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A Review of Sensing Technologies for Small and Large-Scale Touch Panels

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ABSTRACT

A touch panel is an input device for human computer interaction. It consists of a network of sensors, a sampling circuit and a micro controller for detecting and locating a touch input. Touch input can come from either finger or stylus depending upon the type of touch technology. These touch panels provide an intuitive and collaborative workspace so that people can perform various tasks with the use of their fingers instead of traditional input devices like keyboard and mouse. Touch sensing technology is not new. At the time of this writing, various technologies are available in the market and this paper reviews the most common ones. We review traditional designs and sensing algorithms for touch technology. We also observe that due to its various strengths, capacitive touch will dominate the large-scale touch panel industry in years to come. In the end, we discuss the motivation for doing academic research on large-scale panels.

Keywords: Touch Panel Technology, Signal Processing, Finger Detection, Comparison

1. INTRODUCTION

This is the age of touch technology. Once considered revolutionary, it is now ubiquitous. A touch panel is an electronic display that the user can control through single or multi-touch gestures by touching the panel with one or more fingers, thus enabling them to interact directly with the display rather than using a traditional keyboard-mouse interface. Apart from bare fingers, a touch panel can take input commands through a stylus or special gloves. A simple use case scenario would be zooming in on a picture using two fingers or panning a map using one finger. Touch panels are commonly found in smartphones, tablet computers, gaming consoles and kiosks, either as an integrated layer below the cover glass, or as an overlay that can be attached to any display making it touch enabled. Throughout this paper, we will use the term 'touch panel' to refer to any physical overlay on any display which can sense touch. The term itself can be considered as interchangeable with the term 'touch screen'.

In devices such as Automated Teller Machines (ATM) and information kiosks, touch technology has brought a revolution as the user interface for touch is simpler and easier to understand than that of a keyboard-mouse system. Also, in the case of information kiosks, the traditional way of user input through a keyboard does not allow an intuitive, rapid or precise interaction with the display.

Historically, the touch sensor and controller firmware were not sold by display panel manufacturers. They are available in market through a variety of after-market system integrators. In recent years, the trend has changed due to wide demand of touch interface and TV/notebook display manufacturers have begun to incorporate touch sensors in the fundamental design of their products.

Broadly speaking, touch technology can be divided into two categories based on their application/deployment, (1) Smartphones, tablets and laptops and (2) Retail outlets and wall displays. There is no standard definition for what size is considered a large-scale touch panel, but in this paper, we would consider a touch panel greater than 30 inches to be in the second category.

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Touch technology for smartphones, tablets and laptops (small-scale touch panels) is established and saturated as millions of touch enabled phones are sold every year around the world. Mobile applications have adapted to touch input in their user interface (UI) and although multiple technologies are being used, capacitive touch technology is the leader in the smartphone industry. The same can be said for tablets and laptops. Capacitive touch with its non moving parts and high precision took over resistive touch technology soon after the release of iPhone in 2007.

As for the large-scale touch panel industry, there is no monopoly. Multiple technologies are currently used. Resistive touch is the most dominant one due to its low cost; Infrared touch is also capturing the market while capacitive touch is fast growing to overcome both and lead the market just like it did in the smartphone industry.[1]

There are different places in retail where large-scale touch panels are used. For example (1) Point of sales (POS) systems; (2) Kiosks; (3) Vending machines; (4) Digital signage and also in System control and office automation. POS has the highest application for touch panels at the moment but after the advent of Internet of Things (IoT), rapid growth of applications in digital signage and automation is expected. The touch panel industry is a combination of vendors and manufacturers and the supply chain is complex as depicted by Figure 1.

According to market research,[2] the global multi-touch panel revenue was around 9 billion dollars in 2015 as shown in Figure 2. By looking at the historical trend, the touch panel market is not getting saturated soon as the revenue increase is stable. This also presents a good business case for doing research on making touch sensing technology more accurate and precise.

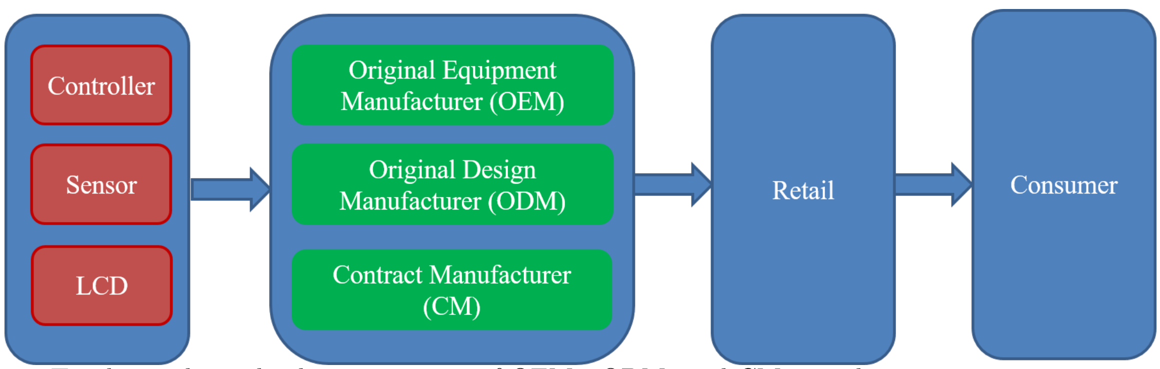


Figure 1: Touch panel supply chain comprises of OEMs, ODMs and CMs supplying various components of the touch panel to the retail market.

