Compensation Algorithm for Misrecognition Caused by Hard Pressure Touch in Plastic Cover Capacitive Touch Screen Panels

Jaewook Kim, Hyeokjin Lim, Sanghyun Han, Yunho Jung, *Senior Member, IEEE*, and Seongjoo Lee, *Senior Member, IEEE*

***Abstract*—When a plastic cover is used on a touch screen panel, IoT (internet of things) equipment, a medium-large size touch screen and a curved surface touch screen can have availability of production. Accordingly, it allows a 75% cost reduction compared to adopting a glass cover. Cost reduction also enables many users to experience products including touch screen panels with lower prices. However, when applying pressure on a hard plastic cover, it takes more time to restore to the original state from the bent state compared to a glass cover touch screen. This aspect gets heavier depending on the intention of the pressure. In this paper, a correction algorithm that compensates for this defect is suggested. The retouching time can be reduced to one-sixth compared to not applying the proposed algorithm.**

***Index Terms*—Hard pressure touch, plastic cover, touch screen panel.**

I. Introduction

FROM internet of things (IoT) and wearable devices, it is shown that electronic devices are still in evolution in terms of convenience. The installation of the touch screen panel in electronic devices has become essential for users to deliver information as a user interface. Customers utilizing IoT or wearable devices, however, are under strain with regard to price, since the touch screen panel has to be additionally installed apart from basic functions.

The touch screen panel is a device that senses the position of a user's touch and provides the information on the touched position for a controller to control electronic equipment [1]–[8]. The touch panel can be categorized into five types: resistive, capacitive, saw, infrared, and optical. Among them, resistive and capacitive touch panels are widely utilized. The resistive touch screen panels are measuring the touch position by the applied pressure. Basically, it is usual to adopt the plastic cover in resistive touch screen panels, because the panels require very slow response time and single touch transaction (discontinuous and not moving) [1]. On the other hand, the capacitive touch screen panels are measuring the touch position by the change of the capacitance value and have drawn interest on high-end mobile devices such as smart phones because of its ability of multi-touch and fast response [1]–[2], [9]. These panels generally uses a glass cover [2], because the glass has a good surface hardness, rigidity and dielectric constant compared with the plastic [9]. Especially, the most of existing capacitive touch screen panels adopt a chemically strengthened special glass for a splinterless cover. For mass production, a method to cut a chemically treated special glass of a large size into many small ones is utilized. However, cutting the special glass is very difficult, which leads to making the production process complicated and increases the unit cost of production. It is possible to use plastic as cover material to ease this problem. Plastic is superior to glass in terms of weight, workability, and price, though it also has disadvantages in terms of transparency, surface hardness, and thermal resistance compared to glass. It is essential for IoT and wearable devices to reduce the cost of the cover material, since the cost of the covers takes upto 30 $\sim$ 50% of the selling price of the touch screen panel [9]. Adopting a plastic cover is easier to manufacture, and reduces the price compared to glass covers [9]. While the price of 4-inch glass cover is from \$1.50 to \$3.00 [22]–[23], a plastic cover of the same size costs only between \$0.40 to \$0.70. The cost of touch panel covers can be reduced by about 75% when changing material from glass to plastic [22]–[23].

Recently, there have been several studies on the use of plastic covers in touch panels. With high feasibility, the SILPLUS shows thermal resistance, surface hardness, and optical properties as good as glass [10]. Plastic covers, however, do not yet have the rigidity of glass ones. This means that the plastic cover will be bent more and longer than glass when the same pressure is applied. Unlike in the general touch condition, where a plastic cover can work well without bending, a plastic cover bends significantly, resulting in the distortion of sensing data when the touching pressure becomes stronger. A bent plastic cover reaches the sensing layer, which

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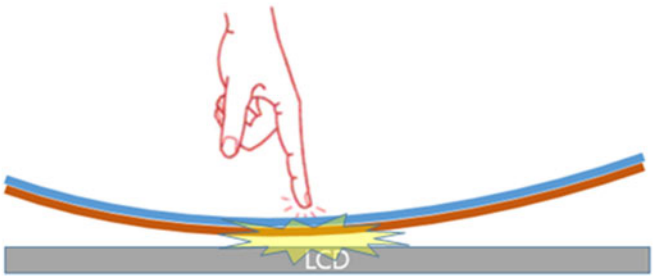

Fig. 1. Hard pressure touch situation in a touch screen panel with plastic cover.

