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Reexamining the Potential of Infrared (IR) Touchscreens

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Abstract

In the last decade, touchscreen equipped displays have become common features in applications ranging from kiosks, point of sale systems, industrial control, and medical instrumentation. There are more choices in touchscreen technologies and branded manufacturers than ever. Paradoxically, the more choices that exist, the harder it is to ensure that the best touchscreen technology for your application has been selected. This paper aims to help you understand the choices that are available to the product designer and integrator, and to assist you in the selection of the most appropriate touch technology option. We will start with an exploration of the historical limitations the CRT placed upon designers and the challenges of interfacing with computing equipment.

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December 5 2007

A Short History of Display Technology & Touchscreens

Twenty years ago, cathode ray tubes (CRTs) were practically the only choice from which to view highly graphical information content. CRTs were used for mainframe and mid-frame terminals in emerging PC workstations; and embedded applications including cash registers, avionics, medical instrumentation, industrial controls, and medical diagnostics. The promise of increased productivity through computer automation was limited because specialized training was required of workers to facilitate computer use. Only specialized vocational users knew the arcane commands of UNIX, DOS, and machine computer commands. Product designers sought a means of making their applications intuitive so that users would not have to be trained in computer use. Combining the CRT, graphical user interface (GUI), and touchscreen delivered an intuitive means of accessing the power of computer based applications.

As explained, the ubiquitous CRT mandated that early touchscreen designs had to accommodate the curved face of the CRT. The viewing area of a cathode ray tube can be molded in one of 3 ways: spherical, cylindrical and flat screen. Flat screen CRTs were size and cost prohibitive for mainstream applications, so spherical and cylindrical touchscreen form factors became the most widespread options.

Touchscreen designs for CRTs were based upon three technical approaches:

1. Resistive, capacitive, and acoustic technologies utilizing a direct sensor overlay affixed to a curved glass plate that conformed to the curved glass surface of the CRT, similar to the manner that a contact lens conforms to the shape of an eye;
2. Infrared (IR) LED based sensors affixed to the perimeter of the active area of the CRT (sensors embedded within the bezel and directed across the face of the curved CRT surface);
3. Strain gauges that measured changes in deflection or balance of the CRT. (Strain gauge sensors mounted inside the CRT enclosure or inside a pizza-box-shaped platform that supported the CRT).

The "contact lens" approach, which included a sensor overlay mounted directly to the curved surface of the CRT, was overwhelmingly adopted over the IR and strain gauge approaches because it was reliable and cleanly integrated at the monitor's place of assembly. Additionally, it offered significant touch accuracy advantages because the sensor was directly affixed atop the display, resulting in minimal parallax induced touch inaccuracy.

Early IR touchscreens on curved "green screen" CRT
Photo courtesy of Old-Computers.com

Touchscreen Market Adoptions – The Early Years

Design Approach	Inherent Advantage	Inherent Disadvantage	Market Acceptance
Direct Sensor Overlay (contact lens)	Packaging advantage, touch zone accuracy.	Display image clarity and contrast reduction.	Winner!
IR	No reduction in display clarity.	Cost of LEDS. X & Y axis touch resolution is proportional to the number of LEDs Parallax caused by curvature in CRT face lessened touch accuracy.	Loser
Strain Gauge	No reduction in display clarity.	Mechanical approach to calibration proved too unreliable.	Loser

CRT Era: Battle of the Direct Sensor Overlay Technologies

The mainstream market adopted "contact lens style" touch sensors utilizing one of four sensor technologies that were acceptable for use on curved CRT surfaces:

1. Resistive 4-wire
2. Resistive 5-wire
3. Capacitive
4. Surface Acoustic Wave (SAW)

The two leading touchscreen vendors, competing on a basis of technical superiority, dominated CRT-based applications with resistive (5-wire), capacitive, and SAW sensors. They developed dependable technology sensors, analog to digital (A/D) controllers, and software drivers. Though offering manufacturing cost advantages, 4-wire resistive touchscreens could not be easily formed to the surface of a curved CRT, so it never ascended to challenge 5-wire resistive, capacitive, and SAW approaches. While resistive, capacitive, and SAW all involve adhering a touchscreen to a piece of formed glass, each vendor's technology operated upon different physical principles.