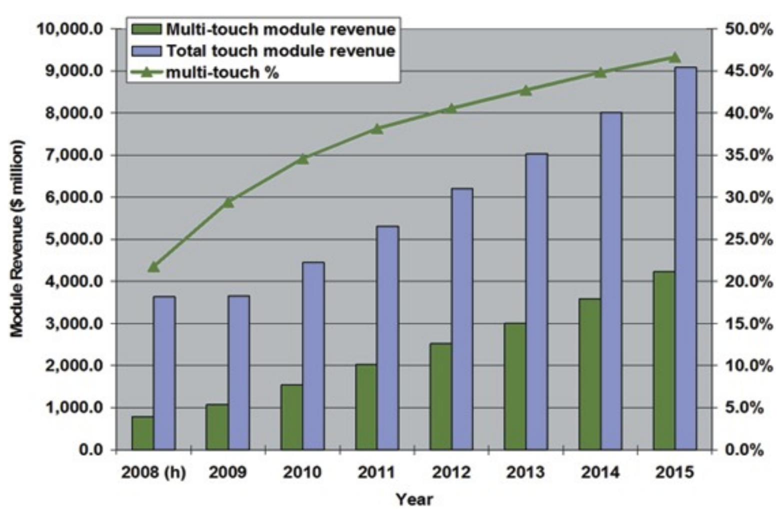


Figure 2: The graph shows touch panel sales revenue topping 9 billion in 2015. Source:.[2]

Technology \ Panel Size	2"-17"	10"-30"	>30"
Projected Capacitive	M	M	E
Surface Capacitive		M	
Resistive	L	L	M
Surface Acoustic Wave		M	L
Infrared		M	M
Camera Based Optical		M	M
Vision Based			E
Force Sensing		E	

Key:

M	Mainstream
L	Low-Volume
E	Emerging

Figure 3: Touch technologies classification.[3]

2. TOUCH TECHNOLOGIES OVERVIEW

There are a number of touch sensing technologies that use different methods for sensing touch as shown in Figure 3. In this paper we will discuss the technologies used for both small and large scale touch panels.

2.1 Resistive Based

Resistive touch is one of the oldest touch technologies (approximately 40 years old) currently in production, although its share has reduced considerably over the years. In 1977, the first transparent resistive touch panel was developed by Elo TouchSystems.[4]

2.1.1 Small-scale Multi-touch Resistive Touch Panels

In a small-scale touch panel like the ones in mobile phones, there are two layers of conductive coating underneath the cover glass separated by small insulating spacer dots. A voltage is applied to one or both sheets depending upon the application (Figure 4). When a finger presses against the outer membrane, the sheets make contact and the resistance of the spacer dots creates a voltage divider circuit at the contact point which is then picked up by the touch controller as a valid touch input. Because the only requirement for generating a touch signal is applied pressure, resistive touch panels can work with gloves on and with nearly any stylus shaped object. This useful feature increases the reliability and usability of the technology. However as pressure is required to press the conductive sheets together, devices incorporating resistive touch are more prone to damage.[5]

2.1.2 Large-scale Multi-touch Resistive Touch Panels

Touch resistive technology was used only in single touch detection devices for many years and it was only around 2009 after the invention of iPhone, when two small firms namely Stantum[6] and now defunct Touchco[7] started researching and producing small prototypes of multi-touch resistive touch panels. Stantum touch panel contains two Indium Tin Oxide (ITO) layers which are separated by an insulating medium. This multi-touch resistive sensing hardware provides two dimensional data from which the data processing algorithm removes the background noise and identifies the valid touch points.[4] The technology was labeled Analog Multi-touch Resistive (AMR). Figure 5 shows the working of a large-scale AMR panel.

In Figure 5, each square is around 10-20 mm wide and that can cause an issue when two fingers are held close together on the panel, as it may report only a single finger touch. On the other hand, if the square is made smaller than 10mm, it increases the manufacturing cost of the panel by a considerable amount. Apart from these fundamental issues, AMR technology suffers from less durability and low optical performance because a touch has to be registered using physical force.[8] It is pointed out that AMR will not have any significant share on the consumer electronics market in the years to come.[4]

