included in the fee. Ample time will be provided for questions from the audience. The speakers are leaders in their respective fields who bring an international perspective to information display.

S-1: Fundamentals of OLED Lighting
S-2: Fundamentals of Flexible Displays
S-3: Fundamentals of Phosphors for Backlighting Applications
S-4: Fundamentals of Touch Technologies and Applications

Monday May 16 Technical Seminars

The SID Technical Seminars present lectures on diverse topics related to electronic information displays. The seminars are tutorial in nature and an attempt is made to provide information at three levels. First and foremost, the technical foundations of the topic are treated in detail. Next, recent technical advances are discussed, and, finally, the current state of the art and projection of future trends are analyzed.

These seminars can benefit both newcomers and experienced professionals. Engineers new to assignments in information display find them especially helpful in getting up to speed quickly. Experienced professionals attend to keep up with recent developments in fields closely related to their specialties. Managers attending the seminars obtain a broad perspective of the display field and a sense of its recent dynamics. Attendees will receive an excellent set of full-color notes, replete with references and illustrations. Ample time is provided for questions from the audience in each session. The speakers are leaders in their fields who bring an international perspective to information display.

Track 1:
M-1: Novel Breakthroughs Leading to Future TV Systems
M-5: Advanced Horizontal Electrode Structure In-Plane Switching (AH-IPS) for Mobile Displays
M-9: Photoalignment of Liquid Crystals
M-13: Blue-Phase LCDs

Track 2:
M-2: Oxide-TFT Technology
M-6: Laser Crystallization for Advanced LCDs and AMOLED Displays
M-10: Displays for e-Readers
M-14: Flexible Displays

Track 3:
M-3: 3-D TV
M-7: Emerging Display Applications: The Next Big Thing
M-11: Bendable-Film Displays with Plasma-Tube-Array Technology for Super-Large-Area Display Markets
M-15: Optical Films for LCD Applications

Track 4:
M-4: OLED Lighting: Promises and Challenges
M-8: Progress in Printed OPV Technology
M-12: Capacitive Touch-Sensing Innovations
M-16: The Leading Edge of Touch

Monday May 16 Applications Tutorials

Six practical and interactive 90-minute applications tutorials are being offered on Monday. These seminars focus on the application and evaluation of information displays. A complete set of full-color applications tutorial notes is included in the fee.

A-1: Various Light Sources for General Lighting
A-2: Flexible Display Technologies and Their Applications
A-3: Image Sources for Near-to-Eye Applications
A-4: Mobile Multimedia Displays
A-5: Introduction to Pico-Projectors
A-6: Professional Applications of Stereoscopic 3D Monitors

For further details visit www.sid2011.org.

