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OVERVIEW AND PERFORMANCE COMPARISON OF CAPACITIVE TOUCH SENSING GRID PATTERNS

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Abstract—Capacitive touch sensors are used in various applications such as mobile phones, mouse pads, smart watches, TVs and various home appliances. Capacitive touch sensors are user interface devices that detect the presence of a finger on or near a sensor using human body capacitance. In this paper, we go through fundamentals of capacitive touch sensing, overview the different sensor patterns used to design capacitive touchscreens and compare them based on key performance parameters. The limitations and potentials of different patterns are discussed and a final conclusion regarding appropriate patterns to be used as per application requirement is summarized in the end.
Keywords—touchscreen, capacitive touch sensing, human machine interface, self capacitance, mutual capacitance.

Introduction

Nowadays smartphones, laptops, smart watches, smart home appliances such as refrigerator, microwave, washing machine, etc. are manufactured with touch panels instead of mechanical buttons. There are several touch screen technologies available, including resistive, capacitive, infrared and surface acoustic wave (SAW) [1]. This paper focuses on capacitive touch sensing technology. Usage of touch screens in current commercial electronic devices has improved due to the user-friendly interface provided by high resolution touch sensors. Hence, many researches have been conducted to achieve accurate finger position in variable environment conditions [2], high noise conditions [3], different touch screen sizes [4-5] and for applications having power consumption restrictions [6-9].

A touch screen is an electronic visual display capable of determining and locating accurate touch position over its display area. When the input is in the form of a gradual increase or decrement (one and two dimensional) and gestures (single/double finger swipe, pan, zoom, etc), touch screens are used. Examples include traversing through display using gestures, lighting (dimmer), volume and speed control, graphic equalizer [10-12]. Capacitive touch screens are preferred when your application or its environment is described as harsh. Capacitive touch screens are more durable than resistive touch screens [13]. They also support multi-touch sensing, which supports recognition of pinch zoom gesture functions [14-15].

In applications that do not have any display below the sensors, copper is generally used to construct the sensor design pattern. Whereas, for applications requiring transparent sensors to showcase the bottom display, Indium Tin Oxide (ITO) is used most commonly for sensor construction [16-18]. Human finger serves as the second conducting layer with the sensor overlay as dielectric in between. Presence of the finger on the touch screen creates voltage drop at the touch point. The controller measures the distortion produced in voltage by finger and reflects whether the touch is valid.

This paper examines the grid pattern design of capacitive touch panels and provides a comparison of touch panels so that an optimal sensor design pattern can be used per application requirements. Section II, recapitulates capacitive touch sensing fundamentals such as self and mutual capacitive touch sensing and Section III focuses on introducing different touchpad sensor design patterns. Section IV will compare different sensing grid patterns and will draw comparison based conclusions.

Fundamentals of Capacitive Touch Sensing

Self-Capacitance based touch sensing

Self-capacitance uses a single electrode, the capacitance between the respective electrode and ground is known as parasitic capacitance. A self-capacitance touch sensing system is operated by driving current on a pin connected to a sensor electrode and to determine the finger touch, voltage on the driven pin is measured. When a finger is placed on the sensor, the measured capacitance increases as shown in Figure 1. Self-capacitance touch sensing is preferred in case of buttons and sliders [19].

When a finger is placed over the sensor surface, a parallel plate capacitor is formed with the sensor pad through the overlay. The result is defined by Equation 1 and can be denoted as CF (finger capacitance). Where CF denotes variation in capacitance due to the effects of the human body and the return path to the circuit board ground.

$$C_F = \frac{\varepsilon 0 \varepsilon \quad A}{D} \qquad \text{Equation 1}$$

Where:

ε_0 = permittivity of free space

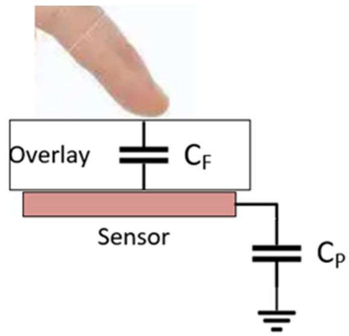
ε_r = overlay dielectric constant

A = finger and sensor pad overlap area

D = overlay thickness

When a finger touches the sensor surface, CS (sensor capacitance) equals the sum of CP (parasitic capacitance) and CF (finger capacitance).

$C_S = C_F + C_P$ Equation 2



Realistically, CP is quite high when compared to CF. CP should be reduced in order to increase the sensitivity, hence in such cases the shielding method is opted. In case of shielding, the ground nearby to the sensor is driven by the same signal as the sensor electrode, this also provides water tolerance.

Mutual-Capacitance based touch sensing

For mutual-capacitance based touch sensing, a typical button sensor has layout as shown in Figure 2. In case of Mutual-capacitance touch sensing, the capacitance between two electrodes is measured, commonly known as transmit (TX) electrode and the other as receive (RX) electrode.