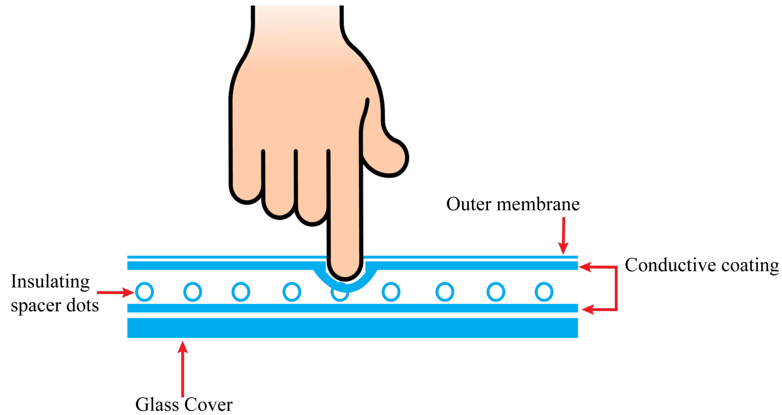


Figure 4: In a basic resistive touch panel, the pressure of the finger is used to create electrical contact between the two conductive layers causing a voltage divider circuit to be formed. Source:.[1]

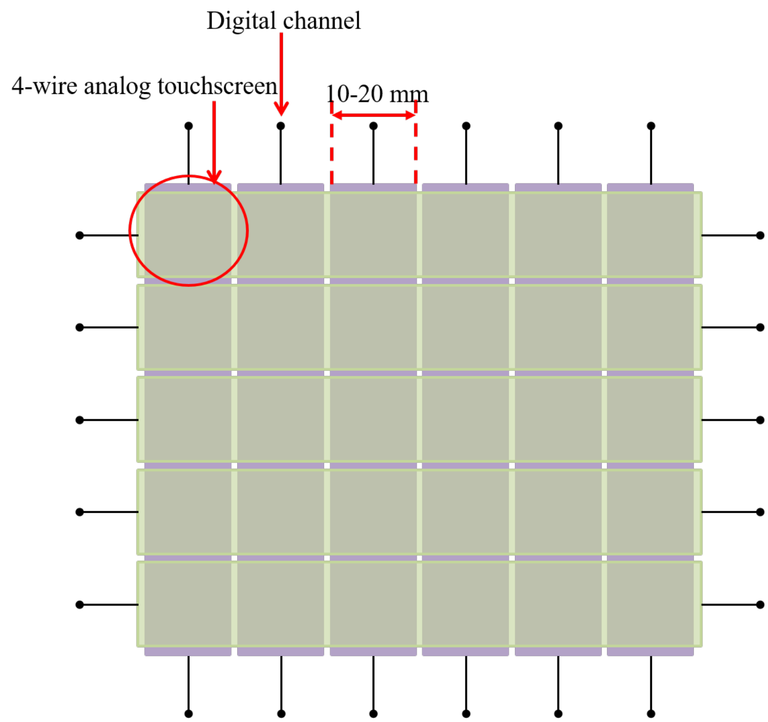


Figure 5: In an AMR touch sensor, the conductive layers are shaped as strips such that each intersection of strips forms a square, Each square is an independent 4-wire analog touch sensor.

2.2 Surface Acoustic Wave Based

Surface acoustic wave (SAW) was first designed and manufactured by Zenith and Elo TouchSystems[9] in 1985. In the late 1980s, there was a production boom for SAW devices when capacitive touch systems were not in high level production.

2.2.1 Working Principle of SAW Touch Panels

Unlike resistive touch, same principle is used for SAW for both small and large scale panels. The technology employs acoustic wave transducers for both receivers and transmitters, which are installed at the corners of the panel. The transmitter sends out bursts of ultrasonic Rayleigh waves that are reflected towards the receiver by an array of reflectors along the sides of the panel. When a finger or stylus approaches, a portion of the transmitted wave is absorbed and thus there is a delay in the time taken for the wave to reach the receiver.[4,8] This delay is picked up by the touch controller as a valid touch input. There is room to measure the touch pressure by measuring the amount of wave absorption and thus computing the Z axis (normal to the panel surface) value but it has never been widely practiced in current devices.

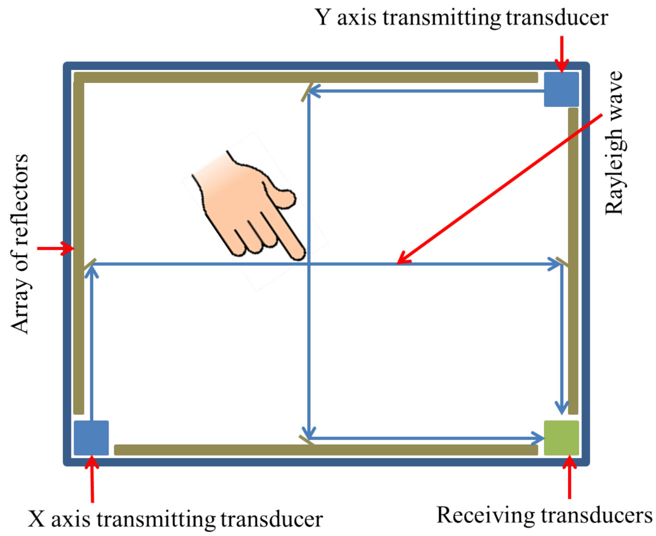


Figure 6: Multi-touch system based on SAW technology. In the figure, touch causes the wave to be absorbed causing a delay on its way to the receiving transducers. This disturbance can be picked up by the controller as a possible touch point.[1]