Display Week 2011 Overview

Los Angeles Convention Center, Los Angeles, CA USA

May 15–20, 2011

TIMETABLE	Sunday	Monday			Tuesday			Wednesday				Thursday			Friday
	Course	App Tuts	Sem	Bus	Symp	Exh	Inv	Symp	Exh	Focus	Focus	Symp	Exh	Focus	Symp
7:45 AM - 8:30 AM				Business Conference	SID Bus Mtg										
8:30 AM - 9:00 AM		App Tuts A1-A2	Seminars M1 -M4		Welcome & Keynote Addresses										
9:00 AM - 9:30 AM	Short Courses S1 & S2							Oral Sessions 21-26	Exhibits/Exhibitors Forum Sessions	Market Focus Conference.: Future of Touch and Interactivity	Market Focus Conference: Green Displays	Oral Sessions 41-47	Exhibits/ Exhibitors Forum Sessions	Market Focus Conference: eBook and Tablet Market Evolution	Oral Sessions 61-66
9:30 AM - 10:00 AM															
10:00 AM - 10:30 AM															
10:30 AM - 11:00 AM		App Tuts A3-A4	Seminars M5 -M8		Oral Sessions 3-7	Exhibits/Exhibitors Forum Sessions	Investors Conference	Oral Sessions 27-33				Oral Sessions 48-54			Oral Sessions 67-72
11:00 AM - 11:30 AM															
11:30 AM - 12:00 PM															
12:00 PM - 12:30 PM				Bus. Conf. Lunch				Luncheon: DYA & Best-in-Show Awards							Auth. Int.
12:30 PM - 1:00 PM															
1:00 PM - 1:30 PM															
1:30 PM - 2:00 PM		App Tuts A5-A6	Seminars M9 - M12	Business Conference								Oral Sessions 55-60			
2:00 PM - 2:30 PM					Oral Sessions 8-13			Designated Exhibit Time							
2:30 PM - 3:00 PM															
3:00 PM - 3:30 PM	Short Courses S3 & S4											Auth. Int.			
3:30 PM - 4:00 PM			Seminars M13 - M16		Oral Sessions 14-20			Oral Sessions 34-40							
4:00 PM - 4:30 PM												Poster Session			
4:30 PM - 5:00 PM															
5:00 PM - 5:30 PM				Bus. Conf. Recept	Auth. Int.		Inv. Conf. Recept	Auth. Int.							
5:30 PM - 6:00 PM															
6:00 PM - 6:30 PM								Special Event							
6:30 PM - 7:00 PM															
7:00 PM - 7:30 PM															
7:30 PM - 8:00 PM					3D Cinema Session										
8:00 PM - 8:30 PM			Awards Banquet												
8:30 PM - 9:00 PM															
9:00 PM - 9:30 PM															
9:30 PM - 10:00 PM															

Display Week 2011 Symposium at a Glance

	Times	Concourse Hall	Petree Hall C	Petree Hall D	Room 403A	Room 403B	Room 408A	Room 408B	Times	
Tuesday, May 17	8:00 – 10:20	SID Business Meeting and Keynote Session (Concourse Hall)							8:00 – 10:20	Tuesday, May 17
	10:50 – 12:10	3 Liquid-Crystal Lenses for 3D Displays (Joint with LCT)	4 Oxide TFTs I	5 Electronic Paper I	6 VA Mode		7 Novel Applications		10:50 – 12:10	
	2:00 – 3:20	8 Liquid-Crystal Technology for 3D (Joint with LCT)	9 Mobile-Display Technology	10 Electronic Paper II	11 Blue-Phase LC I		12 Near-to-Eye and Head-Worn Display Applications	13 Flexible Displays (Joint with Flexible)	2:00 – 3:20	
	3:40 – 5:00	14 3DTV - LCD (Joint with Systems and Applications)	15 AMOLEDs and AMLCD TVs	16 Flexible Backplanes	17 Blue-Phase LC II	18 Colors of Vision	19 Large-Area, Head-Up, and Rugged Display Applications	20 Green Display Applications	3:40 – 5:00	
	5:00 – 6:00	Author Interviews (Exhibit Hall)							5:00 – 6:00	
Wednesday, May 18	9:00 – 10:20	21 AMOLED - Driving (Joint with Active-Matrix)		22 Integrated Flexible Electronics	23 Blue-Phase LC III	24 Visual Perception	25 Digital Cinema	26 Panel-Driving Technology (Joint with Green)	9:00 – 10:20	Wednesday, May 18
	10:40 – 12:00	27 3DTV - OLED (Joint with Electronics and Active-Matrix)	28 Low-Power Active-Matrix Alternatives (Joint with Green)	29 Display Manufacturing: Flexible Displays (Joint with Manufacturing)	30 Cholesteric Liquid-Crystal Displays	31 Medical/Visual Performance	32 Despeckling Despicable Speckle and Rejecting Ambient Light	33 Image and Video Processing	10:40 – 12:00	
	2:00 – 3:30	Designated Exhibit Time (Exhibit Hall)							2:00 – 3:30	
	3:30 – 4:50	34 Autostereoscopic and Integral Imaging (Joint with Systems)	35 Oxide TFTs II	36 Flexible OLEDs	37 Plasma-Display Protective Layer	38 Display Manufacturing: Processes	39 Pico-Projection	40 Interface Technologies for Display	3:30 – 4:50	
	5:00 – 6:00	Author Interviews (Exhibit Hall)							5:00 – 6:00	
Thursday, May 19	9:00 – 10:20	41 Holographic Display and 3D Image Capture (Joint with Systems and Applications)	42 OLED Displays I	43 Capacitive Touch Systems	44 MgO-CaO Protective Layer	45 Display Manufacturing: Substrates	46 Local Dimming (Joint with Green)	47 Laser Light Projection (Joint with Projection)	9:00 – 10:20	Thursday, May 19
	10:40 – 12:00	48 Novel 3D Displays (Joint with Systems)	49 OLED Displays II	50 Optical Touch Systems	51 High-Efficiency Plasma TVs (Joint with Green)	52 Display Manufacturing & Applications: Modules and Components (Joint with Applications)	53 LED and Laser Backlights	54 Solid-State Lighting Applications (Joint with Applications)	10:40 – 12:00	
	1:30 – 2:50	55 Crosstalk in Stereoscopic Displays (Joint with Systems and Measurement)	56 OLED Devices I	57 Touch Systems	58 Advanced Emissive Displays	59 Display Manufacturing: LTPS	60 Integrated Optics for Backlight	73 Late-News: Projection	1:30 – 2:50	
	3:00 – 4:00	Author Interviews (Exhibit Hall)							3:00 – 4:00	
	4:00 – 7:00	Poster Session (Exhibit Hall)							4:00 – 7:00	
Friday, May 20	9:00 – 10:20	61 3D Human Factors - Applied Vision (Joint with Vision)	62 OLED Device II		63 Liquid-Crystal Alignment I	64 Display Measurement Standards and Applications	65 Field-Sequential Color	66 OLED Lighting I (Joint with OLED)	9:00 – 10:20	Friday, May 20
	10:40 – 12:00	67 3D Human Factors and Performance (Joint with Systems)	68 OLED Physics		69 Liquid-Crystal Alignment II	70 Achieiving Accurate Color Reproductions	71 Novel Displays	72 OLED Lighting II (Joint with OLED)	10:40 – 12:00	
	12:00 – 1:00	Author Interviews (Exhibit Hall)							12:00 – 1:00	

