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Applications of Force Sensing Technology in Consumer Electronics Devices and Systems

Abstract: *Although touch sensing technologies have been available since the early 1970's, they were used almost exclusively in industrial products during the first 20 years of their existence. Introduction of touchpad mouse devices for laptop computers, in the early 1990's, represented the first significant transition into the consumer electronics market. Since then, touch sensing devices have permeated a wide variety of consumer products, including mobile phones, game consoles, digital audio systems and more. Today they are an indispensable component of such systems, and are expected to proliferate into even more applications in the near future. This paper reviews the various technologies available, and classifies them by the applications and products to which they are most suited. Particular focus is given to force sensing devices and their ability to provide continuously variable control functionality. Finally, it takes a brief look at what lies ahead for the industry.*

Contents

History and Evolution

Force sensing devices have been used for direct human-machine interaction in electronic systems dating back to the 1960's. Historians generally attribute E. A. Johnson at the United Kingdom's Royal Radar Establishment as the inventor of the world's first such device – a *capacitive* non-transparent touch screen he developed for air traffic control systems, between 1965 – 1967. The first commercially available device, however, was not introduced until 1971. It was known as the 'Elograph' (Figure 1), a touch sensor developed by Dr. Sam Hurst while he was at the University of Kentucky. Dr. Hurst subsequently founded his own company (Elographics) and went on to introduce and patent the first commercially available transparent touch screen

Figure 1. The Elograph

device based on *resistive* technology, in 1974. Later in the decade, Interlink Electronics began development of the first force sensing resistor (FSR®) which it subsequently patented and trademarked. The company introduced its first FSR products to the market in 1985, and followed with numerous patented products utilizing force sensing resistive technology.

During the 1980's, evolution of the technology was primarily centered in industrial instrumentation. Nonetheless, force sensing resistors were used in some specialty consumer products such as 'squeezable' toys and musical instruments (Figure 2). The pioneering work done by Interlink Electronics with FSR integration into products such as Roland keyboards, Akai drum machines, KAT and Simons drums, and Oberheim keyboards laid the groundwork for broader adoption of the technology in consumer products during the 1990's. The most significant market growth occurred with the emergence of laptop and notebook computers and PDA's, plus the increasing adoption of digital technology in numerous household appliances. In 1994, for example, a company named Cirque introduced the first widely available touch pad as a mouse replacement for portable computers. Known as the GlidePoint®, their technology was utilized by Apple Computer in early PowerBook products. Other companies were also active in the evolution of touch pad technology at that time, including Alps and Synaptics (*capacitive* devices), and Interlink Electronics. Interlink introduced the first commercially available *resistive* touchpad product for portable PCs, its 4-wire VersaPad®, which Sony utilized in its Notebook computer in 1996.

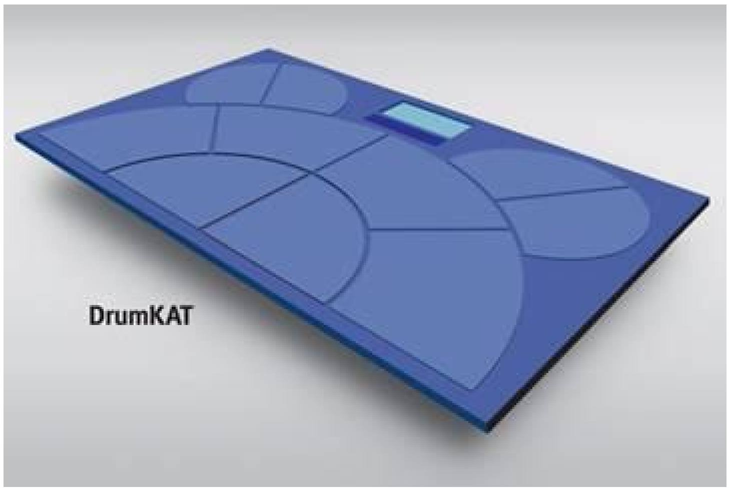


Figure 2. An Early Application of FSR Technology

In the years since then, the evolution of smart phones, tablets, integrated touch pads and touch screen PCs has ensured a growing demand for sensor devices. New applications have emerged such as game controllers, vehicle control centers, kitchen appliances and weight scales, to name just a few. In fact, any device that can utilize force and position sensing inputs to control or enhance its functionality is a candidate for integration of force sensing technology.