Resistive 4-wire- A 4-wire touch sensor is comprised of two layers of ITO (indium tin oxide a transparent conductive film) that have been deposited on a rigid or flexible substrate and a flexible transparent polymer coversheet separated by thin, nearly invisible spacer dots.

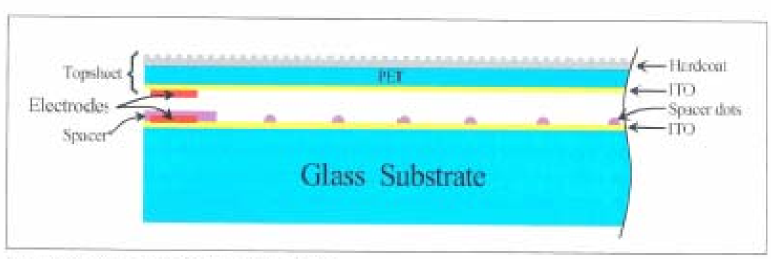


Figure 2. Film on Glass Construction

P*hoto courtesy of 3M*

Resistive touchscreens work on the basis that these two conductive layers of uniform resistivity create a uniform voltage gradient when a voltage input of typically 5V is applied to one side with the opposing side held at ground potential. When the top sheet is pressed and makes contact with the bottom conductive sheet, an electrical switch is closed and a voltage level correlated to the position of the contact point is created.

To establish the X / Y position, voltage is alternately applied to top and bottom sheets. The voltage gradients of each sheet are oriented 90 degrees with respect to each other. The A/D controller measures the voltage drop along the vertical and horizontal axis to identify the location of the touch. Resistive touchscreens can be touched with any type of stylus.

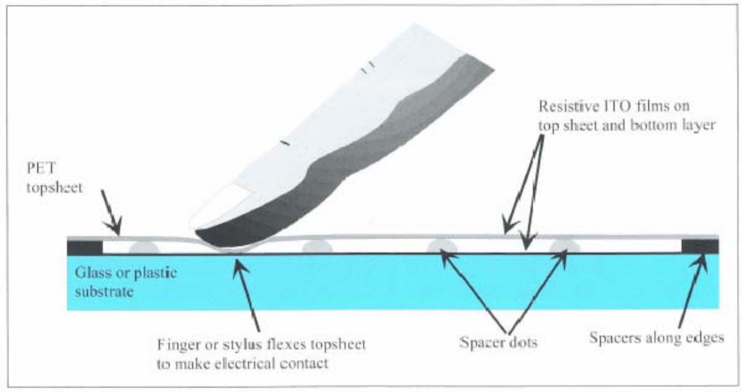
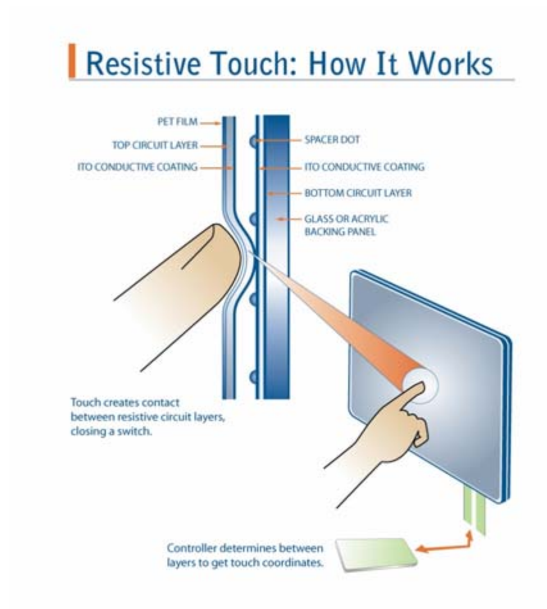
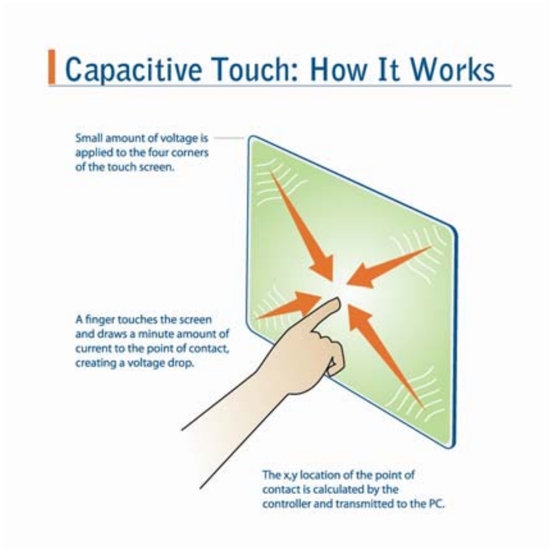