TECHNOLOGY TRACKS KEY

3-D	Active-Matrix Devices	Applications	Applied Vision	Electronics	Emissive
FEDs	Flexible	Green	Lighting	Liquid Crystal	Manufacturing
Measurement	OLEDs	Projection	Display Systems	Touch	

Society for Information Display NEWS

Students from National Chiao Tung University Win 2010 *JSID* Outstanding Student Paper Award for OLED Research

by Meng-Huan Ho, Chang-Yen Wu, and Shang-Yu Su

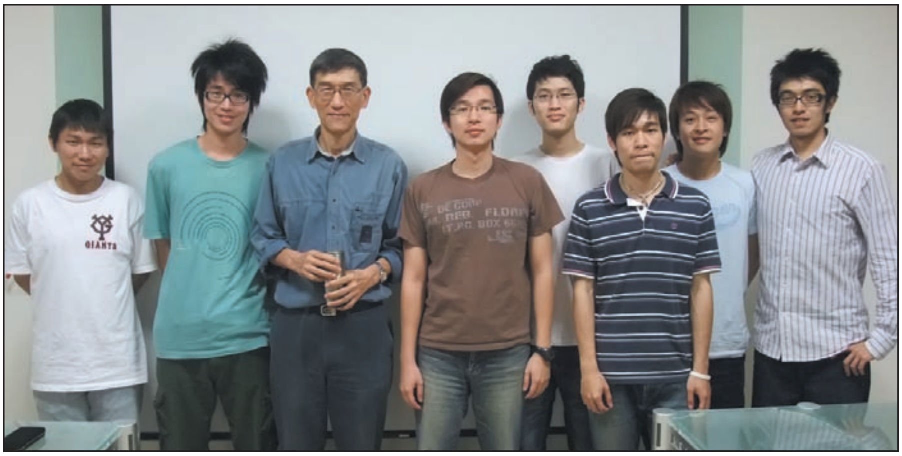


Fig. 1: The paper authors among these NCTU OLED lab group members are Chang-Yen Wu (second from right), Shang-Yu Su (fourth from right), Meng-Huan Ho (center), and Prof. Chin H. (Fred) Chen (third from left).