Surface acoustic wave devices have high light transparency and can be used for multi-touch detection. They generally have high resolution and can work even when the display glass is damaged. However they are highly sensitive to environmental conditions such as temperature and humidity and are costly to manufacture. In order to register a touch on SAW device, considerable amount of pressure is required which limits the usability of this technology.[8]

2.2.2 Large-Scale SAW Touch Panels

Due to the aforementioned issues, SAW did not become popular as a preferable technology for large-scale touch panels over the years. It was used extensively in medium sized kiosks such as ATM. However, in May of 2016, Elo unveiled its new eSAW technology calling it the next generation of SAW. The Elo Intellitouch eSAW panel is available up to 55 inches in size and has the ability to measure touch response on Z axis as well.[10] At the time of this writing, the eSAW technology is very new and untested, and thus it is yet to be seen how well it will perform in the coming years.

2.3 Infrared Based

The first ever commercial application of infrared technology was unveiled in 1983 as HP-150, HP's first touch microcomputer. Infrared touch technology is unique because of its extremely low manufacturing cost and high portability. The early infrared touch systems detected single touch and were composed of a frame containing infrared LEDs and photo-detectors on the sides. Each LED was pulsed in sequence and the light emitted was received by the photo-detectors. As shown in the Figure 7, this mechanism forms a grid of infrared light which gets disturbed when a foreign object touches the panel. The disturbance is read by the touch controller to determine the location of the touch. Due to this simple design, infrared panels can detect any foreign object touching the panel, similar to the resistive touch panels. The resolution of the touch panel can be increased by adding more transmitters. There is an upper limit on the accuracy of infrared panels as the maximum resolution of the panel is proportional to the minimum size of the transmitters installed in the frame.

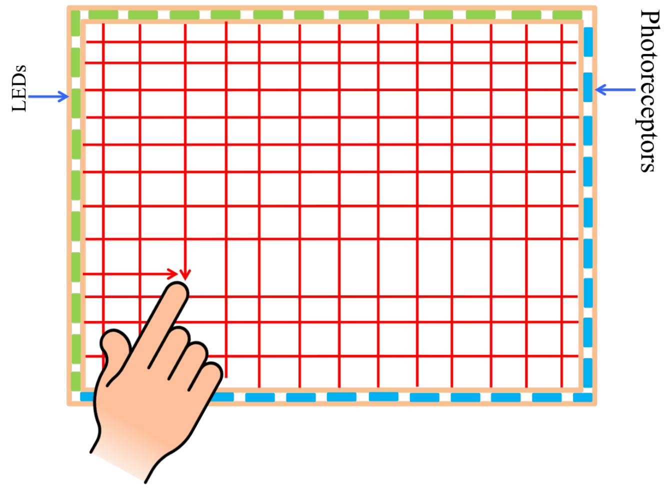


Figure 7: Phenomenon of infrared sensing. Blue and green rectangles represent the photo-receptors and the LEDs respectively. Touching the frame causes a break in the light path as shown by red arrows.

2.3.1 Small-Scale Infrared Touch Panels

Because of the presence of external frame with a noticeable bezel, infrared technology did not become popular for mobile phone touch panel. The panel is also sensitive to direct ambient light thus making it almost impossible to use IR touch panel under direct sunlight.[11]

2.3.2 Large-Scale Infrared Touch Panels

Infrared is a widely manufactured and used technology for large-scale touch panels. Because they are so cheap to manufacture, many small OEMs have started producing infrared panels in large quantities, which is further bringing the cost down. The multi-touch version of infrared touch panel works on the principle of imaging. The difference is in the detection algorithm of the touch controller. Instead of one to one correspondence between detector and transmitter, multiple photo-detectors record their level of light intensity and produce a 'shadow image' of the touch point.[12] This process is repeated over a period of time, creating a sequence of images which can be used for tracking multiple objects. The major providers of this technology are PQ Labs,[13] ZaagTech[14] and Citron.[15]

2.4 Surface Capacitive Based

In surface capacitive technology, the panel is usually covered with a conductive coating constructed from Indium Tin Oxide (ITO) which represents lower plate of a capacitor. The human finger behaves as the upper plate with cover glass acting as the dielectric. The touch controller can easily determine the location of touch by measuring the voltage at four corners of the panel. This technology has no moving parts so it is durable but suffers from limited resolution. It does not support multi-touch and thus can only be used in simple applications such as ATM kiosks and industrial control panels. Figure 8 explains the working of a surface capacitive panel.

2.4.1 Small-Scale Surface Capacitance Touch Panels

Since it can only support single touch, surface capacitance did not take off as a viable solution for smart phone touch display.

