

The Method of Reducing Response Time on Proximity and Tactile Sensor

Satoshi Tsuji, Teruhiko Kohama, *Member, IEEE*

Abstract—We proposed a tactile and proximity sensor (layered 3D touch screen) base on capacitance measurement. In the proposed sensor, the parallel-type capacitance sensor and plane-type capacitance sensor are layered. The sensor can detect the object and position before contact (proximity range), and can detect the indentation and precise position on contact. In addition, it can discriminate materials on contact. In this paper, we propose the method of reducing response time on the proximity and tactile sensor (layered 3D touch screen). The proposed method is that the contact sensing points are selected by the proximity sensing results for reducing response time.

I. INTRODUCTION

Currently, touch screens are widely used as interface between humans and electronic device such as smartphones, tablet PCs and handheld game consoles. So far, various sensing technologies of touch screen have been developed using resistive [1], capacitive [2, 3], optical [4] and ultrasonic [5]. Most these touch screens detect the contact position between the touch screen with display and the object (finger). In addition, the proximity touch screens have been proposed to improve the functionality [6]. However, these touch screen are not considered to detect indentations (pressure). By the way, a 3D display to display depth perception (3D image) has been developed. Some 3D displays equipped with touch screen. However, these touch screens detect contact position only (2D range).

The aim of our research is to develop a 3D touch screen that can be operated the 3D image using the finger at 3D range on the display. Fig. 1 shows the goal image of the 3D touch screen in this research. When the 3D image is on the display surface, the image is operated by applying a small pressure using the 3D touch screen. When the image is at an indentation on the display, the image is operated by applying a relatively large pressure. When the image protrudes from the surface of the display, the image is operated by finger at proximity range. Thus, the 3D touch screen can be made to

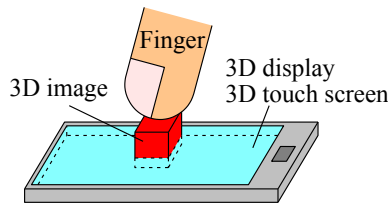


Fig. 1. The image of 3D touch screen in this research.

S. Tsuji is with the Electrical Engineering, Fukuoka University, 8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180 Japan (e-mail: tsuji@fukuoka-u.ac.jp)

T. Kohama is with the Electrical Engineering, Fukuoka University, 8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180 Japan.

respond to a 3D image on the display using a finger. Therefore, it may be the functional and usability interface because the 3D display interacts between the 3D ranges.

Previously, we proposed capacitive layered 3D touch screen [7]. In the proposed sensor, two-type capacitance sensors are layered. The sensor detects the non-contact object and its position (proximity range), and discriminates the materials and detects the indentation and its precise position during contact. However, the sampling time is increased according to the increasing of the measurement point because the proposed sensor measures the capacitance of all measurement point (all scan measurement).

In this paper, the method of reducing response time on the proposed 3D touch screen. We focused on the action that the finger touches the touch screen through the proximity range. The method is that the contact sensing points are selected by the proximity sensing results to reduce the measurement points. Thus, the sampling time can be reduced. In the experiment, the sensor detects the object and its position before contact (proximity range), and detects the indentation and precise position and is able to differentiate between materials in contact to confirm the basic characteristic of the proposed sensor. The reducing response time of the proximity and tactile sensor is considered using the characteristic of the proposed sensor and the proposed method which reduces the measurement point.

II. METHOD

Fig. 2 shows the diagram of the proposed sensor (3D touch screen) and the image for each measurement. In the proposed sensor, the plane-type capacitance sensor which consists of E_1 and E_2 and parallel-type capacitance sensor which consists of E_3 and E_4 are layered. The elastic body is set between E_3 and E_4 of the parallel-type capacitance sensor. The parallel-type capacitance sensor measures the capacitance (C_1) between E_3 and E_4 (Fig. 2(a)). Here, E_1 and E_2 are grounded as the shield. When the object approaches the sensor, C_1 does not change because E_1 and E_2 are grounded. When the object touches the sensor, C_1 changes according to the indentation which is equal to the distance between E_3 and E_4 . Thus, the indentation (x) is given by

$$x = \frac{d_0}{1 + C_{10}/\Delta C_1} \quad (1)$$

Here, ΔC_1 is the variation in C_1 when the object presses the sensor, d_0 is the steady-state distance between E_3 and E_4 , and C_{10} is the steady-state value of C_1 . Therefore, the sensor can detect the indentation (pressure) using Eq. (1).