Touch Sensing Technologies

Table 1 compares the general characteristics of resistive and capacitive sensor technologies. Each of these has its merits that make it the most suitable choice for one or more specific applications.

	Resistive	Capacitive
Activation	Finger, stylus, actuator, gloved finger.	Unreliable except with bare fingers.
Capabilities	- Activation (on/off) - Force sensing - Position sensing	- Activation (on/off) - Coarse force sensing - Position sensing
Force Resolution	1024 levels	32 levels
External microprocessor	No microprocessor or ASIC required; may save cost, space and battery life.	Required. May contributes to cost, power consumption and space requirements.
Power consumption	No polling needed, so no power required in untouched state.	Polling needed to detect touch, so continuous power required.
Operating environment	Surface contaminants do not affect operation.	Water and other contaminants can impact performance.
Sensitivity	Requires 10-20 grams of force.	No force required.
Durability	Over 2 million actuations.	Many million actuations, since surface can be rigid and no force is applied.
Most suitable applications	Ruggedized devices such as laptops and devices used in potentially wet environments (e.g. kitchen appliances)	Multi-touch devices for use in clean, dry environments.

Table 1. Sensor Characteristics by Technology

Resistive

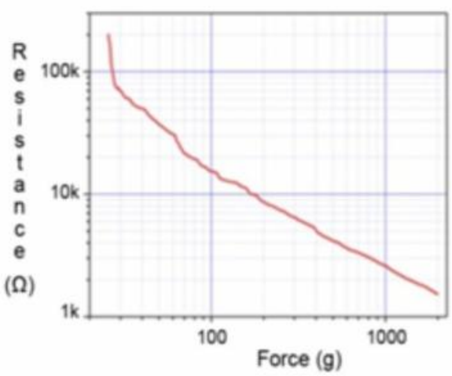


Figure 3. Characteristics of a Force Sensing Resistor

Resistive force sensors are polymer thick film (PTF) devices that exhibit a decrease in electrical resistance when increased pressure is applied to the surface of the sensor, as shown in Figure 3. The typical construction of this kind of device is illustrated in Figure 4. It consists of two membranes separated by a thin air gap. The air gap is maintained by a spacer around the edges and by the rigidity of the two membranes. One of the membranes has two sets of interlaced traces that are electrically isolated from one another, with each set connecting to one trace on a tail. The other membrane is coated with a special textured, resistive ink. When pressed, the ink shorts the two traces together with a resistance that depends on the applied force. The variable resistance enables this type of sensor to be used for continuously variable control functions. For example, in a pointing device, increased pressure can be used to produce faster cursor movement. This makes these devices very suitable for applications where there is a human in the feedback loop (i.e. HMI applications).

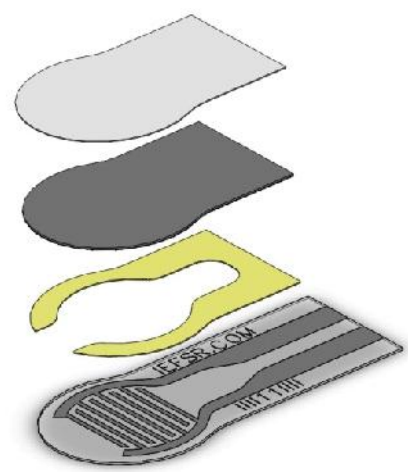


Figure 4. Resistive Force Sensor Construction

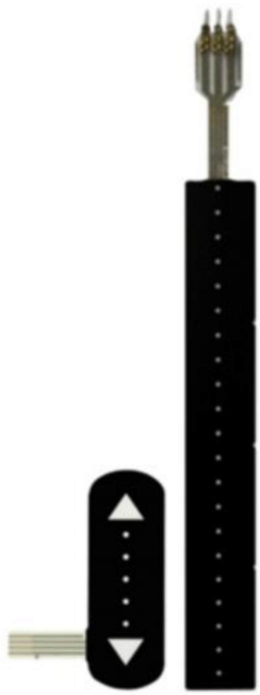


Figure 5. Force Sensing Linear Potentiometers

Unlike capacitive devices, the performance of resistive sensors is not impeded by the presence of moisture, dirt or dust, because their active elements function in a sealed environment, and because their function does not depend on local electric fields. Even when used for position sensing, such as with devices similar to those shown in Figure 5, measurement is simple enough that it can be accomplished directly with the device's host processor without the need for a dedicated microprocessor. This, of course, means that the effective total power consumption of such devices is substantially lower than capacitive sensors, which require their own signal analysis processor.