2.4.2 Large-Scale Surface Capacitance Touch Panels

Surface capacitance is a highly accurate and durable technology which can be scaled up without any significant cost increase. However, due to lack of multi-touch capability, its use declined. The biggest use of surface capacitance can be found in amusement machines and legacy gaming.

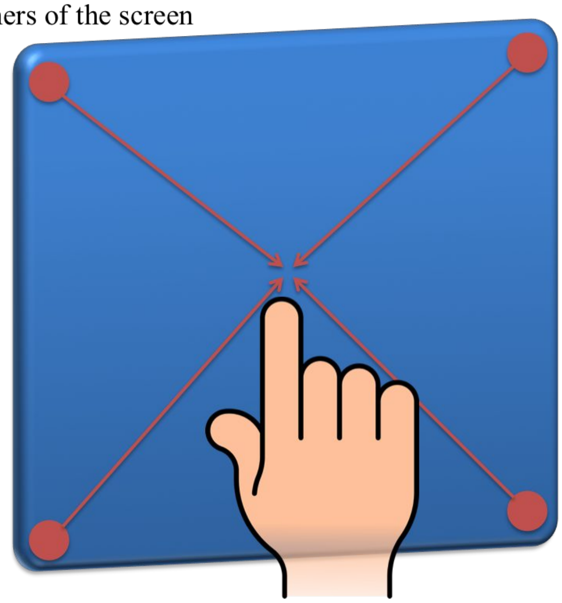


Figure 8: Working of a surface capacitance based touch panel.

2.5 Projected Capacitive Based

2.5.1 History

Projected capacitive touch technology is not new and has been around for more than 50 years. It is generally agreed among historians that the first finger capacitive driven touch panel was invented by E. A. Johnson in 1965 while working at Royal Radar Establishment in United Kingdom.[16] His work was published in electronics letters under the title "Touch display - a novel input/output device for computers". Johnson explained his work further in "Touch Displays: A Programmed Man-Machine Interface", published in Ergonomics in 1967.[17] His invention is shown in Figure 9.

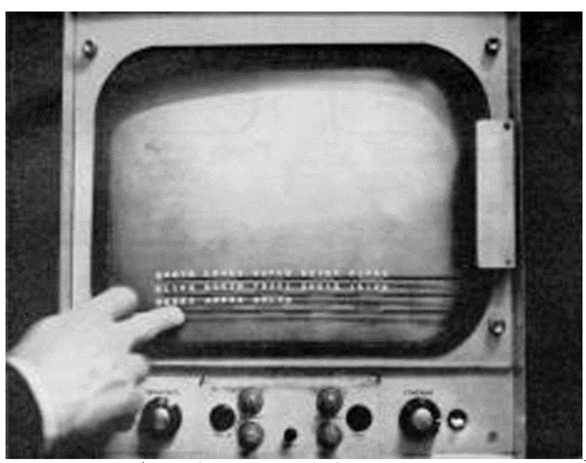


Figure 9: E. A. Johnson with his invention in 1967.[16]

During 1985, surface capacitance based technology was commercialized by Micro-touch systems. In the 1990s, many US based companies started producing capacitive touch panels and accompanying touch controllers. The sensors were manufactured using Indium Tin Oxide (ITO), which is still widely used in manufacturing low cost capacitive touch panel. Dynapro and MicroTouch systems (later acquired by 3M touch systems) were among the first companies to introduce surface capacitance systems in the market. 3M Touch system's first touch panel product named as Near Field Imaging was based on technologies developed by Microtouch and Dynapro and was launched in 2001.

In 1994, R. P. Binstead designed a projective capacitance circuit using a pattern consisting of microfine wires. A single microfine wire thickness is around 25 micron. The technology was licensed to Zytronic and Visual Planet in 1998 and 2003 respectively. The release of Apple iPhone in 2007 brought a revolution to the smart phone industry. It was the first touch enabled smart phone which employed capacitive multi-touch capability to a limited degree.[18] Also in the same year Microsoft released Surface 1.0,[19] which was basically an interactive table surface capable of sensing more than five fingers at the same time. This was used as a tool in collaborative and informative learning environment. Surface 1.0 was followed by Surface 2.0 in 2011. Microsoft re-branded the technology as PixelSense in 2012-2013.

2.5.2 Working Principle of Capacitive Touch Technology

This section applies to both small-scale and large-scale panels running on capacitive technology as the working principle behind is the same. A capacitive touch panel works on the principle of capacitance/charge measurement. The panel is coated with a material capable of storing electrical charge. When a conductor such as a human finger is brought in contact with the panel, a small amount of charge is drawn to the point of contact. The circuit located at the border (or edges) of the panel measures the charge difference and transmits this information to the touch controller for processing. As conductivity of charge plays a central part in workings of capacitive touch technology, they cannot be operated using regular gloves or plastic stylus. Due to the transparent nature of the conducting material, capacitive touch panels have excellent clarity and are unaffected by common contaminants like dirt or grease.