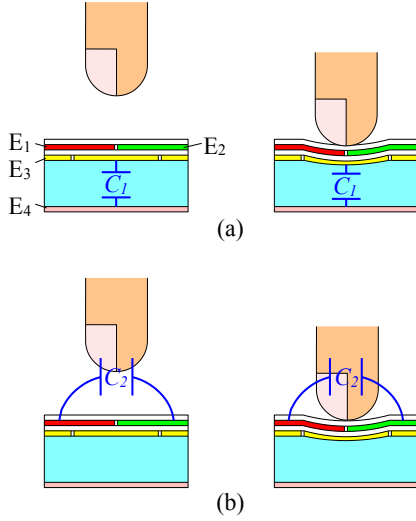


Fig. 2. Principle of proposed capacitance measurements. (a) The parallel plate type capacitance sensor. (b) The plane type capacitance sensor.

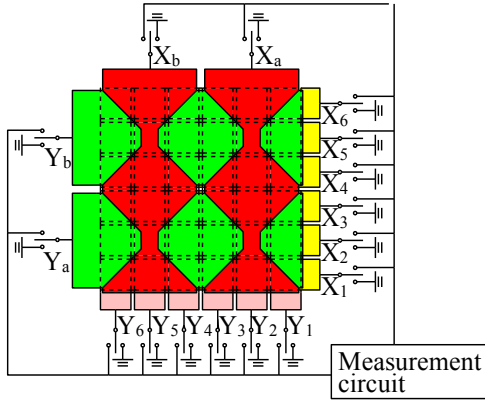


Fig. 3 The proposed method of the sensor.

The plane-type capacitance sensor measures the capacitance (C_2) between E_1 and E_2 (Fig. 2(b)). Here, E_3 is grounded as the shield. When the object approaches the sensor, C_2 changes according to both the permittivity of the object and the distance between the sensor and object. The measured capacitance consists of C_2 and the stray capacitance. Thus, the variation (ΔC_2) to ignore the stray capacitance is written as

$$\Delta C_2 = C_2 - C_{20} \quad (2)$$

Here, C_{20} is the steady-state value of C_2 . Therefore, the sensor can detect the object before the contact, and can distinguish the material in the object from ΔC_2 after the contact [7].

A large electrode is required to increase the sensitivity of electrical measurements. However, the separation between the electrodes needs to be reduced to realize high spatial resolution. Thus, we propose a structure in which the electrodes (E_1 and E_2) of the plane-type capacitance sensor are large to increase the sensitivity at proximity range, and the electrodes (E_3 and E_4) of the parallel-type capacitance sensor are small to realize a high spatial resolution on contact. Thus the measurement points of the plane-type capacitance sensor are fewer than parallel-types. Here, we focused on the action

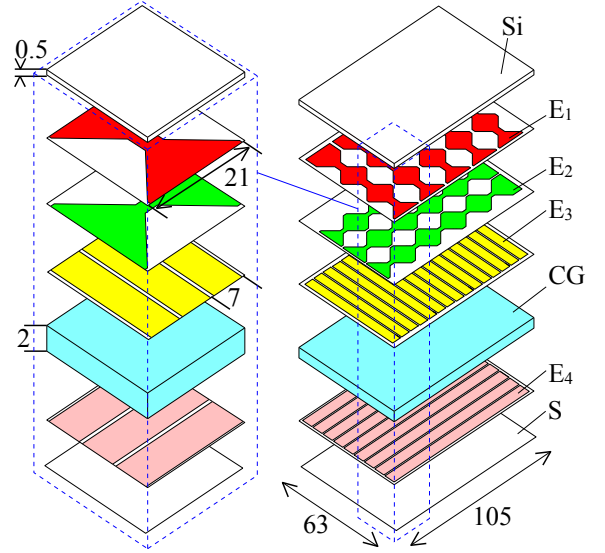


Fig. 4. Sensor structure. E: Electrode, S: Shield, CG: Clear urethane gel, Si: Silicone sheet. Dimensions in mm.