Organic light-emitting-diode (OLED) technology and its application for high-information-content displays continue to be a focus of many research programs around the world. Creating an active-matrix OLED (AMOLED) display requires the use of thin-film transistors (TFTs) such as amorphous-oxide TFTs. However, there are compatibility issues with a-si TFTs and OLED materials, as our student team from the National Chiao Tung University in Taiwan discovered. With guidance from our professor, we sought to find a solution to this compatibility problem by developing an inverted-type OLED structure called an IOLED, as well as by implementing the solution on a flexible substrate to demonstrate the full range of innovation possible using our ideas.

Our efforts, as described in the paper "Flexible inverted bottom-emitting organic light-emitting devices with a semi-transparent metal-assisted electron-injection layer," were recognized by the receipt of the 2010 Outstanding Student Paper award from the *Journal of the Society for Information Display*, bestowed each year to a published student paper on the basis of originality, significance of results, organization, and clarity.

Background

During the time that our team members, Chang-Yen Wu, Shang-Yu Su, and Meng-Huan Ho (Fig. 1), were pursuing their graduate studies at the National Chiao Tung University in Taiwan, organic light-emitting-diode (OLED) technology had begun to draw increasing attention as the next-generation display platform (as well as a potential source for general illumination). We believed that among existing display technologies, active-matrix organic light-emitting diodes (AMOLEDs) had the strongest potential.

At the same time, amorphous-oxide TFTs have attracted much attention and are seen as the next-generation TFT backplane for AMOLEDs. They appear to have neither instability issues in terms of mobility nor a sub-threshold gate-voltage swing, and they exhibit large carrier mobility. Moreover, oxide TFTs can be deposited at much lower temperatures, which, in principle, makes possible the mass production of AMOLEDs on flexible plastic substrates. However, oxide-TFTs can only be used to fabricate n-channel TFTs. For conventional OLEDs, the bottom anode can only be fabricated at the source end of the driving oxide TFT, which invariably impacts the stability of the source voltage that depends on the voltage drop across the OLED materials. The most direct way of solving this problem is to use an inverted-type OLED (IOLED) for n-channel TFTs because it provides a bottom cathode that can be connected to the drain end of the n-channel TFT through which the current circuit of the TFT can be decoupled from the resistive loss of the OLED materials. Accordingly, the research and development of IOLEDs have become increasingly important and timely with regard to the realization of oxide TFTs with n-channel-driven large-panel AMOLEDs. Figure 2 shows a diagram of an inverted-type OLED integrated with an oxide TFT.

