Advances in Force-Based Touch Panels

For what seems to be a remarkably simple concept, force-based touch panels have been extremely difficult to produce and bring to market. This article looks at the history, the challenges, and the latest product launch in force-based touch technology.

by David A. Soss

INTUITIVELY, touching is applying force to an object, and, therefore, force is inherent in touching something. So why not make a touch panel that measures the force of the touch directly? A touch panel that actually senses forces when the panel is touched – a force-based touch panel – is a natural notion.

The basic principle of a force-based touch panel is one of the simplest touch-panel technologies, and the idea for it has been around for nearly half a century – the first patents date from the 1960s. Despite the obvious simplicity of the approach, however, few products have succeeded in the marketplace due to high cost and performance deficiencies.

IBM introduced two force-based touch screens in the early 1990s. One product for personal computers was a cathode-ray-tube (CRT) based monitor with the tube suspended on springs with force sensors. It performed poorly due to the large suspended mass and the springs. The other, called TouchSelect®, was introduced by IBM's industrial monitor division in 1991 and came in various sizes designed to clip on to IBM PC monitors. They were not very successful, probably because the desktop-monitor market was not ready for touch screens. People were just not used to touch screens. The mouse had become the preferred pointing device for desktop computing.

Today, touch panels are widely used in kiosks, ATMs, and, more recently, handheld devices. Recent advances have made force-based touch panels attractive for several applications. Force-based touch technology is typically used in public systems where resistance to vandalism, environmental ruggedness, and exceptional clarity of the display in sunlight is valued. In addition, force-based touch technology can do things that other touch technologies cannot. For example,

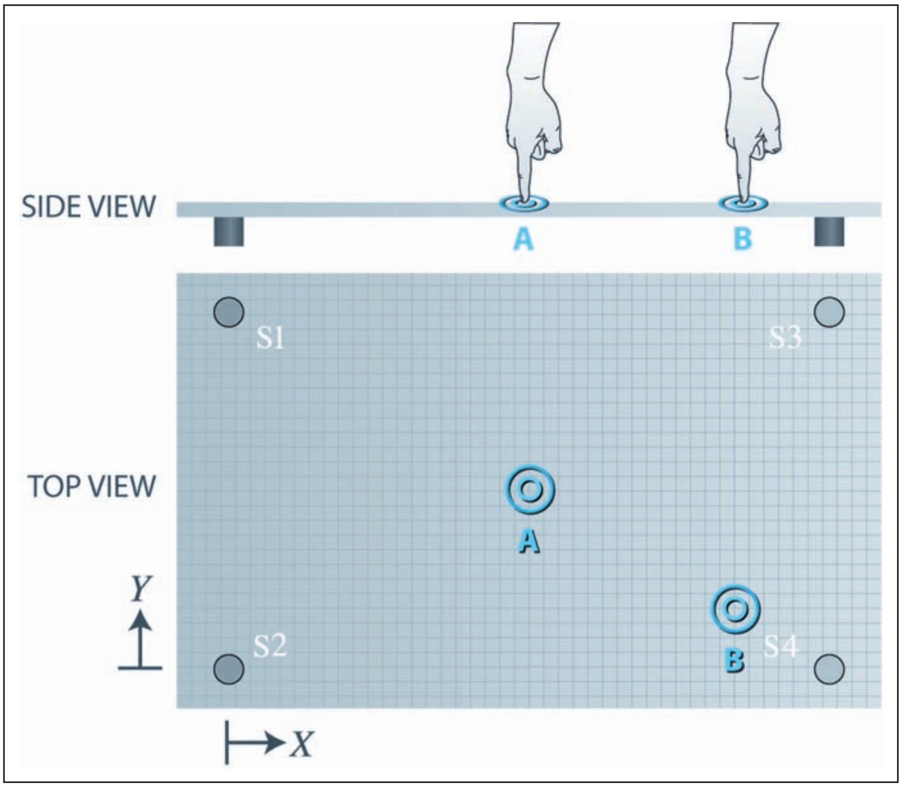

***Fig. 1:** An illustration of how the force sensors work on a force-based touch panel.*

***David A. Soss**, one of the inventors of InfiniTouch™, is a Senior Electrical Engineer at QSI Corp., 2212 South West Temple #50, Salt Lake City, UT 84115-2648; telephone 801/466-8770, e-mail: david.soss@qsicorp. com.*

