Introducing
The NextWindow
1900 Optical Touch Screen

A NextWindow White Paper

Introducing the NextWindow 1900 Optical Touch Screen

The objectives of this white paper are as follows:

- Introduce the 1900, NextWindow's first optical touch screen designed for OEM applications
- Describe how the 1900 works in sufficient technical detail to be useful to engineers
- Compare the 1900 to other touch technologies

Introduction to NextWindow

NextWindow has been the market leader in optical touch screen overlays since it launched its first product in 2003. Now, in response to market demand, NextWindow has created the 1900, the first optical touch screen designed for OEM applications. NextWindow's previous products were focused on touch-enabling existing LCD and plasma screens from 23" to 65" and existing whiteboards up to 120". The new 1900 enables OEMs to integrate an optical touch screen into products that use flat-panel displays from 12" to 30".

Introduction to Optical Touch

Optical touch is one of the more recent additions to the list of eight touch-screen technologies. The other seven technologies include analog resistive, surface capacitive, projected capacitive, infrared, surface acoustic wave (often abbreviated as SAW), bending wave and force-sensing.

An optical touch screen consists of a plain sheet of glass, or other flat substrate, with two or more line-scanning optical sensors located at the corners of the substrate. Infrared light is distributed evenly across the surface of the substrate via either a passive method with illuminated borders on the three facing edges, or an active method (infrared LEDs spaced around the perimeter). When a finger or other object touches the substrate, it blocks the light seen by the optical sensors. Electronics analyze the resulting optical information and use triangulation to calculate the point of touch.

The fundamental characteristics of optical touch include the following:

- Stylus independence (ADA compliant)
- Lightness of touch
- Optical clarity with a plain glass substrate
- Ability to use any flat substrate material
- Superior drag performance
- Multi-touch capability
- Ability to simulate hover
- Stable calibration
- Object size recognition
- Economic scalability
- Low cost
- Long lifetime

Figure 1: NextWindow 1900 optical touch integrated into an OEM LCD display

System-Level Description

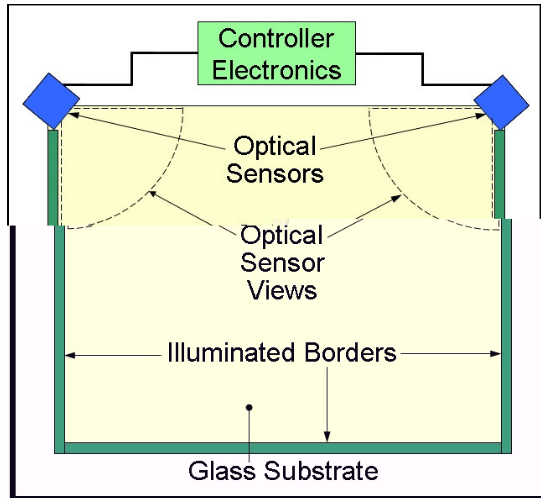

Figure 2: System-level overview of the 1900 optical touch screen

Figure 2 on the right shows a system-level overview of the 1900 optical touch screen. The key elements are: substrate, lighting subsystem, optical sensor subsystem, and controller electronics. While the substrate can be any flat material, in most OEM applications it is plain or chemically strengthened (CS) glass.

The lighting subsystem consists of infrared (IR) light-emitting diodes (LEDs), providing illuminated borders located along the left, bottom and right edges of the substrate. In operation, the lighting subsystem distributes infrared light across the substrate through the use of illuminated borders.

The optical sensor subsystem consists of two optical sensors located in the upper left and right corners of the substrate. Each optical sensor views the entire substrate in a 90-degree sweep. When no touch is present, the two optical sensors see a relatively uniform level of light across the substrate. When a finger or other object touches the substrate, it blocks the light from the illuminated borders, causing the optical sensors to see a silhouette (shadow) of the object. The controller electronics process information from the optical sensors and calculates the location of the touch point.