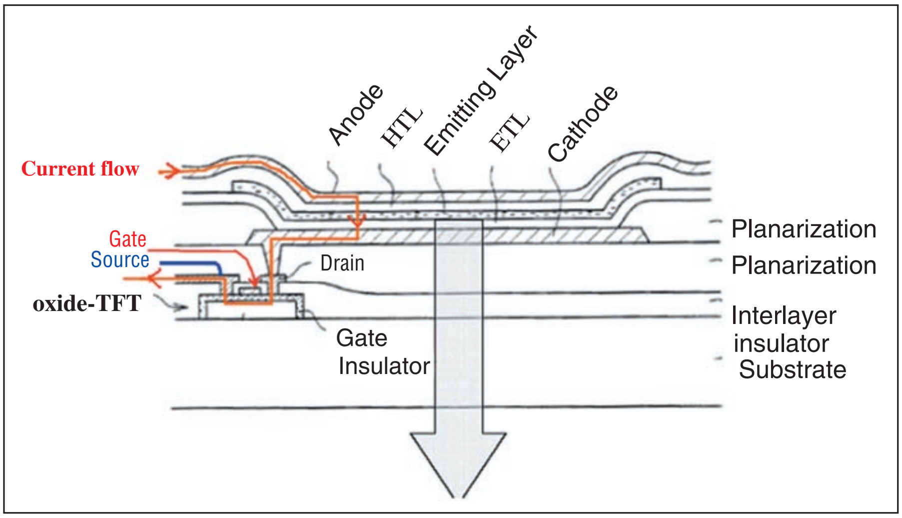


Fig. 2: A diagram of an inverted-type OLED integrated with an oxide TFT.

Lab Work

Typical OLEDs possess a transparent ITO electrode with high work function as the anode. For inverted bottom-emitting OLED (IBOLED) devices, the ITO has to be inverted to function as a cathode. This creates some problems because it is difficult to inject electrons from ITO into the organic layer, due to their severe energy level mismatch. This mismatch, in turn, causes the drive voltage to rise sharply and the efficiency to fall off.

The team members' advisor, Professor Chin H. (Fred) Chen, thought that electron injection could be one of the key factors in developing IBOLEDs and encouraged his students to improve the carrier injection and device performance of flexible IOLEDs. For this project, we chose plastic polyethersulphone (PES) as our flexible substrate because it has a higher glass-transition temperature than most of the other commercially available flexible substrates.

Su was responsible for sputtering ITO on the PES substrate. Ho provided a general n-i-p IBOLED structure to overcome the carrier-injection barrier. One day, Wu came up with a synergy idea to intentionally create a microcavity within the IBOLEDs, which is accomplished by inserting a thin semi-transparent silver (Ag) layer between the ITO and the n-doped layer.

By using this concept in our OLED design, we found that the inserted thin Ag layer not only improved the electron injection but also enhanced the device's normal efficiency and color saturation through the cavity structure between a high-reflection back electrode and a semi-transparent metallic ground contact. By using these flexible IBOLEDs along with the synergistic microcavity effect, we were able to achieve maximum efficiencies that were 1.5 times higher than those of conventional OLEDs, representing more than a 20% improvement over an IBOLED without using Ag thin film.

We therefore demonstrated that both power efficiency and color saturation in an IBOLED on a flexible PES substrate can be enhanced by inserting a semi-transparent metal-assisted electron-injection layer between ITO and the n-doped ETL. This created a beneficial microcavity effect, which could be exploited to enhance color saturation without impacting its electrical properties. We believe that among existing display technologies, AMOLEDs have the best potential to become the "ultimate display" solution, due to their fast motion-picture response time, vivid color, high contrast, and super-slim lightweight nature. We expect that the technology of flexible AMOLEDs will further mature in the near future and that flexible AMOLED products will be seen in the marketplace soon.

On behalf of the Organic Light Emitting Diode Technology Research Laboratory, we deeply appreciate the selection of our paper by the *JSID* Awards Committee. This award gives us great encouragement with regard to the further development of our advanced research.

Chang-Yen Wu and Shang-Yu Su received their masters' degrees from the Institute of Electro-Optical Engineering and the Display Institute, respectively, at National Chiao Tung University (NCTU), Taiwan, in 2009. Meng-Huan Ho received his Ph.D. degree from the Department of Applied Chemistry at NCTU in 2010. ■

continued from page 4

significant – an examination of a serious problem that is facing the touch industry, one that could greatly impede the progress of touch computing. Read the article and learn all about the problem with the impressive name of "the breadth–depth dichotomy"!