The requirement for physical pressure on a resistive sensor offers both advantages and a disadvantage in some implementations. The advantages are that it is less susceptible to false readings or unintended touches than its capacitive counterpart, and that it does not require direct skin contact for activation. A resistive sensor can be operated by a person wearing gloves or using any kind of low cost stylus. The disadvantage arises when the resistive sensor is not embedded under a protective rigid surface, which results in a less durable sensor. However, this can be easily overcome by integrating the resistive sensor in a "pre-loaded" state under a rigid surface, so that only very slight activation force is needed. In this case, resistive sensors are just as durable as capacitive sensors.

Capacitive

Capacitive sensors fall into two categories – single point of contact devices such as buttons, and projected capacitive two-dimensional touch screens. Both rely on the capacitive effect between a conductive layer on one side of an insulating surface and the human body (the user) on the other side. However, differences in construction result in significantly different characteristics. A single point of contact device typically requires direct contact between the user's finger and the sensor's outer surface.

Projected capacitive sensors support multi touch and, in some cases, can support operation by a gloved hand. Figure 6 illustrates the typical construction of a projected capacitive sensor.

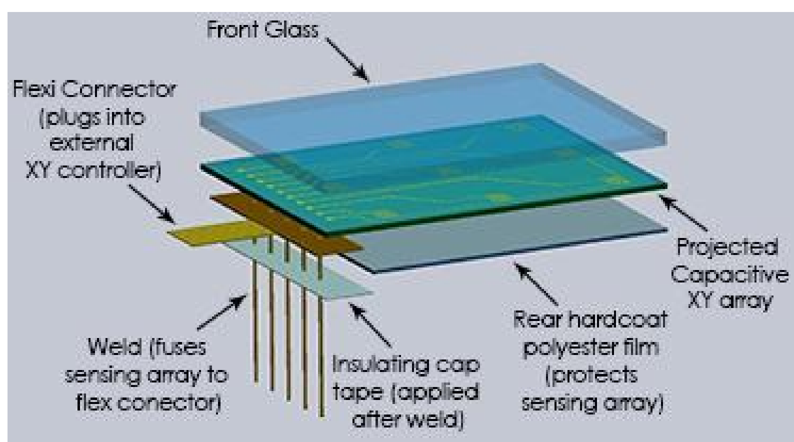


Figure 6. Construction of a Projected Capacitive Sensor

Again, there are pros and cons to the technology. Implementation of multi-touch functionality, such as the zoom in and zoom out control pioneered by Apple Computer in its iPhone®, is clearly its biggest advantage. However, as already noted, these types of sensors need their own processor to determine the XY coordinates of a touch, as well as to reduce the possibility of false positives. This in turn may require a higher operating current and can result in shorter operating cycles for battery powered devices. In addition, the small differential signal between the untouched and touched states can make them susceptible to electromagnetic interference. A second, though less significant advantage of capacitive sensors is that, in some circumstances, they can be more durable over extended life usage.

The most significant drawback to the capacitive technology is its inability to measure force, although there has been some progress recently in enhancing the technology with pseudo force sensing. The lack of true force sensing means that continuously variable control functions such as control of cursor movement speed with a pointing device or proportional game controls (e.g. jump height) are not possible.