The manufacturing material used for capacitive electrodes can be Indium Tin Oxide (ITO), Copper or Silver. The performance of the panel depends upon the type of material used for construction of electrodes. The increase in resistivity decreases the sensitivity of the whole system, thus decreases the performance.

We know that the ability of an electrode to transfer charge is inversely proportional to the resistivity of the conductor. Although ITO has the lowest resistivity among these materials, it is still widely by touch panel manufacturers as it allows the capacitive sensor to be up to 90 percent transparent for both single and double layered solutions.

In Projected Capacitive Touch (PCT), electrodes are etched on an insulator thus allowing accurate and flexible operation. There can be a single or double layer of conductive material and the choice is based on the type of application. These electrodes form an X-Y grid pattern, and an external conductive object can change the voltage flowing through the electrode lines by forming a capacitor with the conductive traces. This phenomenon is illustrated in Figure 10.

The alternating current flow is continuous across the conducting material surface. When human body touches the panel, it starts conducting and hence the voltage drop at the touch point is captured as a touch event. Electronic circuits located under the ITO layer measure the distortion produced in voltage and transmit information to the main controller to translate the event into a meaningful gesture.

The cost of manufacturing capacitive touch sensing devices (although decreasing with the increase in production volume) is greater than infrared as well as resistive devices. Because the device must be able to sense changes in capacitance as small as few Femtofarads (10^{-15} F), the sensors are very sensitive to electromagnetic interference. The aim of a capacitive touch panel designer is to find the optimal point between sensitivity of the sensor and its immunity to noise.[5] Also capacitive touch sensors have the advantage that they can be integrated in a small area and thus are suitable for mobile phones and Personal Digital Assistant (PDA) devices.

Projected capacitance can be further divided into self and mutual capacitance. Self (or absolute) capacitive sensing is used when the processor wants to determine only one finger touch location over the grid. Although self capacitance can measure multiple touches but it is not a common practice due to the phenomenon of ghost points (explained below). As a low cost solution it is still widely used in ATM kiosks and in information and education

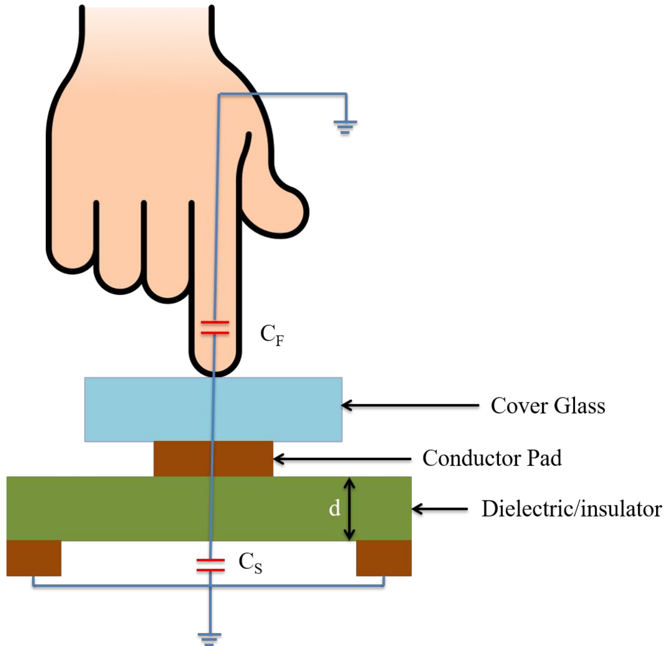


Figure 10: Phenomenon of capacitive sensing. Blue line represents a capacitive circuit formed between finger and conductor(ITO or copper) pad. C_F and C_S represent the finger and sensor capacitance respectively whereas d represents the distance between the plates.[20]

targeted kiosks. Smart phones like iPhone use a different type of touch sensing called mutual capacitance in which the processor can detect multi-touch.

Although both self and mutual capacitance are based on projected capacitive touch technology and in both techniques, capacitance variation is measured in column and row basis, they have notable differences as indicated by Figure 11. In self capacitance, when a conductive object approaches the sensor, the node to ground capacitance of a channel under the object increases. The blue arrow in Figure 11 (a) indicates the transformation from no finger to finger present. As it can be seen, the overall capacitance increases with introduction of finger. In self capacitance, the controller scans all rows and columns to find out the exact location of a single touch. Note that, if the panel has 10 rows and 7 columns, scanning 17 channels can identify 70 touch points in theory. While this approach can be implemented for one touch or simple two touch gestures, it has limitations for more than two-touch (or complex) gestures. The system may detect two x coordinates ($x1$, $x2$) and two y coordinates ($y1$, $y2$) but it has no way of knowing that which x coordinate goes with which y and vice versa, therefore introducing two ghost points on the panel. In Figure 12, a self capacitive system will not be able to tell the difference between two finger touches, $[(x1, y2),(x2, y1)]$ and $[(x1, y1),(x2, y2)]$. However, self capacitance is still very popular because of its ease of implementation in applications which require single touch gestures.

