Acoustic Pulse Recognition Enters Touch-Screen Market

A new approach to bending-wave touch-screen technology called Acoustic Pulse Recognition (APR) uses "acoustic fingerprinting" to better pinpoint the location of impact on a touch screen.

by Ken North and Henry D'Souza

TEN YEARS AGO, virtually all touch screens sold were one of the following four basic types: infrared, resistive, surface wave, or capacitive. The same is true today. However, recent developments in bending-wave touch technology promise a different future.

Bending-Wave Touch Screen: A Simple Concept

Bending-wave touch technology is simple in concept (Fig. 1). A finger touch on a glass plate generates sound waves that propagate within the glass. These sound waves are detected with "microphones" in the form of piezoelectric transducers (piezos) bonded to the glass. Resulting signals are digitized by electronics and numerically processed to reconstruct touch positions. Such a system may be placed in front of a liquid-crystal display (LCD) to serve as a touch-screen input device.

Many types of sound waves or "acoustic modes" propagate in glass plates. The acoustic mode most efficiently excited by a finger touch is a bending wave. Experts in acoustics and ultrasonics use the term "flexural plate wave" and "lowest order anti-symmetric Lamb wave," but here, we use the synonym "bending wave." In mechanical engineering, one refers to "bending" of a beam under the weight of a load. Likewise, a glass plate will bend, if only slightly, under the load of a stylus such as a finger. Here, we are particularly interested in transient forces due to touch impacts and sliding friction of a moving stylus. These transient touch forces generate waves of glass-plate bending. This is shown schematically in Fig. 1. A bending-wave touch screen utilizes such waves to detect touch events.

Before looking in more detail at the features and engineering details of bending-wave

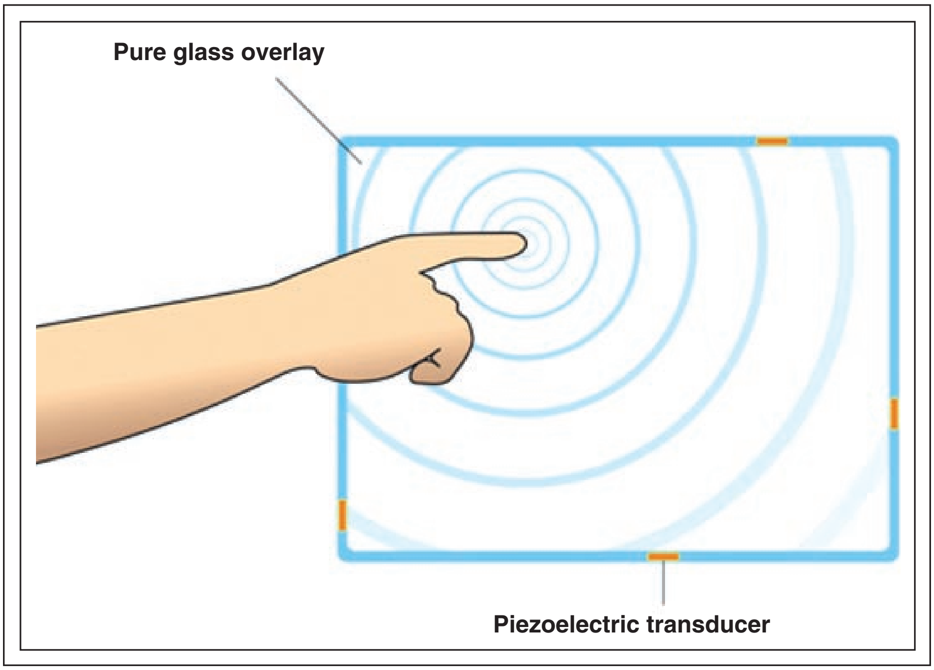

Fig. 1: *Conceptual drawing of a bending-wave touch screen.*

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touch-screen technology, a review of the current mainstream touch-screen technologies will help lend context to the new technology.

Mainstream Touch Technologies

When encountering infrared, resistive, surface-wave and capacitive touch screens during travel and daily life, the curious technologist can quickly determine the touch-screen type. Simple experiments reveal much about the basic touch-detection mechanisms of mainstream touch technologies.

Infrared. If a light brush with a piece of tissue paper is sufficient to trigger a touch, it is likely an infrared touch screen. Hidden from view, circuit boards loaded with light-emitting-diodes (LEDs) and phototransistors surround the touch area similar to a picture frame. Touches are detected and located by shadows within a dense grid of infrared beams above the touch surface. With care, one can activate an infrared touch screen without actual surface contact.