Optical Sensor Subsystem

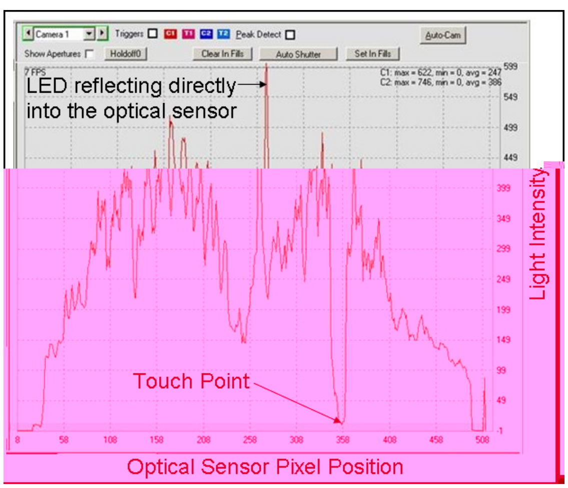

Figure 3: Light intensity vs. pixel position as seen by one optical sensor during a touch

The 1900 uses line-scanning optical sensors (also known as “linear image sensors”). These sensors are used in a wide variety of applications, including bar-code readers, flat-bed scanners, industrial inspection equipment and dimension-measuring systems. A line-scanning optical sensor consists of a single row of pixels aligned parallel to the touch-screen surface, a lens to focus the image and a driver control circuit. The lens in a 1900 optical sensor is a single-element plastic lens. A filter that eliminates visible light is placed in front of the lens.

Each optical sensor has 512 pixels. A single scan of all 512 pixels takes about one millisecond, of which 40% is shutter time and 60% is processing time. Both optical sensors scan simultaneously in order to avoid skew effects while the touch point is moving (i.e., during dragging). This is one of many factors that help to ensure excellent dragging performance.

An example of what one optical sensor "sees" is shown in Figure 3 above. The vertical axis is light intensity; the horizontal axis is optical sensor pixel position. The very distinct dip in the curve at pixel 358 is the touch location; the dip is in effect the "shadow" of the touching finger. The flat portions of the curve at each side (the "shoulders") are safety margins that ensure the optical sensor in fact sees the entire surface of the substrate. The narrow peak in the middle of the curve is the point where the LED light source is reflected directly into the optical sensor. Position interpolation is performed down to one-tenth of a pixel, but system noise is generally about one-quarter of a pixel, which is what actually limits the touch screen's resolution.

The optical sensors scan (sample) at two times the AC power-line frequency (100 or 120 Hz) and output at half that rate. During periods of inactivity (i.e., in idle mode), the scan rate is decreased in order to save power. However, since the 1900's total active power consumption is less than 0.5 watts, the power-saving features that have been implemented are relatively simple.

Touch Detection

Touch detection starts by comparing the real-time (fast-changing) video signal to a reference (slow-changing) copy of the video signal. The reference signal sets a baseline that accounts for ambient light, shadows and other environmental conditions. When the fast-changing signal drops below a selectable threshold percentage of the reference signal (i.e., when a finger or other object starts to block some of the light), the touch-detection process starts. The rate at which the reference signal changes can be adjusted over a wide range (seconds to minutes); among other things, this determines how long something must be stationary on the touch-screen surface before it's ignored. The threshold percentage can also be adjusted from 25% to 87.5%, which provides a degree of control over system sensitivity.

Once the touch-detection process has started, the velocity of the approaching finger (or other touch object) is determined. When the velocity reaches zero, a touch is registered, eliminating most of the problem of pre-touch, which is found on infrared touch screens. The click state of the touch screen is only allowed to change when the touch object is stationary. Interestingly, the finger doesn't have to be resting on the substrate in order to be sensed as stationary. It's actually possible to pause with the finger a few millimeters above the substrate and register a touch – although you have to have really steady nerves to do it.

Each pixel in the optical sensors is 16 times higher than it is wide. This allows the optical sensor to see some distance above the surface of the substrate. Figure 4 on the right illustrates this (as well as a related issue). As shown in the Figure, at the opposite corner of a 19-inch touch screen, a pixel's field of view is 7.6 mm high. While this height decreases as the touch point gets closer to the optical sensor, remember that there are two optical sensors, so as one decreases the other increases. The result is a "saddle-shaped" view-height profile across the touch screen.