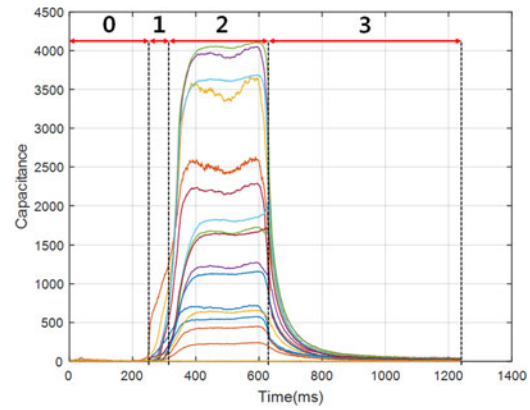

Fig. 2. Capacitance values under hard pressure touch situation.

senses touch entry, and the signal is distorted. Research on the problems caused by the bent plastic cover by hard pressure is still inadequate. This paper suggests an algorithm to solve the issue of applying hard pressure touch entry on plastic covers. In the proposed algorithm, the estimation of decremental function of touching capacitance is utilized under hard pressure touch, and the cancellation of residual capacitance caused by bent plastic covers considerably reduces the available retouching time interval.

II. Hard Pressure Error

Typically a capacitive touch screen panel consists of a cover window and sensing layer. When users put their finger on the cover window, the electric current flowing on the sensing layer is changed, consequently changing the capacitance value measured on the sensor. The touch controller measures the change and finds the touch point [11]–[19]. When the capacitance value, used to calculate touch position, is corrupted by noise, it is not possible to calculate the position accurately. In order to reduce noise, various data processing methods such as averaged data processing and middle value selections are utilized on existing touch screen panels [20], [21]. The existing correction algorithms, however, cannot remove the noise from signal distortion caused by bent plastic covers, because this noise has very high values and remains for a very long time.

Fig. 1 shows the phenomenon of bending a cover layer and sensing layer in a hard pressure situation. When hard pressure touch entry is applied on a touch screen panel with a plastic cover, both the plastic cover and the sensing layer are bent. If the pressure is high enough for the backside of the sensing layer to reach the LCD panel, the capacitance value of the touch sensor increases abnormally. Under hard pressure, an error is caused by the contact between the back side of touch layer and an LCD layer. This contact generates the actual value (sensing error), which can be highly detected by the touch controller, and it cannot be easily removed by existing simple noise cancellation methods [21].

Fig. 2 shows the capacitance values of sensors over time under the hard pressure touch. The touching causes a change of the capacitance value, which changes the RC time constant value, resulting in a change in the charging and discharging time. Because the charging and discharging time is directly related to the capacitance value of sensor, the capacitance value can be easily evaluated by measuring the charging and discharging time. In Fig. 2, the "Capacitance" in the vertical axis denotes the charging and discharging time, because it is directly related to the capacitance value. The unit in the vertical axis is a 1/40 us. In order to solve the hard pressure touch problem, we first divide the operation of the touch sensor into four modes by using the following equation:

$$OP_i = \begin{cases} 0 & \text{when } C_{k,i}\big|_{\text{all}} \le T_1 \\ 1 & \text{when } C_{k,i}\big|_{\text{any}} > T_1 \\ 2 & \text{when } \sum_{k=0}^{K-1} C_{k,i} > T_2 \\ 3 & \text{when } \downarrow C_{k,[i-m,\ i]}\big|_{\text{all}} \end{cases} \tag{1}$$

where, OP_i denotes the operation mode of the touch panel at the i-th sample position, and $C_{k,i}$ is the capacitance value of k-th touch sensor at the i-th sample position. $\downarrow C_{k,[i,j]}$ means that the capacitance values of k-th sensor are continuously decreased from the i-th sample to the j-th sample. $|_{\text{any}}$ and $|_{\text{all}}$ means that any one value just meets and all of the values should meet the required condition, respectively. T_1 and T_2 indicate threshold values and have to be decided by experiments, since these values can vary depending on several factors such as the sensor structure, the characteristics of cover material, the size of panel, and so on. From eq. (1), we can divide the operation mode of the sensor into four modes: 0 (ready mode), 1 (touch mode), 2 (hard touch mode), and 3 (post hard touch mode). The touch panel only can only enter the hard touch mode (mode 2) from the touch mode (mode 1) and do the post hard touch mode (mode 3) from the hard touch mode (mode 2). When none of the sensor channels have a capacitance value larger than the threshold value, T_1, the touch panel operates in the ready mode (mode 0). The touch panel enters the touch mode (mode 1) when a capacitance value of any sensor exceeds T_1. In the touch mode, the touch panel identifies a touch event and estimates the position of it. When the total value of capacitance in all sensor channel is over the threshold value, T_2, the touch panel goes to hard touch mode (mode 2). In the hard touch mode, the touch panel disables the identification of touch events, since the capacitance values are too high to be recognized and cause touch faults. When the capacitance in all sensor channels continuously decrease for m sample points, the post hard touch mode (mode 3) is declared. Since the fluctuation is severe around the off point of the hard touch, continuously decrementing the capacitance