Mutual capacitance eliminates the ghost point problem encountered in self capacitance systems. Usually mutual capacitance has two cross patterned layers with a dielectric in between. This two layer design is the same as self capacitance but capacitance is formed at intersection of both layers. The workings of mutual capacitance is shown in Figure 11 (b). The transmitter and receiver node are coupled via charge field and when a finger is brought closer, the capacitance decreases because some charge is stole by the finger acting as a conductor.

During the scanning process, the upper layer drives the signal (usually a square wave) and the charge magnitude is sensed at each line of lower layer. The touch controller has to scan every single intersection of the driving lines with sensing lines. Thus for 70 nodes, 70 intersections have to be scanned, taking longer time than what is required for scanning the same number of nodes for self capacitance. Also signal sensitivity is lower because charge is measured between the intersections of electrodes rather than on the electrodes itself.

A typical capacitive touch panel has three major parts: physical sensor/analog front end, signal sampling and signal processing as shown in Figure 13. The physical sensor is responsible for changing its state when a

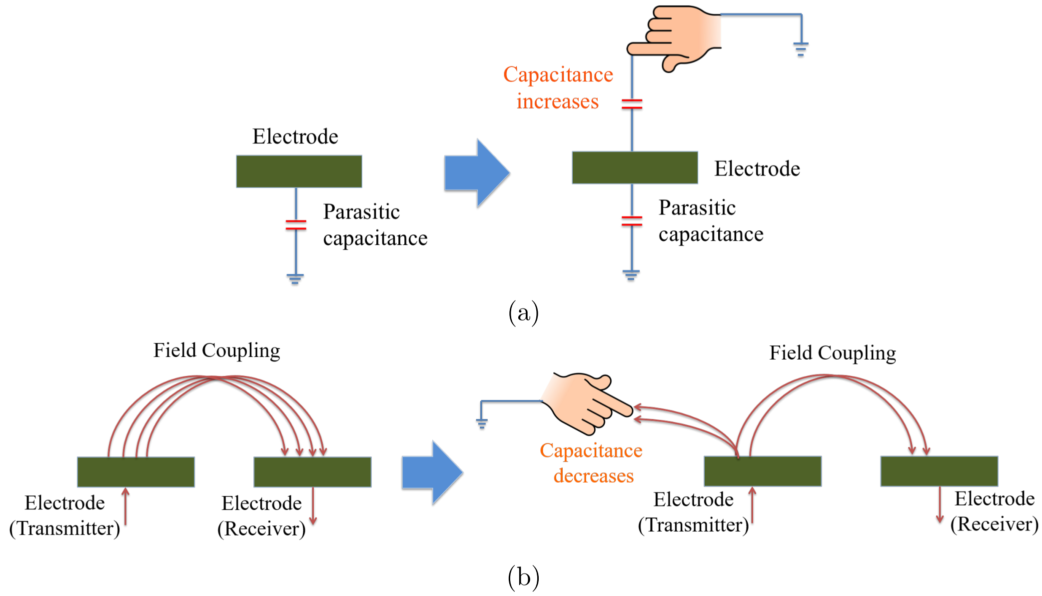


Figure 11: Figure depicting difference between self and mutual capacitance. (a) Self capacitance (b) Mutual capacitance.

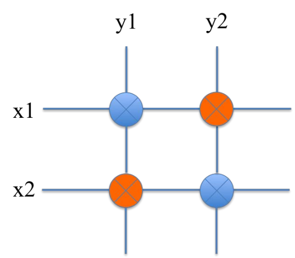


Figure 12: Self capacitance ghost point problem. A self capacitance system will not be able to differentiate between two finger touch $[(x1, y2),(x2, y1)]$ and $[(x1, y1),(x2, y2)]$.

conductive object is placed near the panel which is then sampled by the touch controller. The signal processing part is responsible for noise filtering and interpolation in order to recover the touch location.

The advantages of using capacitive touch technology are numerous. Some of the major advantages are listed below:

1. Capacitive touch panels support multi-touch thus enabling developers to create high-tech applications.
2. They do not require a bezel to operate and the resulting panel is a true flat surface that is aesthetically pleasing.
3. They are scratch resistant and have a high endurance limit. They also do not require finger pressure to operate unlike resistive or SAW touch devices.