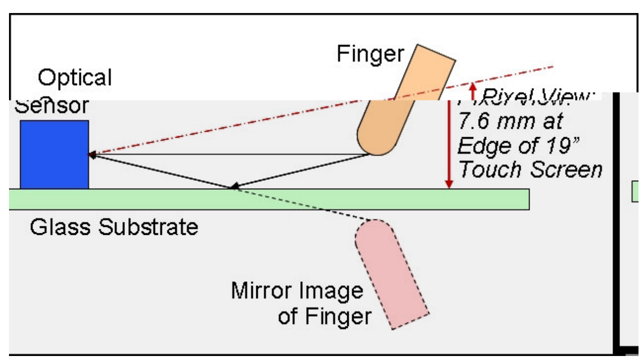

Figure 4: Pixel view at the edge of a 19" touch screen, and (b) the mirror effect

Figure 4 also illustrates the "mirror effect" that comes into play with a glass substrate. When light hits glass at a very oblique angle, the surface of the glass becomes an almost perfect mirror. This means that as a finger approaches the surface of the glass, a mirror image of the finger comes into view. Because the optical sensor sees a "wedge" view, it can see both the actual finger and the mirror image of the finger. This is actually an advantage, since the reflected light from the mirror image doubles the total light received by the optical sensor, effectively increasing the sensitivity of the system and also allowing the pre-touch algorithm to be effective on concave surfaces.

Touch Location

Once the touch detection process is complete, the controller calculates the location of the touch by simple trigonometric triangulation. Figure 5 and Figure 6 show how this works. Considering the touch point as just a single point, Figure 5 illustrates the calculations used to determine the touch location by triangulating off the top edge of the touch screen. Note that this drawing represents somewhat of a simplification; because the optical sensors aren't actually located exactly in the corners of the active touch area, various offsets must be taken into account which makes the calculations slightly more complex.

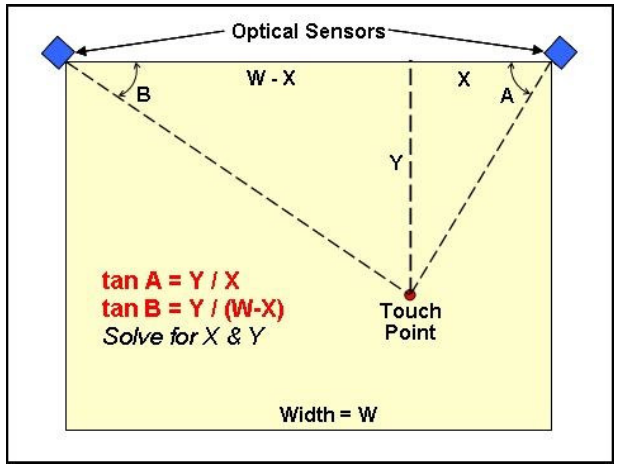

Figure 5: Simplified touch-point triangulation calculations to locate a single touch point

Another complication occurs when the touch point is very close to the top edge of the touch screen. In this situation, angles A and B in Figure 5 approach zero, making X unstable or unsolvable. The result is a slight decrease in accuracy in the X-dimension, mostly confined to the top 10 mm of the touch screen. The accuracy in the Y-dimension is unaffected by this situation. If the typical accuracy in the X-dimension over most of the screen is +/-2 mm, the typical accuracy in the top 10 mm ranges from +/-3 mm in the corners up to +/-6 mm in the top center.

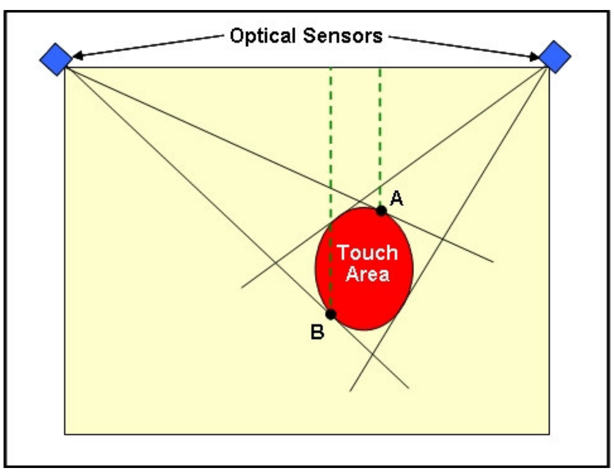

Figure 6: Two triangulations are performed on a touch area by each optical sensor

Figure 6 on the left illustrates the touch point as it really is – a touch area rather than a single point. For a given touch area, each optical sensor does two triangulations, one off each edge of the touch area (e.g., points A and B for the left-hand optical sensor).