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- It can measure the strength of the touch (sometimes called the z-axis).
- The touch surface can be made of nearly anything that is rigid enough.
- The touch surface does not have to be rectangular or any particular shape.
- The touch surface can have holes in it.
- The touch surface can function even in the presence of dirt, moisture, ice, mud, as well as other contaminants.
- Objects such as key tops can be attached to the touch panel; these then become touch-sensitive themselves.
- The touch panel can work in direct sunlight.
- The touch panel can be used with a stylus, finger, gloved finger, conductive or non-conductive object, fingernails, or keys.

Operating Principle

In force-based touch panels, the panel is configured such that the force applied to the panel when it is touched is transferred to the mounting structure through force sensors located at the corners of the panel. The force sensors are used to determine where the panel was touched. For example, if the panel was touched at point A in Fig. 1, the forces registered by the sensors would be equal. If the panel was touched at point B, the force on Sensor 4 would be higher than forces measured by the other sensors.

Force sensors work by measuring the deflection or deformation of a piece of material, often with a strain gauge. Strain is a normalized measure of deformation defined as the change in length divided by the total length as in Fig. 2. For example, if a 10-mm-long bar becomes 0.1 mm longer, the strain is 0.01 or 1%. Piezoelectric transducers, capacitance sensors, inductive sensors, and force-sensing resistors are also used to make force sensors.

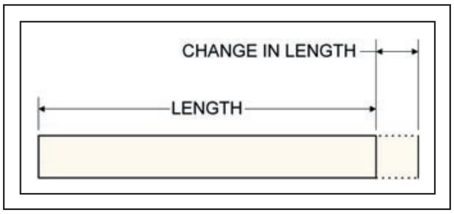

Fig. 2: An illustration of how strain is measured by force sensors. Strain is the normalized measurement of deformation defined as the change in length divided by the total length.

A strain gauge as shown in Fig. 3 is made from a resistive metal foil attached to a plastic backing. The foil is etched in a serpentine pattern of many thin resistive lines parallel to each other. A strain gauge's electrical resistance is sensitive to its length as measured in the direction parallel to the pattern of lines. The lines are like fine wires and the resistance of a wire is proportional to its length. If a strain gauge is stretched to make it longer, its resistance increases because it is longer. Additionally, because the volume of the stretched lines stays almost the same, their cross-sectional area decreases. The resistance of a wire is also inversely proportional to its cross-sectional area. Both the increase in length and the decrease in cross section cause the resistance to increase.

Piezoelectric sensors are materials that produce a voltage when they are deformed; the most common are ceramics, but there are piezoelectric polymers and crystals as well. These materials are insulators with an asymmetrical electron structure. To make a transducer, electrodes are applied to a piece of material and the transducer is "poled" by applying a high voltage across the electrodes. When a transducer is deformed, the electrical charge is displaced.

Capacitive and inductive sensors can also be used to measure displacement in a force sensor. They are used to measure the total deflection of a spring as it is subjected to a force. One common use of these types of sensors is in pressure-sensitive digitizer pens produced by Wacom and InPlay Technologies, used in all currently available tablet PCs. Another early use was a capacitive-based force-sensing system invented by Jerry Roberts from Visage, Inc., that became a product sold in limited applications by MicroTouch in the early 1990s.

The outputs of the sensors of whatever kind, suitably conditioned, are sampled and quantized by an analog-to-digital converter. The analog-to-digital converter requires a higher dynamic range in a forced-based touch panel than, for example, a resistive touch panel. It must accommodate the range of touch forces in addition to the variations with touch location. For example, if 10 bits of location resolution is required over a 30:1 range of touch force, the analog-to-digital converter will need a minimum of 16 bits of resolution. A digital processor is used to determine the location of the touch and the total applied force of the touch. The sensor outputs are passed through low-pass filters to reduce the amount of noise. The cutoff frequency must be about 10–20 Hz to assure adequate response to touches. The sum of the sensor outputs is used to decide when the panel is touched. Modern digital processors make it economical to perform sophisticated processing of the sensor signals such as digital filtering and linearity correction.