Some of the early critics of capacitive touch panels would point out the limitation that it cannot be used while wearing insulating gloves or with plastic stylus, but with the advent of technology, capacitive touch supporting gloves and stylus are now available in market which allow the use of technology in harsh cold environments as well.[21]

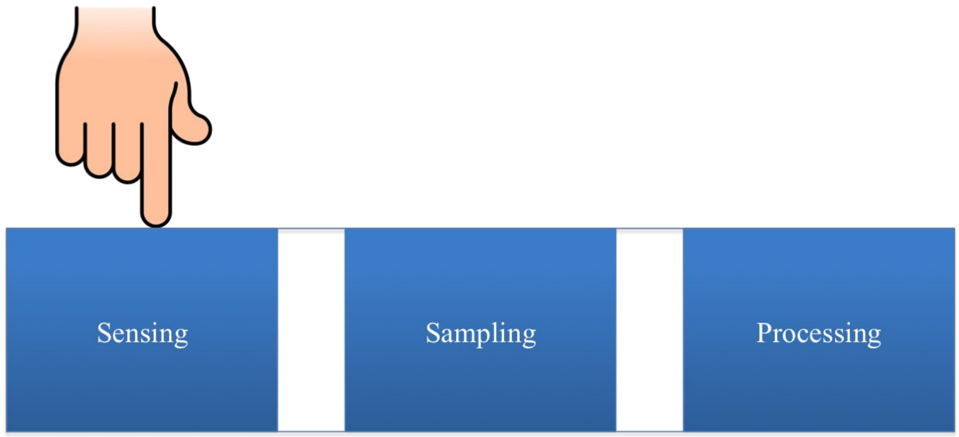
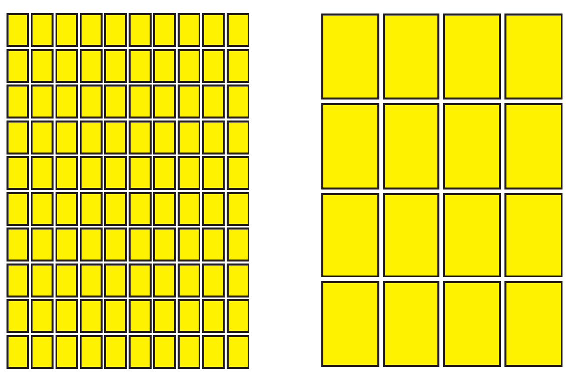


Figure 13: Three main components of a capacitive touch system

3. RESEARCH PROBLEMS ASSOCIATED WITH CAPACITIVE TOUCH PANELS

When reviewing the academic literature, it can be seen that there is very little published research in the field of capacitive touch technology. Most of the research in this fields has been done by industry instead of academia, therefore it is confidential and unpublished.

The little available academic literature is concerned with designing more accurate, robust and noise free analog front end for a capacitive touch sensor and less research effort is directed towards the digital back-end. This provides an interesting research opportunity to explore the issues associated with back end of capacitive touch technology. One of the issues of interest is the scaling of capacitive electrode from a smart phone touch panel to a large wall mounted display. We all know that a small-scale capacitive touch panel is very precise, but what happens when it is scaled up? Figure 14 is a good representation of the two options pattern designer can deploy during the scaling process.



(a) (b)

Figure 14: Capacitance electrode scaling techniques. (a) Scaling up by keeping electrode size same (b) Scaling up by increasing electrode size.

Going by the arrangement in Figure 14 (a), then microprocessor responsible for collecting touch signals from the physical sensors will have to scan a large number of sensors in order to successfully locate the finger. This implies that either one more powerful and costly microprocessor or more than one microprocessors will be used in a multiplex arrangement which will increase the cost and real estate issues. If we decide to go by arrangement in Figure 14 (b) then we can work with only one microprocessor but our results will be inaccurate as now the basic element of the grid is scaled up and for good linearity tracking, the finger must cover more than one grid element in both row and column direction. If we follow a simple formula of scaling up the electrode size in the grid with the increase in area of touch panel, then we will end up with electrodes bigger than the size of normal human finger.

Another option is to add up all the charge present in all electrodes in a row and only send the sum to the controller, similar to what happens in self capacitance. But that, as mentioned earlier will diminish the multi-touch capability of the panel. Some of the current OEMs manufacturing large-scale capacitive touch panels tend to use self capacitance technique instead of mutual capacitance but it is not a viable solution as it does not support multi-touch.[22]

Another interesting topic is the design (or shape) of the sensor itself. Each OEM is using own patented designs in their products which begs the question that whether there is an optimal design and how can it be achieved. Similarly, industry is using exhaustive sampling in existing designs, which is not an optimal solution.[23]

One of the biggest concerns in designing a low cost, thin multi-touch panel is effective noise removal. The major sources of noise are from the LCD and charger. The noise injected by these sources affects the performance of the touch controller. As the race for designing thin touch panels in order to reduce the overall area of the device continues, the problem poised by noise becomes even greater.

4. CONCLUSION AND FUTURE ISSUES TO ADDRESS

In this paper, different touch technologies used for touch panels are reviewed. Pertaining problems for the large touch panels are discussed. As the retail market is shifting to high-tech touch enabled applications, a seamless user experience is the key for both manufacturers and customers. Capacitive touch technology already holds the market for smartphone and tablet touch screens and thus it is pretty certain that with time, it will dominate the touch panel market as well. However, there are a number of challenges faced by the industry in scaling up the touch panel without sacrificing the cost or precision. Exploring touch technology research further will help not only the industry but also retail sector and the consumers in getting the same smooth and precise touch experience from a retail touch panel as they get from their touch enabled smartphone device today.

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