Photo courtesy of 3M

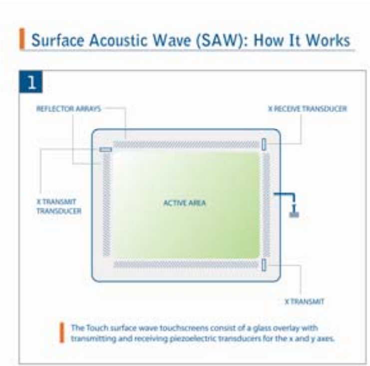
Resistive 5-wire – Similar to the 4-wire construction, a 5-wire touch sensor has a top pliable transparent conductive coversheet combined with a bottom conducting layer of a known resistivity. The 5-wire design differs from the 4-wire by integrating both the X and Y sensing planes onto the bottom conducting substrate. The top coversheet acts as a contact potentiometer. The alternating input voltages are applied to the bottom layer in a 90-degree opposing orientation. The A/D controller measures the voltage drop in the vertical and horizontal axis to identify the location of the touch. Resistive touchscreens can be touched with any type of stylus.

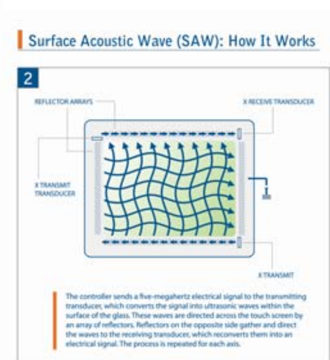


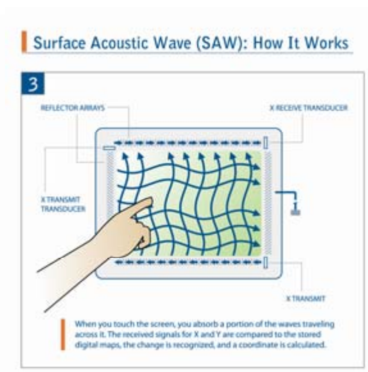


Surface Capacitive – A surface capacitive touchscreen is comprised of a glass substrate with indium tin oxide (ITO, a transparent conductive film) deposited evenly over the touchscreen surface opposite the display. The ITO surface is connected to low voltage electricity, creating a stored electrical charge, or capacitance. The sensor therefore exhibits a precisely controlled field of stored electrons in both the horizontal and vertical axes. When the sensor's "normal" capacitance field, its reference state, is altered by another capacitance field, such as a finger, electronic circuits located at each corner of the panel measure the resultant "distortion" in the sine wave characteristics of the reference field and send the information about the event to the A/D controller for mathematical processing by the computer. Capacitive sensors can either be touched with a bare finger or with a conductive device being held by a bare hand.