The location of the touch is calculated by summing the moments of the forces acting on the touch panel. In Fig. 1, assume that the touch surface is a rigid body. The touch force is applied at point A; the force-sensor containing supports S1, S2, S3, and S4 are the reaction forces. Once an axis is chosen (it helps if the axis is related to the desired system coordinates), the moments are the products of the forces and their distances from the axis. The sum of the moments has to equal zero for a body at rest. Therefore, if the moments of the reaction forces as measured by the sensors are summed, the result is (minus) the moment

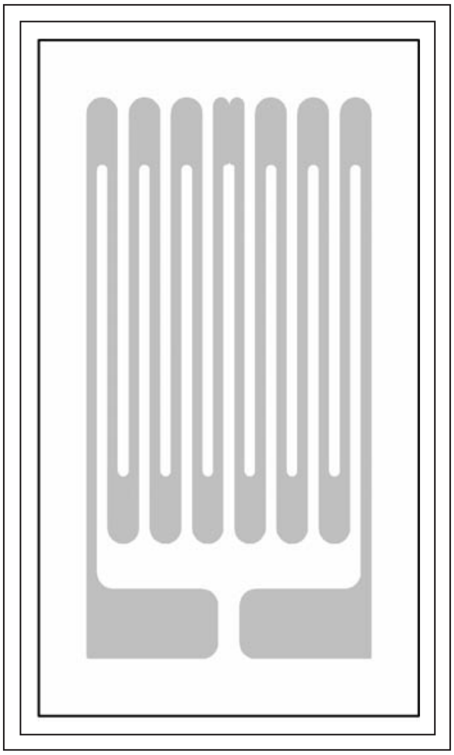

Fig. 3: An illustration of a typical strain gauge.

of the touch force. Dividing the sum of the moments by the total force – which is the sum of the reaction forces – gives the distance to the touch point. By repeating this with a second axis, the result is the touch location.

In general, the x-y coordinates are found from a linear combination of the sensors outputs divided by another linear combination of the sensor outputs:

$$[x\ y] = \frac{[A_1 \cdot P_1\ A_2 \cdot P_2 \cdots A_k \cdot P_k]\begin{bmatrix} X_1 & Y_1 \\ X_2 & Y_2 \\ \vdots & \vdots \\ X_k & Y_k \end{bmatrix}}{(A_1 \cdot P_1 + A_2 \cdot P_2 \cdots + A_k \cdot P_k)}$$

where $[X_k Y_k]$ is a set of calibration factors that have the same dimensions as the location coordinates and that represents the effective locations of sensors 1, 2, … k (for most applications, $k = 4$). The calibration factors $A_1 \ldots A_k$ are dimensionless coefficients that represent the relative sensitivity of the sensor channels. Note that the $A_1 \ldots A_k$ factors appear in both the numerator and the denominator. There are only $k - 1$ independent sensitivity factors because one of them can have an arbitrary value.

It would seem that since three points are sufficient to determine a plane, three sensors would be sufficient to find the touch coordinates. Almost all force-based touch panels have four sensors. It is evident from the location formula that if there are more than three sensors, for any total force there are infinitely many sets of sensor outputs that resolve to each touch location. This would seem to be indeterminate. Actually, three sensors would be sufficient if the touch surface and the supporting structure were truly rigid bodies. In actuality, the touch panel and support deflects or bends slightly with the application of force. The common arrangement of four sensors at the corners of a rectangle allows the signal conditioning to ignore the common warping distortions where one pair of diagonally opposite corners deflect in the same direction while the other pair of diagonally opposite corners deflect in another direction. With four sensors, the warp cancels out if the relative gains of the sensor channels are correct.

Challenges

The accuracy of force-based touch panels is very sensitive to additive errors in the force-sensor outputs. A robust baseline estimation and correction system is required to maintain accuracy. It is also important that the sensor channels exhibit low noise below 20 Hz. Unavoidable noise in the sensor signals will cause the estimated touch location to exhibit jitter. The errors become less important as the applied force increases. Therefore, there is a tradeoff between touch sensitivity and accuracy.