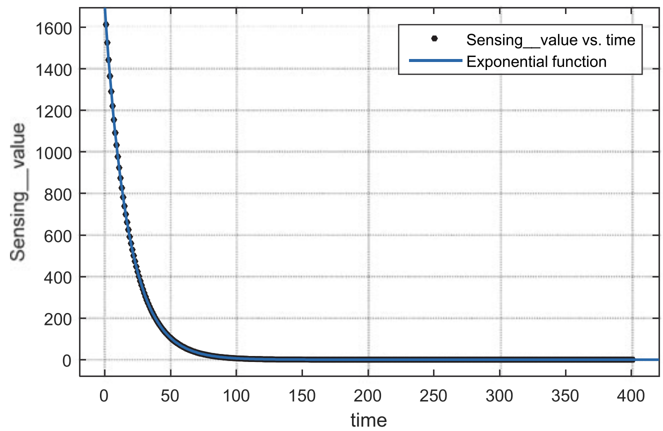

Fig. 3. Exponential decaying model and real sensing values.

in all sensor channels can allow the post hard touch mode to be robustly detected. The value of *m* can be set by the experiments.

The post hard touch mode is the decremental region of the remaining capacitance caused by the hard touch even after the touch is off. In the post hard touch mode, as shown in Fig. 2, the touch panel cannot detect a touch event due to remaining capacitance values higher than touch threshold values in all sensor channels even after the hard touch is physically completed. After all capacitance values are decreased less than the touch threshold, touch can be realized at last, and it takes time to realize any additional touch because of the long decay time of the remaining capacitance. This is a critical issue in touch panels with a plastic cover, and an efficient compensation algorithm is required to reduce the re-entry time of the touch even while consuming low computation power.

III. Compensation Algorithm

In order to reduce the re-entry time of the touch after the hard pressure touch, a method of decay prediction is applied to the existing touch panel with a plastic cover. Fig. 3 shows both an actual capacitance value of a sensor channel and an exponential expectation model over time in the post hard touch mode.

As shown in Fig. 3, the expectation model has good similarity to the actual data by extracting an exponential equation satisfying the minimum sum of square error (SSE) and root mean square error (RMSE) values. In order to obtain the coefficients of exponential function, two sample values are needed for each sensor channel after the hard touch is over. By utilizing the two sample values, the coefficients of exponential decaying function for *k*-th sensor channel can be given by following equations:

$$Y_{k,h} = a_k e^{b_k h} \tag{2}$$

$$Y_{k,h+10} = a_k e^{b_k (h+10)} \tag{3}$$

$$Y_{k,h+10} = Y_{k,h} e^{10 b_k} \tag{4}$$

$$b_k = \frac{1}{10} \ln \frac{Y_{k,h+10}}{Y_{k,h}} \tag{5}$$

$$a_k = \frac{Y_{k,h}}{e^{b_k h}} \tag{6}$$

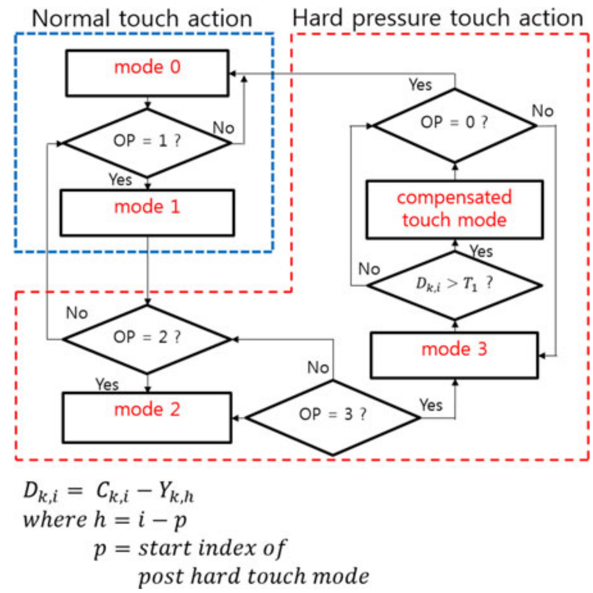

Fig. 4. Hard pressure touch algorithm flow chart.