In the 16 months since the launch of Windows 7, camera-based optical touch has exploded into several dozen consumer-desktop products. This is a big change, since prior to Windows 7 this technology appeared in only one consumer product (the HP TouchSmart all-in-one computer) and was found mostly in large displays such as wayfinders and in display-based interactive whiteboards from SMART Technologies. During the 16 months, at least a half-dozen new suppliers have entered the market, touch performance has steadily improved, the OEM cost of the technology has steadily declined, and the meaning of "optical touch" has shifted from traditional infrared to camera-based optical touch.

This issue includes a Frontline Technology article by me, Geoff Walker, the Guest Editor for this issue of *Information Display*. To my knowledge, this is the first technical article on camera-based optical touch that has appeared in any media anywhere (except for conference papers, of course). What else does a Guest Editor do, you wonder? The role starts with deciding what topics the issue's articles should cover, then finding people who are willing to write the articles. It continues with sometimes creating illustrations for authors, and always shepherding the articles and working with the staff at *Information Display* through the multi-step editing and review process. The last step is writing this editorial. The whole thing is actually a very satisfying effort, especially when (as happened recently) someone told me that they keep the 2010 touch issue on their desk because they often refer to the very useful information it contains.

I hope you enjoy reading this issue!

References

[1] Heraclitus (540 BC - 480 BC), quoted by Diogenes Laërtius, in "Lives and Opinions of Eminent Philosophers." ■

***Geoff Walker** is the Marketing Evangelist & Industry Guru at NextWindow. He can be reached at 408/506-7556 or geoff@walkermobile.com.*

continued from page 2

Suddenly the big next leap does not seem that far-fetched. First, drop the qualifier "Graphic" from GUI because the interface no longer needs to rely solely on either touchscreen gestures or on graphically predetermined options. Next, add the ability to interpret speech (as Watson can do now), with face-recognition technology to establish mood (as has been demonstrated in several academic settings) and the UI of tomorrow could really be a conversation with the machine that incorporates all the nuances of gesture, mood, spoken idea, and maybe even tone of voice that we use with each other as human beings.

All of the basic hardware building blocks to achieve this exist today, in many and various forms. Digital cameras can be used for recording faces and bodies. Sensors mounted on a person (or held in hands) can determine all the required states of motion as well as body temperature. Microphones can capture audio speech and speakers can allow the machine to talk back. It is no longer the hardware that is holding us back. It is now a matter of how much functionality we can envision and how much artificial intelligence the computer science community can bring to bear on the task. We already have handheld devices that can make calls on command, surf the Web, and even write messages with speech commands. Imagine being able to ask your iPhone to survey the local restaurants, recommend a place with good seafood, and speculate based on the fishing seasons and the migration patterns whether the salmon will be available fresh or frozen that day. Whimsical for sure, but no more unreasonable than Captain Kirk asking his computer to speculate on the likelihood of some complex astrophysics effects contributing to the dilemma du-jour he is facing in deep space.

So, I brought you through this train of thought culminating in a Star Trek reference because my goal was to illustrate that the relatively basic embodiment of touch, in my view, is one of the cornerstones on the journey to a free-expression UI, and still extremely relevant to the future of computing devices. The vast array of touch or body motion interface technologies available today are building blocks in the critical hardware foundation needed to support the next generation of UI capabilities I am so easily suggesting. That is why, more than ever before, keeping our eyes and hands around innovation in the touch space is a critical part of understanding the future of the display industry.

To keep us up to date and focused on the latest trends, we continue to rely on this month's Guest Editor and one of our most ardent supporters, Mr. Geoff Walker, whose official title at NextWindow is Marketing Evangelist and Industry Guru. Geoff has done an outstanding job assembling this month's array of articles and you can read his great introductions in his Guest Editor's note. Geoff is also a frequent seminar speaker at SID and I hope you have the chance to experience one of his seminars if you are coming to Display Week in LA this year.

Every year, the March Touch Technology issue of *ID* is one of our most popular issues. We receive many requests for extra copies, our advertisers provide us very generous support, and the articles are always in-depth and fun to read. People just naturally understand touch paradigms and all seem to have strongly formed opinions on how the technology should perform. That leads to lively discussions I always look forward to. Next year, I suspect we will be calling this the User Interfaces issue and expanding our reach even further, based on where the industry appears to be going and on my own logic discussed above.