Products and Applications

The objective of this paper is to review examples of some of the diverse consumer applications that utilize the force-sensing aspect of touch operated sensors. Through these examples, the reader may be inspired to conceive new applications for these remarkable devices. Since capacitive sensors do not offer force-sensing, the remainder of this paper will focus on resistive devices. In general, these sensors fit into one of three application categories:

- force sensing control only
- force sensing plus one-dimensional position control
- force sensing plus two-dimensional position control

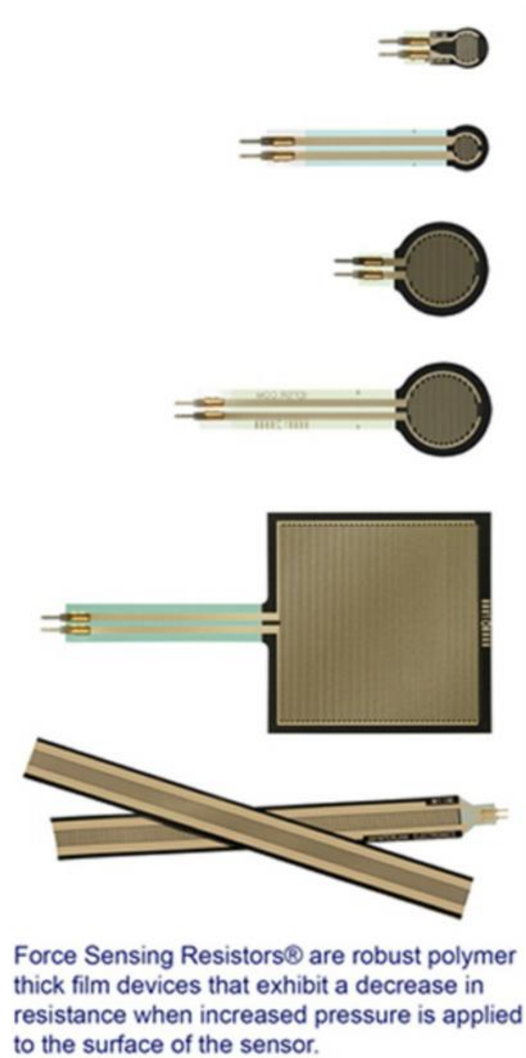


Figure 7. Force Sensing Resistors

Force Sensing Control

Devices that meet the needs of the first category come in many shapes and sizes as illustrated in Figure 7, and the technology is also well-suited to customization. Table 2 summarizes three specific examples of consumer applications that make use of force sensing – a game controller, a smart phone and a digital stylus.

These examples illustrate two different ways in which the measured force data can be utilized: threshold control and continuously variable control. The smart phone application implements threshold control; when the force exerted on a key reaches a pre-defined level (threshold), the system provides tactile feedback simulating the 'feel' of a physical key click. The other two products both use the force data for continuously variable control. On the game controller for example, some games use the variable force applied to a button to control the motion of game characters – jumping higher or further with increased force, or simply running faster.

Application	Force Sensor	Product example	Force sensing function
Game controller	Interlink Electronics custom FSR®	Microsoft® xBox 'Duke'	Force response added to 6 buttons on controller for enhanced gaming experience.
Smart phone	Interlink Electronics custom FSR®	Blackberry® Storm2 9550	Pressure curve used to give enhanced tactile feedback.
Digital stylus for graphic designers	Interlink Electronics custom FSR®	JaJa pressure sensitive stylus	Variable force used to control width or density of lines drawn on tablet computers

Table 2. Applications using Force Sensing alone

Force Sensing plus One-Dimensional Position Control

Devices that offer both force sensing and one-dimensional position sensing are illustrated in Figure 8. They are referred to as force sensing potentiometers. Although this type of sensor may take various physical formats, such as the linear and ring sensors shown, the position data they provide is still one-dimensional; only a single position value is provided, which is the distance from the beginning of the sensor path to the point of user contact – regardless of whether the path is straight or circular.

Table 3 includes product examples that utilize these dual functions. The large music capacity of the iRiver products necessitated a variable rate playlist scrolling capability, for which the FSLP provided an excellent solution; scrolling direction is asserted according to which end of the FSLP is pressed, while the force applied controlled the scrolling rate. The Wacom tablet makes a different use of its embedded Ring Sensor; the further along the circular path that a user moves their pen or finger, the greater the zoom level.