The TX electrode is driven by a predefined signal and the amount of charge received on the RX pin is measured. The mutual capacitance (CM) between the two electrodes is directly proportional to the amount of charge received on the RX electrode.

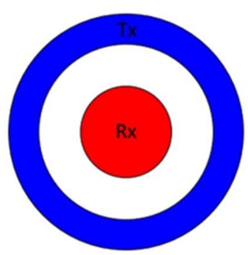


Figure 2: Mutual capacitance based button sensor layout

When a finger is placed on the sensor, it interferes with the electric field between TX and RX electrodes, which leads to reduction in the mutual-capacitance as indicated in Figure 3. The charge received on the RX electrode decreases due to the reduction in overall mutual-capacitance. This change in mutual capacitance is used to detect the touch/no touch condition. The mutual-capacitance effect is best suited for multi-touch systems such as touchscreens and trackpads. As the number of controller pins required are quite less for a larger number of sensors in mutual-capacitance method.

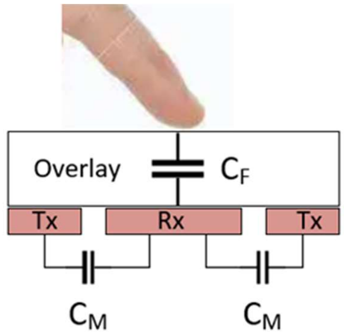


Figure 3: Mutual capacitive touch sensing

Touchpad Designing Basics

A touchpad consists of two-dimensional array of capacitive sensors called x and y electrodes, which are placed in the form of a matrix as shown in Figure 4. Each junction formed by these x and y electrodes forms one node which can successfully detect a touch. Either x or y axis electrodes are driven by transmit signal (Tx-electrodes), other axis electrodes are connected to receiving pins (Rx-electrodes). In order to detect a touch, full touchpad is scanned in both x and y axis. In case of a Self-capacitance based touchpad, all electrodes are scanned individually. Whereas for mutual-capacitance based touchpad, each electrode intersection i.e. nodes are scanned [20]. The firmware processes the raw counts from the Rx pins to calculate the position of the finger touch.

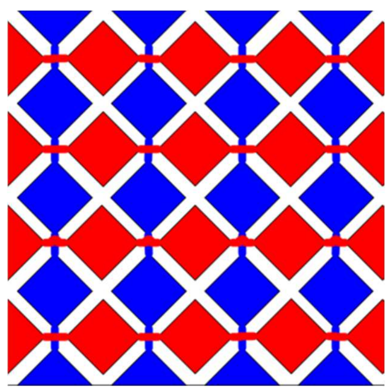


Figure 4: Generic touchpad sensor design arrangement

Touchpad design patterns

This section will provide a brief overview of different sensor design patterns which can be used for constructing touchpads.

Diamond Pattern

Diamond pattern is a most commonly used sensor design pattern for designing a touchpad. Figure 5 denotes the individual sensor node of the diamond pattern which is continued in horizontal and vertical direction, enabling the touch screen capable of detecting touch in two-dimension (2-D). These electrodes can either be stacked upon each other in a single layer or two different layers.

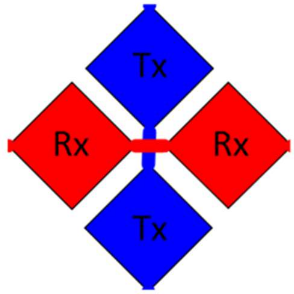


Figure 5: Diamond pattern individual sensor node

Electrode Pitch: The pitch of a trackpad is defined as the distance between consecutive diamonds in a row or a column. The pitch size is also limited by the overlay thickness, and should be smaller than the total overlay thickness. Typically diamond patterns are constructed using 4-5 mm pitch, ensuring that the pitch is less than overlay thickness.

Gap spacing: Gap is distance between the edges of adjacent diamonds, as shown in Figure 6. It is also strongly correlated to overlay thickness, and should be smaller than the overlay thickness, typically around 0.5 mm.

Finger separation: finger separation is known as the minimum distance that enables correct detection of multiple touches in close proximity to one another. Usually the minimum finger separation distance is 2 times the pitch.

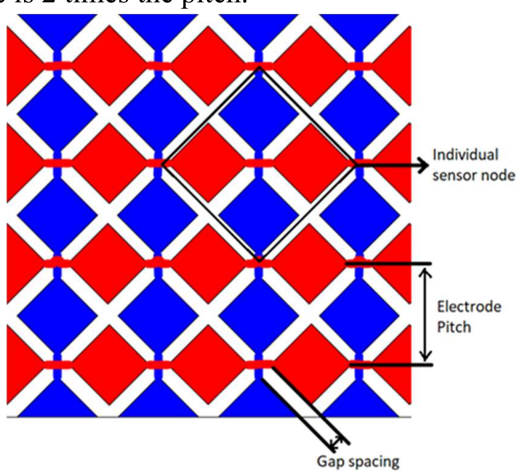


Figure 6: Diamond pattern design considerations

Z Pattern

As shown in Figure 7, a 'Z' shaped pattern is used to form the Y electrode and the X and Y electrodes are distributed across two layers of a substrate. The primary advantage of this pattern is that the X electrode completely shields the Y electrode from behind, making the sensor insensitive to touch from behind. In this pattern, an individual sensor node is formed at each intersection of the X and Y electrode.