This is the mechanism that allows the 1900 to determine the size of an object that's touching the substrate. Each optical sensor locates two points on the touch area for a total of four points, which is enough to make a good estimation of the size. However, as previously noted, when the touch area is very close to the top edge, then point A is eliminated and triangulation can only be done off the bottom edge (point B).

Hover

The same mechanism illustrated in Figure 6 above also allows the 1900 to simulate hover (also known as “proximity” or “tracking”). A very light touch on the substrate produces a small touch area, while a more forceful touch produces a larger touch area. “Small-area” can be defined as a hover-touch, and “large-area” can be defined as a click-touch. In effect, this is equivalent to supporting z-axis detection.

In a 2006 ACM paper, a team of researchers from Microsoft Research and Columbia University (Benko, Wilson & Baudisch) suggested a technique for making the “small-area vs. large-area” difference more distinct. They call it “SimPress”, short for “Simulated Pressure”. Figure 7 on the right illustrates the technique, in which the finger is moved from a convex shape into a concave shape with a rocking motion. This is much more comfortable than trying to press harder – which isn’t very effective for people with bony fingers in any case.

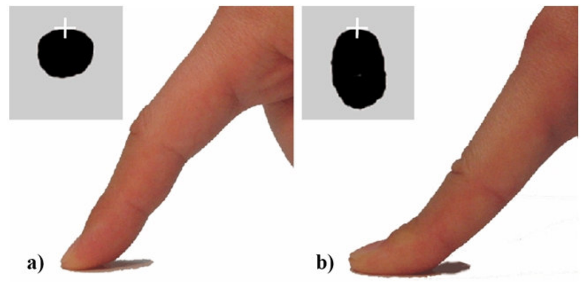

Figure 2. A small rocking motion of the user’s finger triggers the *SimPress* clicking technique: a) tracking (hover) state, b) dragging (click) state. (The top left corners show the actual area of contact detected by our device as well as the stabilized cursor location.)

Figure 7: The “SimPress” technique suggested by Benko, Wilson & Baudisch

Figure 7 also illustrates a related refinement in touch-location determination. Since the increase in touch-area occurs predominantly in one direction (from the tip of the finger towards the wrist), the touch point (cursor) location can be stabilized by using the top center of the touch area as the defining point rather than the center of mass. This reduces undesirable movement in the cursor location while clicking.

Multi-Touch

Multi-touch is the ability to simultaneously touch in more than one location and have multiple touch points reported. Of the eight existing touch technologies, only three are capable of supporting multi-touch: optical, infrared and projected capacitive. Although historically there hasn’t been much demand for multi-touch, interest has been increasing rapidly throughout the first half of 2007. A few of the most obvious applications of multi-touch are as follows:

- Pinching two fingers together to indicate zooming out (i.e., making an image smaller)
- Spreading two fingers apart to indicate zooming in (i.e., making an image larger)
- Rotating two fingers to indicate rotating an image (e.g., from 12 & 6 to 3 & 9 o’clock)
- Touching and holding one point, then touching a second point to indicate a route

Generally speaking, most practical applications of multi-touch involve only two points. Applications for more than two points tend to be artistic in nature. Accordingly, the 1900 supports only two simultaneous touch points. Note that this is more than resistive, surface capacitive, surface acoustic wave, bending wave or force-sensing touch technologies can support.

Controller Subsystem

The controller assembly for the 1900 optical touch screen is shown in Figure 8 on the right. Inputs to the controller are on the left edge; they consist of two 10-conductor, 0.5 mm-spacing ribbon cables from the optical sensor modules. The output from the controller is on the right edge; it's a flat USB connector with four conductors plus ground. The USB connector also serves as the power input connector, since the controller is USB-powered.