Figure 8. Force plus One-Dimensional Position Sensing Resistors

Application	Force Sensor	Product example	Force/ position sensing functions
MP3 player	Interlink Electronics FSLP	iRiver H-10 and H-11	Enhanced adjustable-rate playlist scrolling.
Pen tablet	Interlink Electronics Ring Sensor	Wacom® Bamboo™	Zoom control.
Music remote control	Interlink Electronics Ring Sensor	Sonos Controller 100	Variable speed menu scrolling.

Table 3. Applications using Force and One-Dimensional Position Sensing

Force Sensing plus Two-Dimensional Position Control

Typical devices in the third category are illustrated in Figure 9. These sensors provide coordinate values in two orthogonal directions (XY) for the location of a touch, making them the appropriate choice for pointing and touchpad applications.

Traditionally, the primary application for these types of devices has been in laptop and notebook computers. Capacitive sensors are preferred for normal operating environments due to their rigid surface. However, for ruggedized computers, the only suitable choice is the resistive touchpad, as noted in Table 4.

Recent advancements in home entertainment systems – particularly interactive televisions – have opened up new uses in remote controls for both content control and application control (e.g. for gaming). Remote controls, however, are commodity items where cost is a major concern. The low cost of resistive devices makes them very well suited to such applications. They also offer the advantage of eliminating unintended touches.

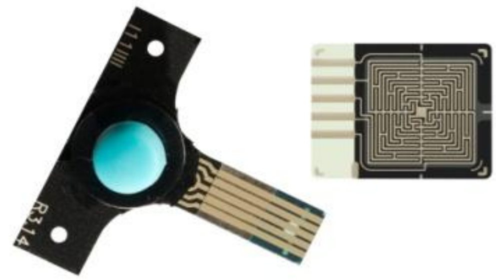


Figure 9. Force plus Two-Dimensional Position Sensing Resistors

Application	Force Sensor	Product	Force/XY position sensing functions
Rugged mobile computer	Interlink Electronics VersaPad®	Panasonic Toughbook® 19 and 31	Touchpad for cursor control. Suitable for use in wet and/or dirty conditions, with bare or gloved hand.
Home entertainment remote control	Interlink Electronics 4-Zone Mouse Sensor	*unannounced*	Control of content and applications on new generation of interactive televisions.
Home entertainment remote control	Interlink Electronics VersaPad®	*unannounced*	Control of content and applications on new generation of interactive televisions.

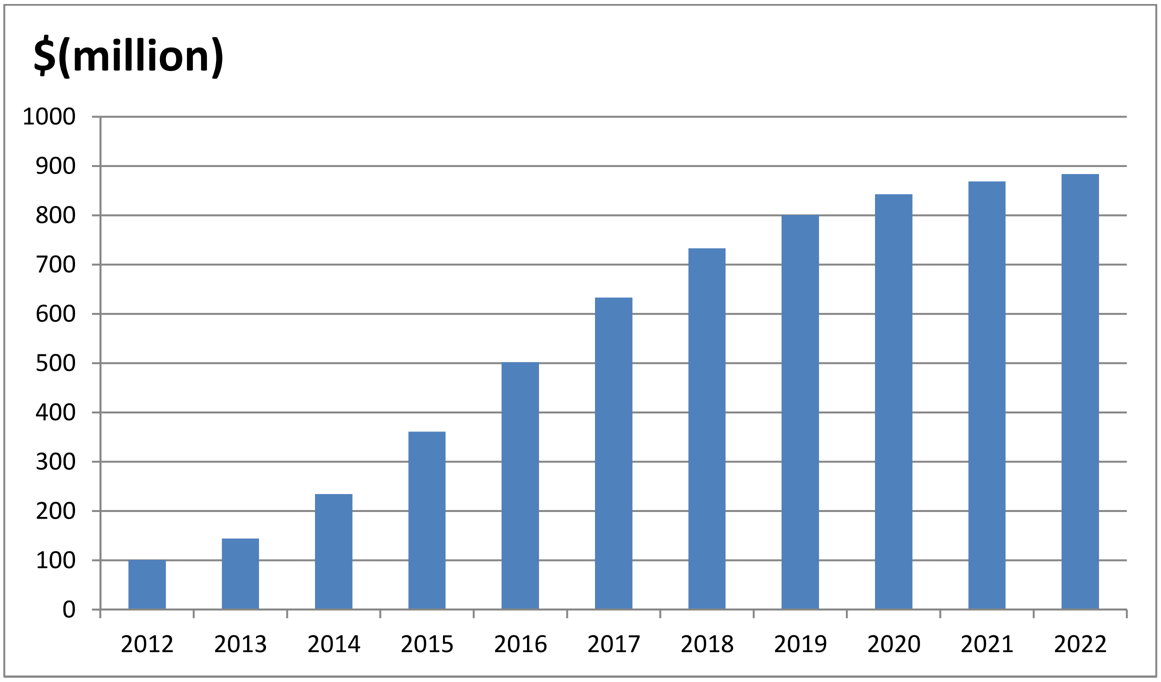
Table 4. Applications using Force and Two-Dimensional Position Sensing