Resistive. If a poke with a toothpick activates a touch screen that is not an infrared touch screen, it is a resistive touch screen. Resistive touch screens are activated by sufficient pressure to close an air gap between a plastic membrane and an underlying substrate such as a glass plate. Both surfaces defining the air gap are provided with resistive coatings in order to electrically read out the presence and location of such a touch. Despite the name "resistive," the electrical characteristics of the finger or stylus are totally irrelevant. A resistive touch screen is a pressure-activated device.

Surface-Wave Touch. If a touch screen is activated by the eraser end of a pencil, and it is not an infrared or resistive touch screen, it is in all probability a surface-wave touch screen. Surface-wave touch screens are sometimes referred to as "SAW" or "surface acoustic wave" touch screens. In the megahertz frequency range, a glass surface will support miniature "ocean waves" with sub-millimeter wavelengths. A touch of a finger or pencil eraser on a glass surface will cast a shadow in such surface acoustic waves much like an ocean freighter will cast an ocean-wave shadow on its leeward side. In contrast, the small area of contact of a toothpick is similar to a small ocean buoy that casts no ocean wave shadow. Surface-wave touch screens are activated by mechanical contact with sufficient area to shadow surface acoustic waves. A finger nail or credit-card corner is not enough.

Capacitive. If a touch screen cannot be activated by a firm touch with the eraser end of a pencil, it is a capacitive touch screen. Capacitive touch screens measure the transfer of AC energy through a capacitance formed between the surface of the touch screen and the surrounding environment. The sensor consists of a transparent conductive coating covered by a very thin insulating layer. When an AC signal of the proper amplitude and frequency is introduced to the conductive coating, the electronics can measure the capacitive load of any highly conductive object. Human beings with a finger pressed on the sensor glass tend to be large electrical conductors and are easily detected. Erasers are not conductive and cannot complete the capacitive circuit.

In addition to these simple stylus tests, the following dual-touch experiment can be amusing. First, touch one location on the screen with the left hand. While keeping the left-hand finger on the surface, touch another location with the right hand. What happens? For resistive and capacitive touch screens, the cursor will move to some intermediate position. In contrast, surface-wave and infrared touch screens will perceive shadows from both touches, and software code will generally choose to move the cursor to the location of the new touch.

What would it mean if one encountered a touch screen that responds correctly, locates the new touch position in the dual-touch experiment, and further responds to any stylus but only if the stylus truly makes contact with the touch surface? That would mean that bending-wave touch screens have arrived.

Bending Waves and Surface Waves: Distant Cousins

Bending-wave touch screens and surface-wave touch screens have much in common. Both are acoustic touch screens that require nothing more than a glass plate in the touch-input area. Bending-wave and SAW touch screens share the valued features of high transparency, no-wear mechanism for normal usage, and stable calibration based on the speed of sound.

However, bending-wave touch screens and surface-wave touch screens are only distant cousins and have some significant differences. For example, bending-wave touch screens are completely unpowered signal sources (much like a receiving radio antenna), while surface-wave touch screens must be powered to constantly generate waves to illuminate touches.

A particularly interesting difference concerns the effect of contaminants on the touch surface. When compared to surface waves, bending waves travel inside the glass substrate. Once excited, bending waves are difficult to stop. This is because bending-wave power is distributed throughout the entire thickness of the glass plate, while surface-wave power is concentrated at the surface. Bending-wave touch screens also operate at much lower frequencies than SAW touch screens, further contributing to the embedded behavior of bending waves. Therefore, bending waves are little affected by contaminants on the touch surface such as water or even the palm of the user's hand.

Comparing Touch Technologies

Table 1 details various features of bending-wave touch screens compared to the four industry standards.

Bending-wave, surface-wave, and infrared touch screens provide the transparency of a simple glass window, something that is difficult to match with the multi-layered construction of resistive touch screens. Bending-wave touch screens eliminate the membrane-wear issues of resistive touch screens.

Bending-wave touch screens provide a touch area that includes almost the entire surface of the glass plate up to a narrow perimeter, which can be as little as 3 mm. Such a narrow border is difficult to achieve in the circuit-board layout and sealed infrared-transparent bezel design of an infrared touch screen, for example.