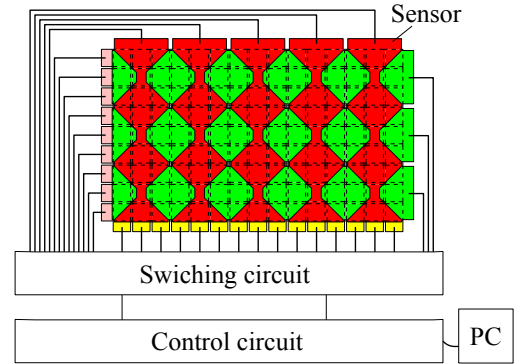


Fig. 5. Measurement system.

that the finger touches the touch screen through the proximity range. The method is that the contact sensing points are selected by the proximity sensing result to reduce the measurement points. The parallel-type capacitance sensor does not measure the capacitance to detect the indentation until the plane-type capacitance sensor detects object and its position in close proximity. When the plane-type capacitance sensor detects the object and its position in close proximity, parallel-type capacitance sensor measures the capacitance to detect the indentation on its position. For example, the all measurement point is 40 in case that the sensor consist of 2×2 ($X_a - X_b, Y_a - Y_b$) array of the plan-type capacitance sensor and 6×6 ($X_1 - X_6, Y_1 - Y_6$) array of the parallel-type capacitance sensor in Fig. 3. The plan-type capacitance sensor measures the capacitance between $X_a - X_b$ and $Y_a - Y_b$ (4 points) only until the plan-type capacitance sensor detects the object in close proximity range. In addition, when the plane-type capacitance sensor detects object and its position between X_a and Y_a in close proximity, parallel-type capacitance sensor measure the capacitance between $X_1 - X_3$ and $Y_1 - Y_3$ (9 points), and plane-type capacitance sensor measure 4 points of capacitance. Thus, the measurement points are reduced by the proposed method, and the response time on proximity and tactile sensor can be reduced.

III. PROPOSED SENSOR

Fig. 4 shows the structure of the prototype sensor. The sensor is arrayed with 5×3 units; one unit of the sensor consists of 3×3 electrodes for E_3 and E_4 and one pair for E_1 and E_2 . Thus, the prototype 3D touch screen consists of 5×3 electrodes for a plane-type capacitance sensor (15 measurement points) and 15×9 electrodes for a parallel-type capacitance sensor (135 measurement points). The size of this sensor is about 4.8 inches (105×63 mm). The electrodes are transparent ITO films to pass the image from the display. The transparent urethane gel (thickness: 2 mm, hardness: 5 (ASKER C), CG in Fig. 4) is set between E_3 and E_4 . A transparent silicone sheet (thickness: 0.5 mm, Si in Fig. 4) is placed on top of the sensor that is isolated from the object. The grounded ITO film functions as the shield (S) and is placed at the bottom of the sensor [7].

The capacitances are measured by a control circuit that consists of an analog switch (Analog Devices, ADG734), capacitance measurement IC (Analog Devices, AD7143), and microcomputer. The data (measured capacitances) are captured by the PC (Fig. 5).

IV. RESULTS AND DISCUSSION

A. Characteristic of the Proposed Sensor

We considered the characteristic of the proposed sensor. The objects (10×10 mm) are grounded conductors (GND) which is finger models and acrylic which is pen model. The position 0 mm is the contact point between the sensor surface and the object. The object is set to be at the center of the sensor. At first, we evaluated the proximity measurement using the proposed sensor. The distance (positions from 0 to 40 mm) between the sensor and object was changed by a robot arm. Fig. 6(a) shows the calculated indentation (x) obtained using Eq. (1) from ΔC_1 which was measured by the center electrodes of the parallel-type capacitance sensor (E_3 and E_4). Here, C_{10} was calculated using the capacitance measured at position -0.4 mm beforehand. Fig. 6(b) shows the variation (ΔC_2) which was measured by the center electrodes of the plane-type capacitance sensor (E_1 and E_2). In Fig. 6(a), x does not change as the distance varies between 1 mm and 40 mm (proximity range). In addition, x changes after contact. Thus, the sensor can detect the contact using x . In Fig. 6(a), the standard deviation (SD) of x was $8.6 \mu\text{m}$ when the object was far from the sensor. Thus, the sensor could detect the contact when the value changed by more than 3SD ($25.8 \mu\text{m}$). In Fig. 6(b), ΔC_2 changes according to the distance between the sensor and object. Thus, the sensor detected the object using ΔC_2 at proximity range. Thus, the sensor can detect the object before the contact using the change in ΔC_2 from the steady-state value (air). In Fig. 6(b), the SD of ΔC_2 was 14.7 digits when the object was far from the sensor. Thus, in the case of the grounded conductor, the sensor detected the object within approximately 20 mm. Thus, the plane-type capacitance sensor can detect that the object approach in the close proximity range.