The Future

According to a recent study by IDTechEx (*Printed and Flexible Sensors Forecast, Players and Opportunities, 2012-2022*), the overall market for these devices is projected to grow from $100.9 Million in 2012 to $877.78 Million in 2022 (Figure 10). Of these totals, the projected figures for the consumer electronics segment of the market are $19.58 Million in 2012 growing to $178.53 Million in 2022. The study bases these latter projections on a variety of emerging consumer applications that include:

- Pressure sensitive 'smart' buttons integrated into shelves, entertainment electronics, household appliances, electric tools and even clothing (for control of music players).
- 'Smart' buttons in posters, packaging and other advertising media.
- Pressure point measurements in shoes, mattresses, dance mats, et al.
- Massage pressure management.

While many of these applications are simply the result of innovative thinking by industry visionaries, there are also some practical factors that have been enablers for such innovation. These factors are largely, though not solely, dependent on continuing technology advancements. They are summarized in Table 5 along with their 'predicted impact' – the percentage that each factor is projected to contribute to the growth. It is worth noting that force-sensing resistors possess all of these enabling factors.



Source: IDTechEx

Figure 10. Market Forecast for Printed and Flexible Sensors 2012-2022

The ever increasing popularity of tablet computers and e-readers presents and exemplifies the ongoing challenge to sensor manufacturers resulting from the higher and higher packing density of components in these devices as they become increasingly sophisticated. The latest generation of such devices has restored some functionality to physical controls rather than earlier generation efforts to implement all functions through on-screen controls. This avoids potential conflicts and lockouts when high priority functions must take precedence over on-screen activities, as well as providing enhanced user experience resulting from the haptic feedback available with force-sensing switches and buttons.

This combined use of capacitive (screen) and resistive (smart button) sensors is seen as a trend that is likely to continue in a wide variety of consumer products. The thin form factor and flexibility of force sensing resistors makes them the ideal choice for such physical controls, as the demand for increasing miniaturization continues unabated.

Enabling Factors	Impact
Flexibility, conformal design, rollability, increased area, lower process temperatures, improved ink chemistries, lapsed patents	58%
Better performance, reduced manufacturing costs	31%
New functionality such as multi-sensory capabilities	11%

Source: IDTechEx

Table 5. Leading Market Drivers Through 2022

Conclusions

Touch interaction with consumer electronic devices is becoming more pervasive, and there will be an increasing need for technologies that enhance and enable intuitive human-machine interactions. The very nature of innovation precludes the possibility of foreseeing all the potential new applications of force sensing technology. The list of emerging applications cited above will undoubtedly grow in the coming years, simply because the control functions offered by force sensing resistor devices are so broadly applicable. Any consumer application that requires the human touch to provide proportional control – for example: faster/slower, louder/softer, brighter/darker, higher/lower, etc. – is a potential candidate for utilizing force/position sensors. With this in mind, readers are encouraged to re-examine their intended applications, opening the possibility for discovery of exciting new ways of utilizing force sensing technology to gain a competitive edge.

About Interlink Electronics

Interlink Electronics is a world leader in the design of patented Force-Sensing Resistor (FSR®) technology. For over 28 years, Interlink Electronics' solutions have focused on handheld user input, menu navigation, cursor control, and other intuitive interface technologies for the world's top electronics manufacturers. Interlink has collaborated and helped consumer electronics product designers to integrate FSR technology for numerous successful human machine interface (HMI) projects. Consider Interlink your trusted advisor as you conceive your next innovative design.