Calibration stability is a more subtle topic. Infrared touch-screen calibration is very stable because the physical location of the LEDs and phototransistors define the geometry of the infrared beams. This is one reason they are widely used for interactive digital signage, including screens that are 40 in. and larger. Resistive touch screens involve quasi-DC voltage measurements and require stable DC reference voltages and stable low-frequency gain elements in the electronics – nothing terribly challenging for modern electronics. Capacitive touch screens present the engineer with the greatest calibration stability challenge: Various AC gains and offsets must be well-controlled to avoid calibration drift. In

Table 1: Comparison of bending-wave technology to other touch technologies

	Bending Wave	Resistive	Surface Wave	Capacitive	Infrared
Transmission[1]	92% Glass only	85% Many layers	92% Glass only	85–91% Coated glass	92% Glass only
Stylus	Any	Any	Wave absorbing area of contact	Conductive area of contact	Any
Contaminants			Subject to heavy water contamination		
Calibration Drift/ Stability Factor	Speed of sound	DC analog gains and offsets	Speed of sound	AC Analog gains and offsets	Beam geometry
Wear	Glass surface	Membrane with ITO	Glass surface	Coated glass surface	Glass surface
Perimeter[2]	5 mm Narrow piezos	6–16 mm Electrode pattern	12 mm Arrays	8–16 mm Electrode pattern	16 mm Optos/ PCB/bezel

[1] Transmission values given are typical values or ranges.
[2] Perimeter border width values given are typical values or ranges.

contrast, surface-wave touch-screen systems enable stable calibration with little effort because relevant geometry is determined by signal timing and the very stable speed of sound in glass. Hence, bending-wave touch-screen calibration also traces back to signal timing and the speed of sound in glass. Bending-wave touch screens share the very stable calibration of surface-wave touch screens.

Bending-Wave Signal Processing and APR

The above discussion suggests that from a scientific perspective, bending-wave touch technology has much in its favor. Why did bending-wave technology not become a dominant touch technology many years ago? The answer lies in the engineering challenges of the associated signal processing.

"Time-of-flight" is the most obvious approach to touch-position reconstruction. The basic time-of-flight approach is simple in concept. A finger touch generates waves that are detected by piezos at known locations. The time delay between the touch event and the start of the piezo signals, divided by the bending-wave velocity, gives the distance from the finger to each of the piezos. With a sufficient number of piezos, and appropriate math, the touch position is uniquely determined. Early patent work on such time-of-flight touch-position systems concern active styli rather than finger touches [for example, see U.S. patent 4,488,000 (1984) of William E. Glenn]. One of the first bending-wave touch-screen products designed to be activated by a passive stylus was the work of Intelligent Vibrations in France (see PCT patent application WO 00/38104 of Jean-Pierre Nikolovski, *et al.*). Indeed, until recently, this was the basis of all bending-wave touch-screen work.

While simple in concept, bending-wave signal processing provides challenging complexities in practice. Bending waves are highly dispersive. The bending-wave velocity increases with the square root of frequency. Even for a hypothetical touch in the form of an infinitely brief tap, the resulting wave pulse quickly spreads out ("disperses") as it propagates. The faster high-frequency components of the wave move ahead of the slower lower-frequency components; see the "direct wave" schematically illustrated in Fig. 2. How does one determine the arrival time of such a dispersed wave packet, particular if the frequency content of the touch is not well controlled? New Transducers, Ltd., a U.K. company, developed innovative signal processing to undo the dispersion of the received signal (for example, see Fig. 10 of U.S. patent application 2001/0006006 of Nicholas P. R. Hill). New Transducers, Ltd., partnered with 3M Touch, appropriately labeled this variation of bending-wave technology as "Dispersive Signal Technology" or "DST."

Another complication is that signals at any piezo are generated not only by the direct wave, but also by bending waves that reflect off the perimeter of the glass plate. In fact, glass edges are very efficient bending-wave reflectors – this is analogous to the reflection of an electronic signal off the open circuit at the end of a coaxial cable. Bending waves typically reflect many times before damping away. Reflections add complexity to time-of-flight signal processing. One approach here is to add specially designed acoustic dampers at the glass perimeter to minimize reflected waves (for example, see U.S. patent 6,871,149 assigned to New Transducers, Ltd.). Another approach is to limit touch-screen designs to very large sizes so that reflections are fewer, weaker, and more delayed in time. In this fashion, time-of-flight signal-processing requirements can add design requirements, complicating the sensor's construction.

Yet another complication is that actual finger touches are wave sources that are not ideal – they are similar to isolated radar pings. This is clearly the case for a dragging stylus. However, what a human perceives as a quick touch continues for a finite amount of time. This compounds the signal complexity facing time-of-flight signal processing.