where $Y_{k,h}$ and $Y_{k,h+10}$ denote the capacitance values of *k*-th sensor channel at the sample position when hard touch is off (*h*) and at the sample position after 10 samples from *h*, respectively. a_k and b_k are coefficient values of exponential decaying model. Equation (6) requires complex operation and high computation power, and has to be simplified in order to lower hardware costs. In our algorithm, the expectation model is applied just for the post hard touch mode, and the absolute sample index is not needed for *h*. The value of *h*, therefore, can be set to 0 (for initial time index), and eq. (6) can be simplified by

$$a_k = Y_{k,h} \tag{7}$$

By utilizing equations (2), (5), and (7), the exponential decaying model can be obtained and is applied for post hard touch mode. The proposed algorithm can effectively remove the remaining capacitance by the exponential model and can detect a touch event even in the post hard touch region without waiting until the capacitance of all sensor channels return to their normal state.

Fig. 4 shows a flow chart of the touch panel adopting the proposed compensation algorithm for hard pressure touch. In the flowchart, *OP* is given in the eq. (1). The operation of the proposed touch panel is divided into two actions: normal touch and hard pressure touch. In the normal touch action, a general touch algorithm is used. In the hard pressure touch action, the touch panel works in two modes: hard touch mode (mode 2) and post hard touch mode (mode 3). The hard touch mode disables the touch panel to prevent it from fault touch recognition. By utilizing the estimated decaying function in eq. (2), the post hard touch mode can remove the remnant capacitance values caused by the hard pressure touch. In the flowchart, $D_{k,i}$ means the compensated sensing data and can be obtained by the difference value between the sensing capacitance value and the predicted capacitance value. When $D_{k,i}$ is greater than T_1, the touch panel goes to compensated touch mode where the normal touch

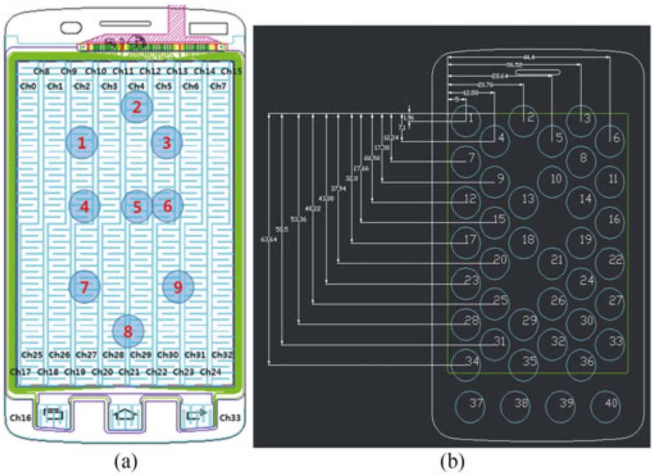

Fig. 5. Touch position (4 inch touch screen panel). (a) the touch data collecting position. (b) the conductive stick's position.

estimation can be evaluated by not the original sensing data, $C_{k,i}$, but $D_{k,i}$. By utilizing the proposed method, the touch panel can identify a touch event even under the severe interference caused by the hard pressure touch and reduce the recovery time considerably compared to conventional touch panels without the proposed compensation algorithm.

IV. Experimental Results

In order to verify the proposed algorithm, the proposed algorithm is applied for the real touch sensor panel with a plastic cover as shown in Fig. 5. The touch screen panel is actually used in a commercial low-end smartphone, which would be produced, and has the model number L30. The threshold values of T_1 and T_2 are obtained by experiments and are set to 300 and 2000, respectively. The value of m is set to 5.

As shown in Fig. 5, nine touch positions are example points tested for the evaluation of the proposed algorithm. In the test environments, 40 positions can be tested by using conductive sticks. The hard pressure error is the most severe in the central position of the touch panel, because the restoration time in the center is much longer than the edge. The nine positions around the center, therefore, are mainly evaluated. The experiment is executed for 1000 times on each position: 500 times with the human finger and 500 times with the conductive stick. The data get from the experiment are averaged for each position.

Fig. 6 is a picture of the experimental environments, and Fig. 7 is a picture of software that analyzes touch data. Fig. 7 shows the graphic user interface (GUI) of the simulator. This can express the sensing results in both numeric and graphic forms. Also it can display the sensing position on the virtual touch screen.

Fig. 8 shows the simulation result when there is an additional touch event after the hard pressure touch. The X-marked line is an original capacitance curve under a hard pressure touch situation, and the solid line is the proposed exponential decaying function, which is the expectation model extracted from the initial two sample values. The O-marked line shows the value

Fig. 6. Experimental environments.