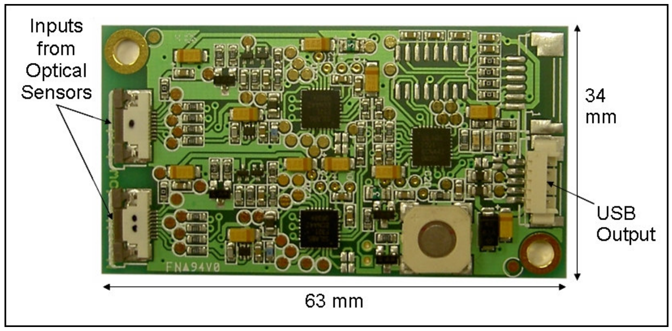

Figure 8: Controller assembly for 1900 touch screen

The assembly's dimensions are shown in the Figure; note that the controller's total area is less than half of that of a standard credit card.

Figure 8 also reveals one of the secrets of the 1900: the very low component-count. As can be seen in the Figure, the entire controller assembly consists of only three small ICs and a small handful of discrete components. This keeps the 1900's cost very low and the reliability (MTBF) very high.

Another characteristic of the 1900's controller is its HID (Human Interface Device) compatibility. This means that from an operating systems perspective, the 1900 is a plug-and-play device. When it's connected to a PC or Macintosh, it works immediately without loading any drivers and it supports all normal mouse functions (left and right click, double-click, click & drag, etc.). HID compatibility is particularly valuable during an OEM's evaluation period, since it allows testing the product with minimal effort.

The 1900 can also be configured to report itself as an HID Touch Digitizer to take advantage of Windows Vista's built-in support for touch. This means that an OEM can enable Vista's "flick" gestures and the "touch pointer" (the on-screen mouse graphic used to enhance finger-touch precision) without doing anything other than changing a few configuration settings.

One potential refinement in this area could be the development of a dual-mode (touch and pen) interface – depending on market demand, of course. Even just as is, handwriting recognition works very well on the 1900. However, one possible difficulty is that both optical sensors must be able to see the pen; some left-handed writing styles may block one or both of the optical sensors' views.

The 1900 is supplied with diagnostic software that can assess the health of the touch screen even without touching it. Also supplied is a utility to set mouse and multi-touch modes, and production setup software. The latter allows setting a wide variety of parameters, such as the video reference signal change-rate and the touch-detection threshold level previously described in the "Touch Detection" section.

Integration

Integrating the 1900 into an OEM product is a straightforward process. Figure 9 on the right illustrates a simplified view of integration. The optical sensors and illuminated borders are normally supplied already bonded to the substrate glass. The touch-screen assembly is aligned and calibrated by NextWindow during manufacture so that an OEM only has to do a single four-point calibration when the assembly is attached to an LCD, covered with a bezel and installed into the final product. There is no user calibration required at any time.