However, a new approach to bending-wave touch-screen signal processing called acoustic pulse recognition (APR) makes bending-wave signal complexity a benefit rather than a problem. The APR approach may be described as acoustic fingerprinting. When a touch signal is received, no attempt is made to compute an arrival time or otherwise clean up the signal. The signal in all its complexity is simply recorded much like collecting a fingerprint. Each location on the touch-screen surface has its own distinctive fingerprint. Signal complexity is now a friend. APR signal processing has nothing to do with time-of-flight measurements, but rather is analogous to matching a fingerprint from a crime scene with a fingerprint in a police data base.

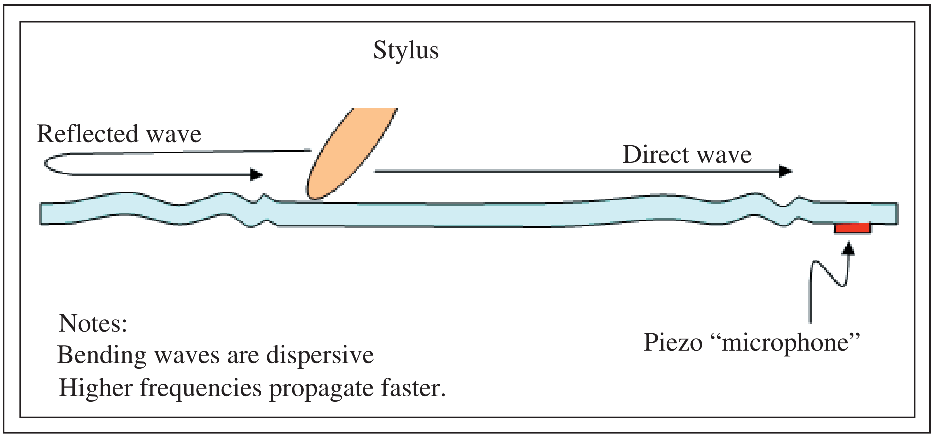

***Fig. 2:** Schematic of bending-wave signal mechanism*

Figure 3 shows APR sensors[1] such as introduced by Elo TouchSystems at the SID 2006 International Symposium, Seminar, and Exhibition in San Francisco. While the keyword in the APR acronym is “recognition” of the fingerprint of a given location, users of APR sensors quickly learn that the word “pulse” is to be interpreted very loosely. The user experiences excellent drag performance. The cursor nicely follows a moving finger for even a very light touch. Thus, APR demonstrates the ability to process not only signals from brief impacts of styli, but also “pulses” in the form of a continuous stream of acoustic noise from a finger sliding across the touch-screen surface.

The above observation that bending-wave and surface-wave touch screens are cousins correctly implies that surface-wave-manufacturing expertise is relevant to APR sensor manufacture. For example, the glass seen in Fig. 3 is “surface-wave touch-screen glass” in the sense that the optical-quality specifications, anti-glare surface treatment, *etc.*, were borrowed directly from surface touch-screen designs. Even the piezos seen in Fig. 3 are identical to piezos found in certain surface-wave touch-screen products sold by Elo TouchSystems. While the principles of operation and the performance features of APR and surface-wave touch screens have many differences, APR sensors are a great fit for a surface-wave touch-screen production line.

As discussed above for bending-wave touch screens in general, APR fulfills the promise of a water-immune touch surface. To take full advantage of this, a water-tight seal is desirable. This may be easily provided with a continuous strip of foam tape filling the gap between the APR sensor surface and the lip of a bezel. This simple foam tape bond is all that is needed to complete a secure mechanical mounting of the sensor to the touch-monitor assembly. Touch-screen glass is suspended from the bezel in this fashion in APR touch monitors sold by Elo TouchSystems. The robustness of APR acoustics and signal processing is demonstrated by the fact that this simplest of water-tight mounting methods is completely compatible with APR operation.

The APR touch screens shown in Fig. 3 only subtly reveal the conceptual leap from time-of-flight bending-wave technology to APR bending-wave technology. The seemingly random locations of the piezos increase the complexity and hence uniqueness of the acoustic fingerprint of a touch at any given location. The small black object seen in Fig. 3 near the end of the cable is a 4-MB memory that contains numerous such acoustic fingerprints and hence holds a key to a whole new approach to bending-wave technology known as APR.

Conclusion

APR represents a step forward for bending-wave touch-screen technology, one that holds the promise of allowing bending-wave to become a standard technology for touch screens alongside the already established quartet of infrared, resistive, surface wave, and capacitive touch screens.

References

[1] See http://www.elotouch.com/Products/Touchscreens/AcousticPulseRecognition/default.asp for more details. ■

***Fig. 3:** Photograph of APR-type bending-wave touch screens.*