Surface Acoustic Wave (SAW) - A SAW touch sensor is comprised of a single layer of clear glass formed to the shape of the display. Acoustic waves are emitted by Piezo transducers across the surface of the touchscreen glass with carefully timed bursts. Receiving sensors mounted directly atop the touchscreen glass opposite the emitters receives the acoustic wave energy traveling across the surface of the touchscreen glass. Acoustic energy captured by the receivers is transformed into analog electrical energy and transmitted to the A/D controller to establish a baseline voltage threshold in conjunction with pre-established signal timing. Should an energy absorbing stylus come in contact with the touchscreen, a small portion of acoustic energy is absorbed by the stylus changing the wave energy/time parameters that the A/D controller is expecting to receive. The A/D controller interprets the changes in energy/time to identify the location where the energy was absorbed from the face of the touchscreen. SAW touchscreens can be touched with any soft stylus that absorbs energy.







CRT Era: Touchscreen Technology Comparison

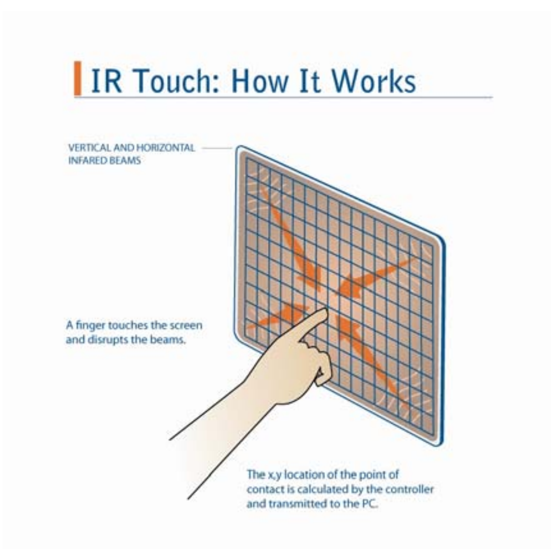
Design Approach	Inherent Principal Advantages	Inherent Principal Disadvantages	Market Acceptance
4-wire resistive	▪ Inexpensive to manufacture, no glass substrate required. ▪ Actuated by gloved hand, hard or soft stylus, and finger. ▪ Easily sealable. ▪ Low power.	▪ Wrinkle prone when bonded to spherically curved surfaces. ▪ Display image reduction; only 75-80% transmissivity. ▪ ITO on polymer sheet degrades after heavy use. ▪ Screen becomes worn in frequently touched areas obscuring image, especially in high ambient light conditions. ▪ Proprietary drivers common. ▪ Polymer coversheet can be torn or cut which disables sensor.	Very limited acceptance in CRT applications. Widely used in small monochrome LCD designs (like a PDA).
5-wire resistive	▪ Durable, precise touch calibration without drift. ▪ Easily sealable for wet applications. ▪ Could bond to curved glass substrate without wrinkles. ▪ Actuated by gloved hand, hard or soft stylus, and finger. ▪ Will continue to function even if sensor is torn or cut.	▪ Display image reduction; only 75-80% transmissivity. ▪ Plastic can be torn. ▪ Screen becomes worn in frequently touched areas obscuring image, especially in high ambient light conditions. ▪ Proprietary drivers common. ▪ Curved glass design is expensive to manufacture. ▪ Sensor can be torn or cut.	Market share leader, particularly in point-of-sale applications.
Surface capacitive	▪ Very good image clarity. ▪ Hard glass surface is resistant to vandalism. ▪ Foreign objects on screen (like food or mud) do not trigger a touch because they are not a path to ground.	▪ Occasional re-calibration-required. ▪ Conductive stylus required. ▪ Changes in user's skin moisture, relative humidity, or proximity to metal can create cursor drift. ▪ ITO on surface can create reflection. ▪ Curved glass design is expensive to manufacture. ▪ No gloved hand functionality.	Market share leader, particularly in gaming.
SAW	▪ Best image clarity. ▪ All glass construction no conductive films. ▪ Precise touch calibration without drift. ▪ Actuated by gloved hand, soft stylus, and finger. ▪ Z axis sensing capability.	▪ Foreign objects on screen such as food, liquid, or mud will create a touch event. ▪ Difficult to seal edges of screen to a bezel because the gasket can interfere with acoustic wave form. ▪ Curved glass design is expensive to manufacture. ▪ Hard stylus will not activate display.	Widely adopted for indoor use.