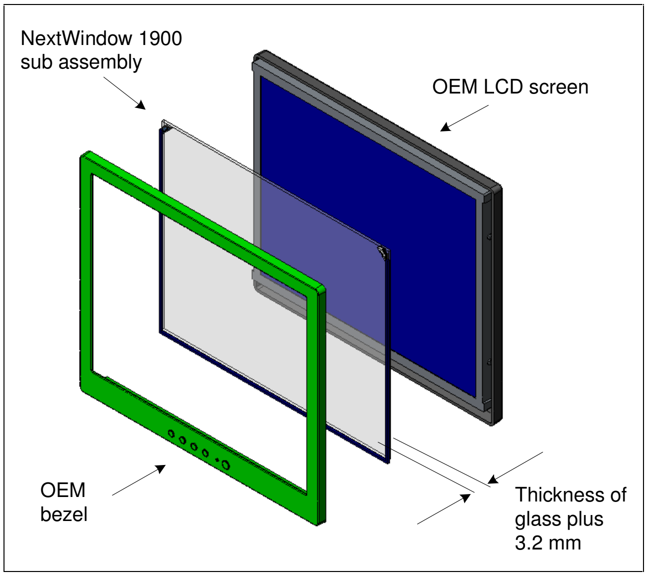

Figure 9: Simplified view of 1900 touch screen integration

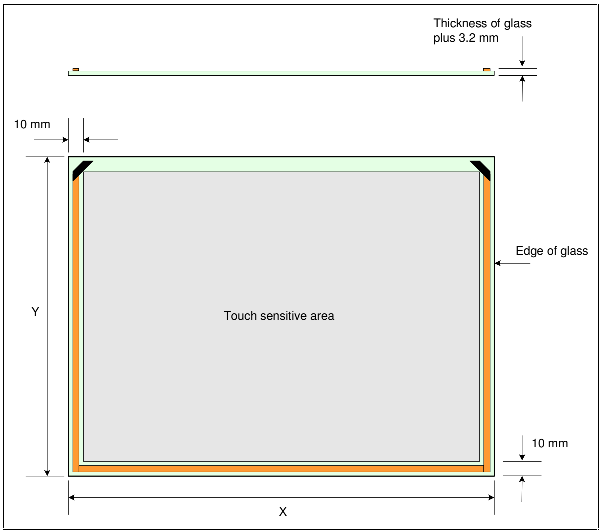

Figure 10: Dimensional drawing of the 1900 touch screen

Figure 10 on the left shows a dimensional drawing of the 1900 touch screen. A larger version can be found on the website (www.nextwindow.com).

Other Touch Technologies

In order to understand how optical touch technology compares against the other seven touch technologies, it's useful to review each of them briefly.

1. The most common type of touch screen is the analog-resistive touch screen, consisting of a solid glass or plastic substrate overlaid with a flexible polyester membrane, with the facing surfaces coated with transparent conductors. The force of a touch collapses the membrane, causing contact between the conductive surfaces. Electronics measures the resistance along the edges in two dimensions and calculates the point of touch.

2. The second-most common type of touch screen is the surface-capacitive touch screen, consisting of a glass substrate coated with a transparent conductor that's energized by an AC signal and covered by a very thin, transparent insulating layer. When a conductive element such as a finger or a wired stylus touches the insulating layer, a small amount of current flows through the capacitance formed between the surface of the touch screen and the finger. Electronics measures the current flowing from each corner of the substrate into the conductive element and calculates the point of touch.

3. Projected-capacitive touch screens consist of a two-layer, X-Y grid of very thin wires or patterned transparent conductors attached to the back surface of a glass or plastic substrate. The grid is energized with an AC signal that creates a three-dimensional electrostatic field. Electronics measures the change in the field caused by the presence of a conductive finger at a small distance from the X-Y grid and calculates the point of touch.

4. Infrared touch screens consist of a frame surrounding a glass or other flat substrate. Two adjacent sides of the frame contain a series of very closely spaced infrared LED transmitters; the other two sides of the frame contain a matching series of infrared photodiode receivers. The transmitters and receivers create an X-Y grid of infrared light beams just above the surface of the substrate. When a finger or other object enters the grid, it interrupts the light beams; electronics senses the interruption and calculates the point of touch.

5. In surface acoustic wave (SAW) touch screens, ultrasonic sound waves emitted by transducers in two corners of a glass substrate are distributed across the surface in X and Y directions by reflectors formed on the edge of the glass. Ultrasonic transducers in the other two corners receive the sound waves via a second set of reflectors. When a finger (or any sound-absorbing object) touches the substrate, it interferes with (damps) the sound-wave propagation in both directions. Electronics analyzes the changes and calculates the point of touch.

6. Bending-wave touch screens consist of a plain sheet of glass or other rigid substrate with four piezoelectric transducers attached to the back surface near the corners. When a finger or any object touches the substrate, minute vibrations (bending waves) occur within the substrate. Electronics compares the "signature" of the vibrations against a stored list of signatures (in APR from Elo TouchSystems) or analyzes the vibrations in real time (in DST from 3M) and calculates the point of touch.

7. Force-sensing touch screens consist of a rigid but not necessarily flat substrate with four strain-gauge or piezo-ceramic force sensors attached in a beam structure at the corners of the substrate. When a finger or any object touches the substrate, the four sensors measure the force exerted on the substrate by the touch. Electronics uses algorithms to reject any off-axis forces, analyzes the dynamic touch waveforms and calculates the point of touch.

As of the publication date of this white paper, bending-wave touch screens are only available in 32" sizes and larger from 3M, and only integrated into touch monitors from Elo TouchSystems – i.e., not available as integrateable components. Since this white paper focuses on OEM-integrateable touch screen components in the 12" to 30" size range, further consideration of bending-wave touch screens is excluded.