Next, we evaluated the contact measurement. The distance (positions from 0 mm to -0.6 mm) between the sensor and

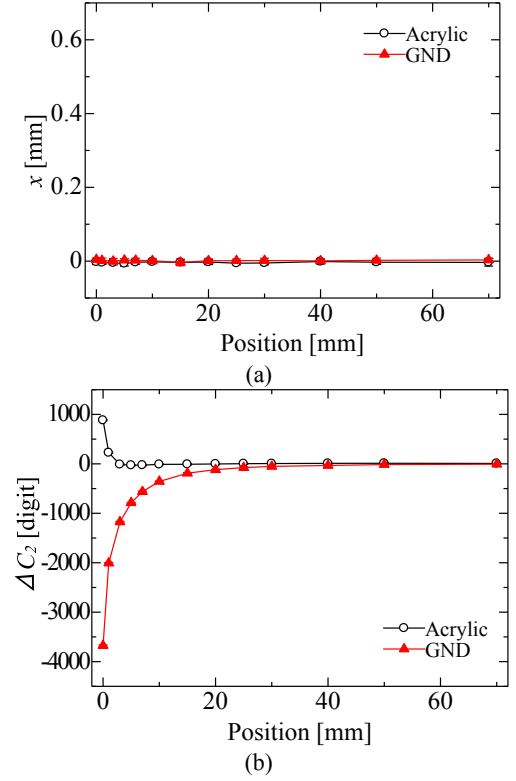


Fig. 6. Relationship between the position and the result at non-contact. (a) The parallel plate-type capacitance sensor. (b) The plane-type capacitance sensor.

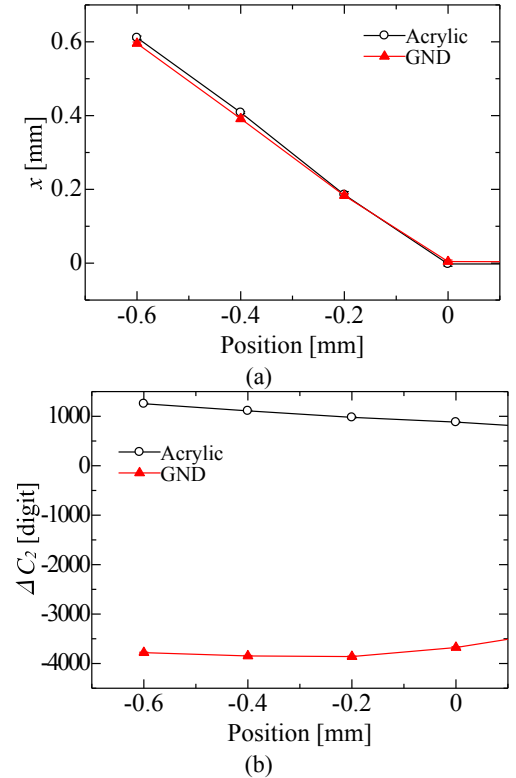


Fig. 7. Relationship between the position and the result on contact. (a) The parallel-plate type capacitance sensor. (b) The plane-type capacitance sensor.