IR Touchscreens in the AMLCD Flat Panel Era

Arriving as a mainstream design choice in the late 1990's, TFT displays offered product designers an alternative to CRTs. Flat panel displays offered obvious advantages to the their CRT predecessors: low power, less size, and flat image presentation.

Flat displays utilize flat touch sensors, making manufacturing and integration much simpler and cost effective. Flat displays eliminate parallax and wrinkles common with 4-wire resistive when they were formed over the CRT's curved surface. Touch sensors designed for curved CRT faces were simply adapted for use on flat displays; however, shouldn't designers reassess infrared (IR) sensor technology as there is no longer a need to compensate for the curved CRT surface?

Today's product designers have continued to use the technologies and vendors they became familiar with as a result of earlier CRT experiences. One of the adages of product design is "design for today, remember the past." Today's flat display world provides the opportune time to reexamine the IR touchscreen. Integration into your product is simple: simply mount a display, with or without a protective glass or plastic window, and an IR equipped bezel in the product. Earlier in this paper, the IR touchscreen was described as offering excellent optical characteristics because it does not rely on ITO coated polyester coversheets used in resistive technologies, and it does not require reflective ITO coating required for capacitive touchscreens.



IR touchscreens have sensors mounted around the active area of the display. Unlike other touch technologies, the IR array is not part of the display overlay. The display overlay is not an active part of the touch system. Provided one uses a glass window, the active area of the display cannot be marred by wrinkles, tears or wear spots. Horizontal and vertical sensors mounted in the bezel emit and receive IR light energy. Breaking the horizontal and vertical light paths provides a simple, all digital grid that identifies the touch location. The digital nature of the IR touchscreen makes it immune to drift, thereby eliminates the need for re-calibration in the field. On the down side, the IR sensors are occasionally susceptible to false touches caused by objects which break the IR light beam path, such as a rain drop or fly landing atop the display and breaking the IR path. Software is improving to reject raindrop touches. IR overload from direct sunlight can also create false touches, but only in extremely bright, direct light.

The principal disadvantages of all IR touchscreens in the CRT era were parallax and high LED cost. Today, using a flat display with IR touch, there is no longer the parallax issues that limited success with CRT's curved display surfaces. Additionally, the growing affordability of the ubiquitous LED has resulted in cost effectiveness that was not previously available. Appropriately designed bezels and display cover glass can be designed to endure splashed liquid hazards that were previously prime reasons for selecting resistive touchscreens instead of SAW. Thick glass display overlays can absorb punishment that standard resistive, SAW, and capacitive products are less likely to survive. Finally, shrinking package size of IR LEDs has increased the quantity of X & Y axis sensors, thereby improving touch resolution.

IR-based touchscreen displays are independent from proprietary touch controllers. IR touchscreens generally have USB connectivity, so they are compatible with any PC-based system that supports USB and allows new drivers to be loaded.

The latest consideration for product designers is the increasing use of optical bonding and GUI applications requiring multi-touch in their products. The growing demand for higher contrast TFT LCD displays to be used in demanding, bright ambient light environments requires technologies whose characteristics won't inhibit the optical path. Optical bonding is the process of adhering the touchscreen to the face of the display to eliminate internal reflections between the two surfaces. Bonding consists of "sandwiching" silicone, urethane, or epoxy gel between the TFT and the touchscreen. A clear glass touchscreen is mandatory if optimal gains from the bonding process are to be obtained. Touchscreen technologies with an air gap (resistive) or ITO coating (capacitive & resistive) are not optimal for bonding because their index of refraction will impair gains sought by the bonding process. IR technology is being adapted to enable multi-touch input, but this technology is not on the market presently.