Piezoelectric sensors have a much higher output than strain gauges, but they have their own special problems. They only respond to changing forces. Figure 4 shows a typical output of a piezoelectric transducer. Eventually, the displaced charge redistributes itself, causing the output to return to zero. The good side of this is that baseline drift is insignificant. Another practical consequence of the piezoelectric transducers' steady-state response is that the accuracy degrades with continued touch at one point. It is possible – with appropriate signal conditioning and processing – to achieve good location accuracy for more than 12 sec. Piezoelectric transducers have a much higher electrical-signal–to– noise ratio than strain gauges. Piezoelectric sensors are also very good at button presses for which the location does not change during the touch. The signal processor can detect the touch release event from the negative excursion of the sensor output. Sliders or similar controls also work. Piezoelectric sensors work less well in signature-capture applications.

The forces of a touch are not static. A touch creates a dynamic, and often very erratic, force profile on each of the sensors. For example, Fig. 5 shows the outputs of the four sensors when the touch panel is touched in a corner. Because accuracy depends on signal strength, it is desirable to use the higher-force portions of the touch profile to determine the touch location. It takes a significant amount of processing power to detect the four waveforms and properly determine the appropriate time to measure the relative forces. The computing power to do this did not exist on an integrated circuit as recently as the early 1990s.

Force-touch panels have an interesting response to multiple touches. When the panel is touched in two places simultaneously, it reports the touch location as being on a line drawn between them. The location of the point on the line depends on the relative force of the two touches; it is closer to the touch with the most force. In other words, a force-based touch panel returns the centroid of the applied force.

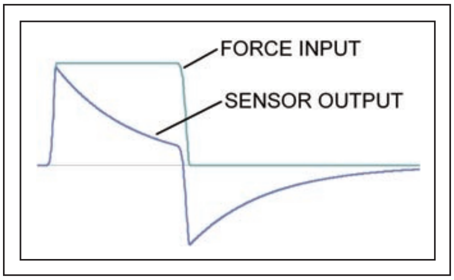

Fig. 4: *The typical output of a piezoelectric transducer.*

Force-based touch panels can be sensitive to vibration. If the support structure is subjected to vibration at low frequencies similar to those of a touch event, the touch panel experiences a force, $F = ma$, that depends on the mass of the touch panel and associated structures. Low-frequency vibrations cause errors in the touch location or may even register extraneous touch events. Some ways of reducing the sensitivity to vibration include keeping the natural resonant frequencies of the touch panel above 20 Hz and filtering the sensor signals to remove the higher-frequency components. It is also possible to use vibration sensors mounted on the support structure along with signal processing to cancel the effects of vibration on the touch panel. An accelerometer attached to the support can be used to ignore the false touches generated by momentary shocks.

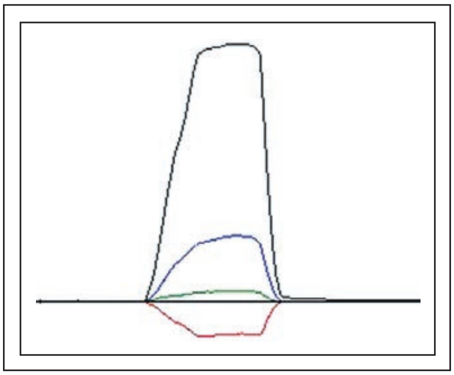

Fig. 5: *An illustration of the outputs of the four sensors when a touch panel is touched at a corner.*

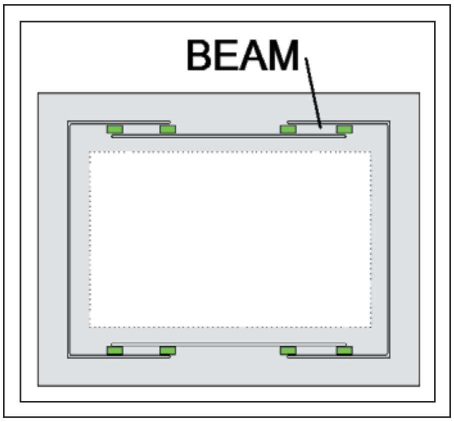

Fig. 6: An illustration of the structure of QSI Corp.'s InfiniTouch™ planar touch-panel configuration.