Electrode Pitch: The pitch is typically between 5mm to 7mm for an optimum balance between resolution and sensitivity. Y electrodes should have thickness between 0.2mm and 0.5mm.

Gap spacing: Gap spacing between the X electrodes is around 0.5 mm, and typically 1 mm between Y electrodes.

Finger separation: For above mentioned dimensions, this pattern supports edge to edge finger separation of 2 mm.

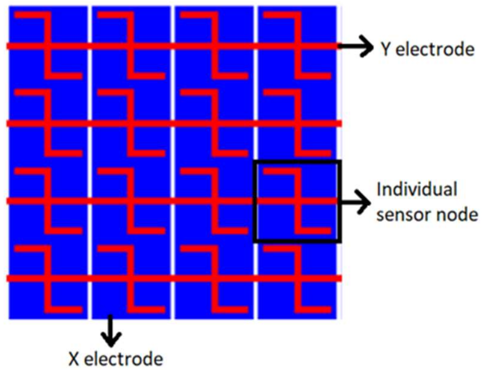


Figure 7: 'Z' Pattern

I Pattern

This pattern has Y electrodes in the shape of letter 'I', as displayed in Figure 8. Since this pattern is quite similar to the 'Z' pattern, it incorporates the benefit of noise immunity behind the sensor layers. The larger X electrode is below the Y electrode with a solid fill. The X and Y electrodes overlap each other, with the Y-electrode nearest to touch.

The design parameters such as electrode pitch, gap spacing and finger separation for this pattern are similar to the 'Z' pattern. Due to symmetry in the 'I' pattern, the linearity along the diagonal is better compared to the 'Z' pattern.

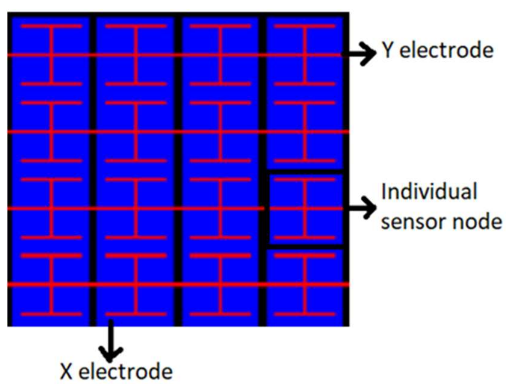


Figure 8: 'I' Pattern

Performance Comparison

Key Parameters

Sensitivity: It is the magnitude of the capacitance variance for a finger touch on the sensor. Sensitivity depends on the geometry of the sensor pattern and gain setting used.

Jitter: Jitter can be represented by the overall noise in the system, and can be reduced by implementing filters. It is known as variation in the reported touch position when a stationary finger touch is present on the sensor.

Cross Talk: It is the change caused in one node due to a neighbouring node which received the signal i.e. finger touch present on it. The amount of cross-talk present depends on the geometry of the sensor pattern.

Linearity error: It is the deviation between reported touch position and actual touch position as finger slides over sensor.

Resolution: Resolution refers to the number of distinct touch positions reported when a finger traverses in a straight line along the horizontal or vertical axis of the sensor. Resolution is specified in DPI.

Finger separation: It is the minimum distance required between the edges of two fingers for the sensor to recognize them as two distinct touches. The finger separation that can be supported depends on the geometry of the sensor pattern.

Performance Comparison

Table 1 showcases the comparison of diamond, 'Z' and 'I' pattern with respect to above described key parameters.

COMPARISON OF KEY PARAMETERS

Key Parameters	Diamond Pattern	'Z' Pattern	'I' Pattern
Sensitivity	40	95	100
Jitter	1.2 mm	0.3 mm	0.3 mm
Linearity error	1.3 mm	2.6 mm	1.6 mm
Resolution	162 DPI	162 DPI	162 DPI
Finger separation	2 mm	2 mm	2 mm

Note: These values approximately indicate the expected performance

Conclusion

In this paper, the capacitive based touch sensing technology is introduced. From the description given for each sensor design pattern and their comparison with respect to key parameters, we can come to below mentioned conclusions - diamond pattern is suitable for single-layer as it provides improved sensitivity, the 'Z' and 'I' patterns have good sensitivity, low noise levels and good linearity along both X and Y axes, smaller nodes give better resolution and larger nodes give better sensitivity, since 'I' pattern increases overall area of Y electrode, linearity along the diagonal of touch surface for this pattern is better. The overview and performance comparison showcased through this paper will be helpful for one to determine the correct sensor design pattern per the application requirements.

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