I would like to once again acknowledge the very generous and enabling support being given to us by Avnet. As a strong backer of the display industry through its many activities, which include application-engineering support, customer education, and supply-chain management, as well as its support for SID and *Information Display* magazine, Avnet helps us all move the world of displays forward in new and innovative ways. We really appreciate the company coming on board and co-sponsoring *ID* this month.

One final note: As we were going to press we learned of the dreadful circumstances following the earthquake and tsunami in Japan. I can only imagine the scope of the tragedy that will slowly be revealed to us in the coming days. Our thoughts and prayers go out to everyone involved with the sincere hope that recovery comes fast. What we do as technologists is only a small part of who we are as human beings and in these times, the real measure of our spirit is how we reach out to help each other and convert our compassion to actions that truly heal. The whole world will be working and praying for those involved.

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[1] Watson is an artificial intelligence computer system capable of answering questions posed in natural language, developed in IBM's DeepQA project by a research team led by principal investigator David Ferrucci. In 2011, as a test of its abilities, Watson competed on the quiz show *Jeopardy!* in the show's only human *vs.* machine match-up. In a two-game combined-point match, broadcast in three *Jeopardy!* episodes February 14–16, Watson bested Brad Rutter, the biggest all-time money winner on *Jeopardy!* and Ken Jennings, the record holder for the longest championship streak. http://en.wikipedia.org/wiki/Watson_(artificial_intelligence_software)

[2] http://www-03.ibm.com/innovation/us/watson/what-is-watson/why-jeopardy.html

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The following papers appear in the March 2011 (Vol. 19/3) issue of *JSID*.
For a preview of the papers go to sid.org/jsid.html.

Contributed Papers

Active-Matrix Devices and Circuits

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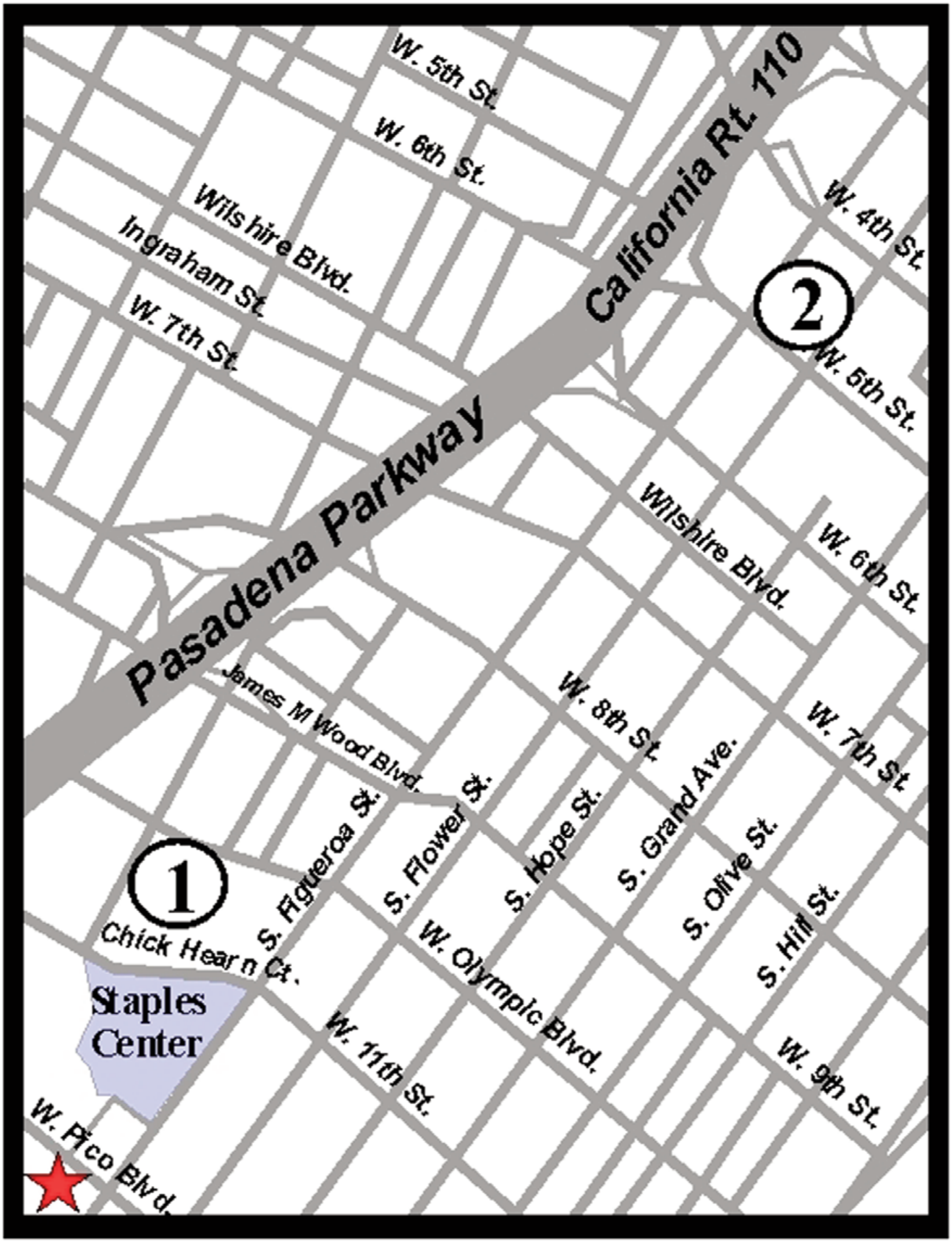