AMLCD Era: Touchscreen Technology Comparison:

Technology	Inherent Principal Advantages	Inherent Principal Disadvantages	Market Acceptance
4-wire resistive	▪ Inexpensive to manufacture, no glass substrate required.	▪ Display image obfuscation ; only 75-80% transmissive; cracks in ITO affixed to polymer ruin screen; screen becomes worn in frequently touched areas obscuring image, especially in high ambient light conditions; proprietary drivers and controllers. ▪ Not optimal for bonding applications.	Commonly used in low cost consumer devices
5-wire resistive	▪ Highly reliable, precise touch calibration without drift, sealable for wet applications.	▪ Cost. ▪ Display image obfuscation; only 75-80% transmissive; benefit of wrinkle free construction is irrelevant because substrates are no longer curved. ▪ Screen becomes worn in frequently touched areas obscuring image, especially in high ambient light conditions. ▪ Sensor can be torn or cut. ▪ Impractical for optical bonding applications.	Market share leader in point of sales & medical devices
Capacitive	▪ Image clarity. ▪ Hard glass surface is resistant to vandalism. ▪ Foreign objects, like food or mud, on screen do not trigger a touch because they are not a path to ground.	▪ Cost. ▪ Conductivity is required to provide path to ground; changes in skin moisture, relative humidity, or proximity to metal can create calibration loss. ▪ ITO on surface can create specular reflection. ▪ Not useful for gloved hand operation. ▪ Not optimal for bonding applications.	Market share leader in gaming
SAW	▪ Best image clarity because touch surface does not have any deposited or adhered layers found with the above technologies; precise touch calibration without drift. ▪ Actuated by gloved hand, soft stylus, and finger. ▪ Excellent for bonding applications.	▪ Cost. ▪ Foreign objects on screen such as food, liquid, or mud will create a touch event. ▪ Difficult to seal edges of screen to a bezel because the gasket can interfere with acoustic wave form. ▪ Hard stylus will not activate display. ▪ Difficult to seal.	Widely used in gaming machines and kiosks
IR	▪ Parallax free when used on flat display. ▪ Best image clarity because display cover is clear glass. It does not have any deposited or adhered layers found with resistive and capacitive touch sensors. ▪ Front panel can be sealed. ▪ Drift free calibration. ▪ Vandal resistant hard surface display window does not become worn with use. ▪ Near 100% stylus independence. ▪ Lower cost compared to 5-wire resistive, capacitive, and SAW for large screen sizes. ▪ Excellent for bonding applications.	▪ Touch resolution is lower than analog sensor technologies. ▪ No tactile feedback. ▪ Can be sensitive to rain, snow, insects that break the IR light beam. ▪ Very bright, directed sunlight can interfere with IR sensor.	Growing body of IR touch suppliers and customers

Conclusion

Twenty years ago, PCs were just arriving on the scene and simple GUI interfaces were almost unheard of. Designers strove to use touchscreens to simplify computer input commands for largely unsophisticated computer users. The proliferation of touch-enabled self-service kiosks, the conversion from cash registers to point of sale systems, and countless automotive, medical, training, and industrial products that use touchscreens as operator interfaces have validated the touchscreen concept.

Today, a larger share of our population is PC literate, yet the touchscreen has become adopted by computer users of all abilities because it is simple, fast, and intuitive. Today's product designer or system integrator would be served to remember yesterday's technology adoption challenges and flexibly adopt new technological approaches if they wish to solve today's application challenges. With the advances in AMLCDs, it is time to revisit the potential for IR touch technology as an effective solution for bringing touch capabilities to the current generation of computing devices.