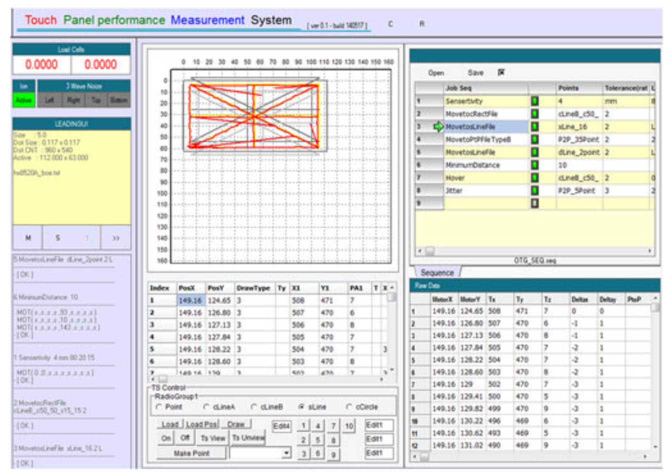

Fig. 7. Simulation screen.

TABLE I
Detection Probabilities of Touch Event in the Post Hard Touch Mode

Property	100 ms	300 ms	600 ms
Without proposed algorithm	11%	20%	78%
With Propose algorithm	93%	100%	100%

subtracted the exponential expectation model from the original capacitance. As shown in Fig. 8, since the touch event can be detected when the capacitance of sensor channel goes from the low value over the threshold value, T_1, the touch event cannot be identified by the original capacitance value, X-marked line, which is always higher than T_1. On the other hand, the compensated capacitance, O-marked line, goes down to near zero values even in the post hard touch mode (prior to 100 sample points) and can detect the touch event properly at about 100 sample points.

Table I is the detection probability of a touch event in the post hard touch mode. The experimental data are acquired when a touch screen panel is retouched after 100 ms, 300 ms, and 600 ms from a hard pressure touch, and the test is repeated 1000 times for three retouch cases. The decision criterion

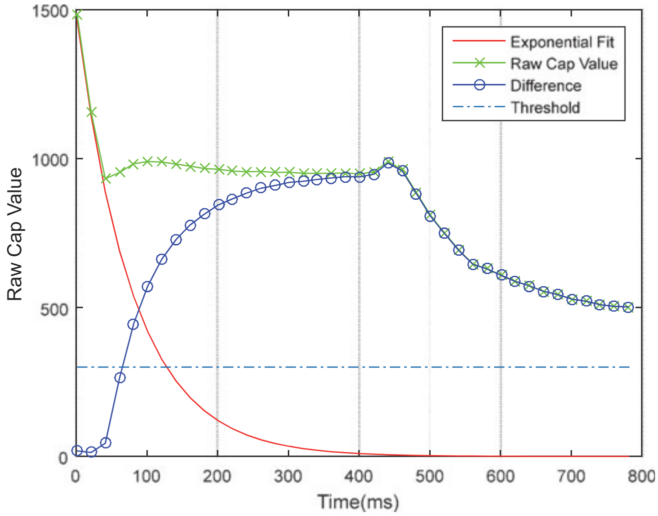

Fig. 8. Simulation result (hard pressure touch + additional touch).

of touch recognition is set when the recognized position is placed within ±2.5 mm from the original position. As shown in Table I, it is possible to reduce the sensing recovery time of the touch panel to 100 ms by applying the proposed algorithm to the existing touch panel. Unlike the proposed method, the touch panel without the proposed algorithm cannot detect a touch event properly even after 600 ms from the hard pressure touch. From the experimental results, it is shown that the proposed algorithm can remove the remaining capacitance caused by a hard pressure touch and can reduce the recovery time to 1/6 compared to the existing touch panel with a plastic cover. The proposed method is very useful for a touch panel with a plastic cover, in which the recovery time is a very important issue, compared to a glass cover.

V. Conclusion

This paper presented a simple compensated algorithm which could be implemented by a simple controller (MCU) and could ease the hard pressure touch error problem in touch panels with a plastic cover. The proposed algorithm identified the post hard touch mode and reduced the recovery time considerably by removing the remaining capacitance value effectively. From the experimental results, the recovery time of touch detection in the proposed panel was reduced to 1/6 compared to existing touch panels. By adopting the proposed method, the plastic cover could be applied on the middle and large size of a curved surface display and a low-price smart phone. In addition, it could make the production process easier compared with a glass cover and could have strong strength with respect to manufacturing costs. This benefit could make a plastic cover easily applicable to commercialized equipment, reducing users' strain when using IoT and wearable devices.

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