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315 ☐ Displays (Other)
316 ☐ Display Components, Hardware, Subassemblies
317 ☐ Display Manufacturing Equipment, Materials, Services
318 ☐ Printing /Reproduction / Facsimile Equipment
319 ☐ Color Services /Systems
320 ☐ Communications Systems / Equipment
321 ☐ Computer Monitors /Peripherals
322 ☐ Computers
323 ☐ Consulting Services, Technical
324 ☐ Consulting Services, Management /Marketing
325 ☐ Education
326 ☐ Industrial Controls, Systems, Equipment, Robotics
327 ☐ Medical Imaging /Electronic Equipment
328 ☐ Military /Air, Space, Ground Support /Avionics
329 ☐ Navigation & Guidance Equipment /Systems
330 ☐ Oceanography & Support Equipment
331 ☐ Office & Business Machines
332 ☐ Television Systems /Broadcast Equipment
333 ☐ Television Receivers, Consumer Electronics, Appliances
334 ☐ Test, Measurement, & Instrumentation Equipment
335 ☐ Transportation, Commercial Signage
336 ☐ Other *(please be specific)*

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4. What is your purchasing influence?

410 ☐ I make the final decision.
411 ☐ I strongly influence the final decision.
412 ☐ I specify products/services that we need.
413 ☐ I do not make purchasing decisions.

5. What is your highest degree?

510 ☐ A.A., A.S., or equivalent
511 ☐ B.A., B.S., or equivalent
512 ☐ M.A., M.S., or equivalent
513 ☐ Ph.D. or equivalent

6. What is the subject area of your highest degree?

610 ☐ Electrical /Electronics Engineering
611 ☐ Engineering, other
612 ☐ Computer /Information Science
613 ☐ Chemistry
614 ☐ Materials Science
615 ☐ Physics
616 ☐ Management /Marketing
617 ☐ Other *(please be specific)*

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7. Please check the publications that you receive personally addressed to you by mail (check all that apply):

710 ☐ *EE Times*
711 ☐ *Electronic Design News*
712 ☐ *Solid State Technology*
713 ☐ *Laser Focus World*
714 ☐ *IEEE Spectrum*

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