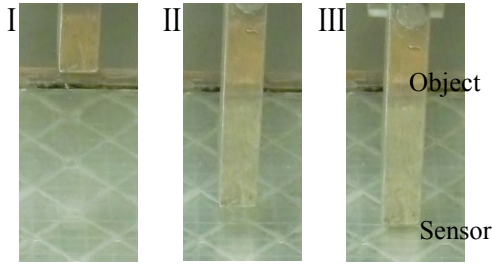


Fig. 8 The view of the approach and push with the object

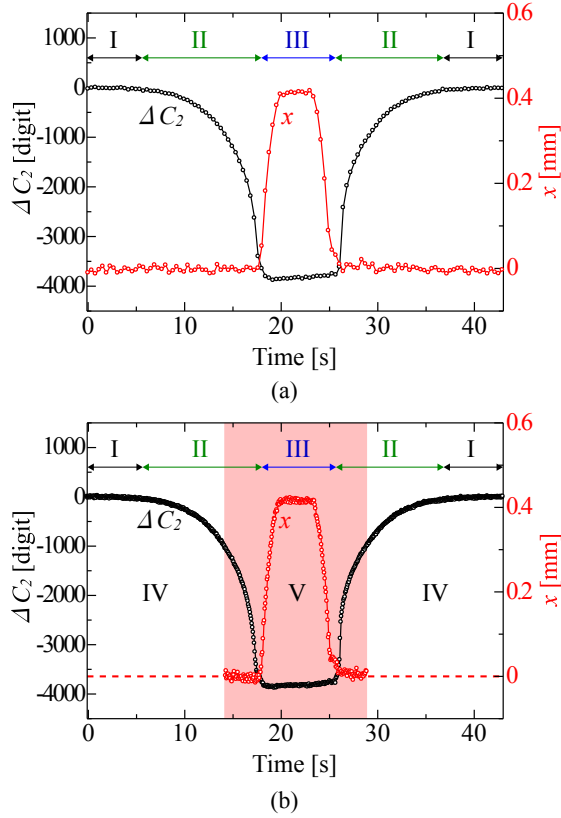


Fig. 9. The results of the proposed sensor. (a) All scan measurement. (b) Selective scan measurement.

object was changed by a robot arm. Fig. 7(a) shows x that was obtained using Eq. (1) from ΔC_1 which was measured by the center electrodes of the parallel-type capacitance sensor (E_3 and E_4), while Fig. 7(b) shows ΔC_2 which was measured by the center electrodes of the plane-type capacitance sensor (E_1 and E_2). In Fig. 7(a), x changes according to the indentation. In addition, x does not change with the permittivity of the object. Thus, the sensor can detect the indentation using x . In this experiment, the max measurement error of x was $30.3 \mu\text{m}$. In Fig. 7(b), ΔC_2 changes with the permittivity of the object. The values of the grounded conductor were low, while the values of acrylic were high. Thus, the sensor can discriminate between the grounded conductor and other. Here, the conductance of humans is high and a part of the human is grounded. Thus, the values of the finger were similarly changed as the grounded conductor. Therefore, the sensor recognized whether the object was a human (grounded conductor) or not [7].

B. Selective Scan Measurement

We evaluated the proposed method which is selective scan measurement on this proposed sensor. The object ($10 \times 10 \text{ mm}$) is grounded conductors (GND). The object is attached to a robot arm to control the position. In this experiment, the parallel-type capacitance sensor measures C_1 when ΔC_2 changes to 1000 digits and over as the object approaches the sensor in the close proximity range. In this experiment, the object is far from the sensor (Fig. 8 I), approaches in the proximity range (Fig. 8 II), presses the sensor (Fig. 8 III), and release the sensor. Fig. 9(a) shows the result on all scan measurement. Fig. 9(b) shows the result on selective scan measurement. ΔC_2 changes according to the distance between the sensor and object in the both all scan and selective scan measurement. In case of the all scan measurement, x is not changed without contact, and x is changed according to the indentation. Thus, the sensor can discriminate whether the object is in proximity range (Fig. 9 II) or not (Fig. 9 I). In addition, the sensor can detect indentation and recognize whether the object was a human (grounded conductor) or not (Fig. 9 III). In case of selective scan measurement, x is not measured until ΔC_2 changes to 1000 digits and over (Fig. 9(b) IV). In addition, when ΔC_2 changes to 1000 digits and over as the object approach the sensor in the close proximity range, the sensor measure C_1 , and calculate the indentation (colored area in Fig. 9(b) V). In this experiment, the sensor takes approximately 383 ms to obtain one complete cycle of all scan measurements that the number of measurement points is 150. On the other hand, it takes approximately 38 ms to obtain one complete cycle of selective scan measurements that the number of measurement points is 15 (parallel-type capacitance sensor) when the object is far from the sensor (Fig. 9(b) IV). And, it takes approximately 61 ms to obtain one complete cycle of selective scan measurements that the number of measurement points is 24 (parallel-type capacitance sensor (15 points) and plan-type capacitance sensor (9 points)) when the object is near the sensor (Fig. 9(b) V). In addition, it takes approximately 84 ms to obtain one complete cycle of selective scan measurements that the number of measurement points is 33 when the object push 2 points on the sensor. Thus, the method can reduce response time on proximity and tactile sensor.

V. CONCLUSION

In this paper, we proposed the method to reduce the response time of the tactile and proximity sensor. In this proposed method, we focused on the action that the finger touches the touch screen through the proximity range. The method is that the contact sensing points are selected by the proximity sensing results to reduce the measurement points. The sensor does not measure the indentation until the sensor detects object and its position in close proximity. When the sensor detects object and its position in close proximity, the sensor detects the indentation and its precise position in its position. Thus, the method can reduce response time on proximity and tactile sensor.

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