Fig. 8: A tollbooth terminal with an InfiniTouch™ touch panel, where it is subject to repeated touches by the tollkeeper. Resistive touch panels in the previous monitor frequently failed due to extreme wear. The clarity of the touch panel contributes to the contrast of the display in the sunlit booth.

In an earlier explanation, it was assumed that all of the forces were perpendicular (normal) to the touch panel. Actually, they are not, and this was a problem with earlier designs. It is common when touching a surface to induce off-axis or lateral forces in the plane of the surface. These lateral forces are a problem if the force sensors react to off-axis forces. In fact, the most obvious arrangement of piezoelectric transducers (Fig. 1) is more sensitive to lateral forces than to normal forces. Additionally, if the sensors are not coplanar with the touch surface, lateral forces are translated into rotational torques at the sensors. The lateral forces must be transferred to the support somehow or the touch panel would slide sideways. The solution lies in the supports' transmitting lateral components of the forces to the mounting structure without including them in the measurement of the normal forces.

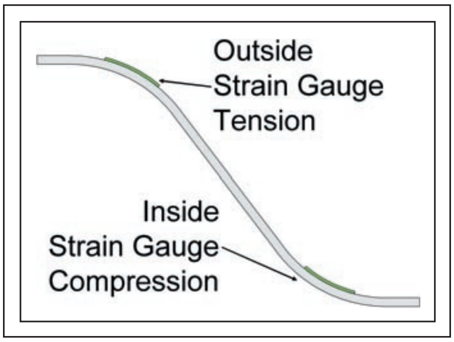

Fig. 7: In QSI's InfiniTouch™, the sensors are placed where the beams bend in response to normal forces. The sensors on opposite ends of one beam experience strains with opposite signs in response to normal forces. Lateral forces cause the sensors on a beam to experience the same strain.

Recent Advances

Force-based touch panels have recently found some applications. Deutsche Bahn AG (German railways) has deployed ticket-vending machines that use a force-based touch sensor. The machines are manufactured by Höft & Wessel Co. of Hanover using force sensors from HBM.[1] It is reported that their touch panels easily withstand being hit with a baseball bat. The intellectual property company F-ORIGIN has developed a force-based panel technology that it calls HaptiTouch.

QSI Corp. has developed a unique planar touch-panel configuration called InfiniTouch™ that overcomes many of the historical difficulties of force-based touch technology. QSI's panel consists of a metal plate with some slots in it (Fig. 6). The slots define four mechanical beams. The beams are arranged so that they are subject to all forces applied to the inner area of the plate. The beams have strain gauges or piezoelectric transducers attached to them. The sensors are placed where the beams bend in response to normal forces as shown in Fig. 7. The sensors on opposite ends of one beam experience strains with opposite signs in response to normal forces. Lateral forces cause the sensors on a beam to experience the same strain. The placement and electrical connections of the sensors make them insensitive to lateral forces. The planar touch panel is connected to a signal processor that detects the force waveforms and generates accurate touch locations.

Figure 8 shows a terminal with an InfiniTouch™ touch panel deployed in a tollbooth, where it is subject to repeated touches by toll takers. Resistive touch panels in the same terminal in this application frequently failed due to extreme wear, and force-sensing panels have proven to be a strong solution for gloved hands and a wide temperature range. The clarity of the touch panel contributes to the contrast of the display in the sunlit booth.

There are multitudes of applications for force-based panel technology beyond the traditional touch panel, including using it on something other than a display. Buttons, keypads, and controls can be located adjacent to the display area. These keys can have tactile features (*e.g.*, Braille or engraved characters) and be made of unusual materials such as stone, wood, or even textiles for artistic and architectural appeal.

Conclusion

Force-based touch panels deserve another look as advanced electronics and new designs have made them practical and affordable. Indeed, force-based panel technology has unique capabilities beyond the traditional display overlay.

References

[1]Andreas Karaus in *HBM HOTline*, 1 March 2000; http://www.hbm.com/custserv/SEURLF/ASP/SFS/ID.485/mm.4, 36, 32/SFE/hotlinearticles.htm. ■