Similarly, as of the publication date of this white paper, force-sensing touch screens are not actually available. While QSI Corporation has announced that force-sensing technology is ready to be implemented in practical applications, they haven't yet announced any actual touch-screen products. For that reason, further consideration of force-sensing touch screens is excluded.

Touch Technology Comparison

Table 1 on the next two pages compares optical touch against the remaining five other touch technologies. The characteristics selected for comparison don't include every possible technical specification; instead, they're focused on things that make a difference in real-world touch-screen applications, such as how a touch is activated, how clear the touch screen is, how long it lasts, whether it needs periodic recalibration, and so on.

Rating Scale: 5 = Best; 1 = Worst

Characteristic	Optical	Projected Capacitive	Infrared	Surface Acoustic Wave	Resistive	Surface Capacitive
Activation Method	**5** Any object (minimum 2 mm)	**2** Finger or gloved finger	**5** Any object (minimum 4-5 mm)	**3** Any sound-absorbing object	**4** Any non-sharp object	**1** Finger only
Optical Clarity	**5** Plain glass or no substrate	**4** Plain glass with one additional layer	**5** Plain glass or no substrate	**5** Plain glass with edge reflectors	**1** Multiple layers and coatings	**3** Single coating
Touch Activation Force	**5** Very light touch to full finger contact	**4** 0g to 80g typical	**1** Allows significant pre-touch activation	**2** 80g to 100g typical	**4** 20g to 100+g	**3** 50g typical
Dragging Performance	**5** High resolution & high data-rate	**3** OK when designed for high resolution	**3** Low resolution & low data-rate	**2** Not designed for good drag	**2** Not designed for good drag	**4** Good but needs high pressure
Lifetime	**5** No wear-out mechanism	**5** No wear-out mechanism	**3** High component count = low MTBF	**5** No wear-out mechanism	**2** 1M-30M touches	**4** 180M touches
Economic Scalability (Max. Size)	**5** Increase LED brightness (120”)	**3** Expensive patterning (60”)	**2** Large increase in electronics cost (150”)	**3** Add only longer reflectors (42”)	**2** Expensive ITO coating (30”)	**2** Expensive ATO coating (30”)
Substrate Material	**5** Any material or no substrate	**3** Glass, plastic or any non-conductor	**5** Any material or no substrate	**1** Glass only	**2** Glass, plastic or film only	**1** Glass only
Calibration Stability	**5** Factory calibration only	**4** Factory calibration only	**5** Factory calibration only	**5** Factory calibration only	**2** Drift requires user calibration	**1** Drift requires user calibration
Cost	**4** Lower than surface capacitive	**2** Higher than surface capacitive	**1** Most expensive touch technology	**2** Higher than surface capacitive	**5** Lowest-cost touch technology	**3** Higher than resistive & optical

Table 1: Comparison of Touch Technologies

Rating Scale: 5 = Best; 1 = Worst

Characteristic	**Optical**	**Projected Capacitive**	**Infrared**	**Surface Acoustic Wave**	**Resistive**	**Surface Capacitive**
Ease of Integration	**5** Fewest integration issues	**4** Fairly easy once bonded	**2** Thick and wide frame	**3** Difficult to seal	**3** Compression issues	**1** EMI/RFI, ESD, grounding, etc.
Vandal Resistance (ex. substrate)	**2** Spray paint can readily disable it	**5** Nothing accessible to be damaged	**2** Spray paint can readily disable it	**3** Difficult to damage transducers	**1** Sharp knife can disable it	**4** Surface coating is hard as glass
Weather Resistance	**2** Sensitive to light blockage	**5** Unaffected by rain, snow or ice	**2** Sensitive to light blockage	**2** Won't work with rain	**2** Won't work with condensation	**3** Light rain OK; no snow or ice
Debris Resistance	**2** Sensitive to light blockage	**4** Unaffected by most debris	**2** Sensitive to light blockage	**2** Very sensitive to debris	**4** Unaffected by most debris	**3** Unaffected by thin debris
TOTAL	**55**	**48**	**38**	**38**	**34**	**33**

Table 1: Comparison of Touch Technologies *(continued)*

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