

# Multi-point Flexible Touch Sensor Based on Capacitor Structure Using Thin Copper-Plated Polyimide Film for Textile Applications

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**Abstract** A multi-point touch input sensor having different sizes or different capacitance touch points connected by only one pair of signal transmission lines was fabricated using a polyimide film coated with a thin copper plate. The capacitance increases with the decrease in the number of sheets of fabric spacers placed between the two sheets of the polyimide film. Therefore, the touch input sensor could be manufactured without fabric spacers, which was possible by the action of the polyimide film as a dielectric material in the capacitor. On the multi-point touch sensor, higher capacitance was obtained when pressing wider-area touch points with 10mm to 25mm diameter on average. However, the capacitance of a system comprising two sheets of touch sensors was considerably low, causing a serious overlap of the capacitance values according to the data collected from the reliability test. Although the capacitance values could be increased by stacking several sheets of touch sensors, the overlap of data was still observed. After reducing the size of all touch points to 10mm and stacking up to eight sheets of sensors, reliable and consistent capacitance data was obtained. Five different capacitance signals could be induced in the sensors by pushing touch points simultaneously.

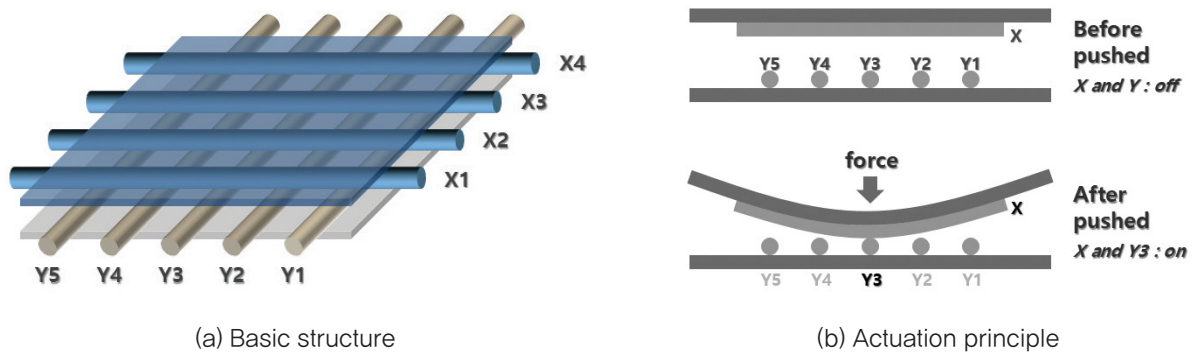
**Keywords** flexible touch sensor, wearable, polyimide, capacitance, convergence

## 1. Introduction

Recently, wearable technology has drawn significant attention, which has manifested as an increase in research and development efforts<sup>1-5</sup>. This technology allows the convergence of textile and IT fields. This approach has yielded a variety of devices that enable monitoring the health state and activity of users by using sensors and communication devices, such as miniature resistance strain gauges, fiber optic sensors, piezoelectric sensors, micro-electromechanical systems sensors, heart rate sensors, and temperature sensors, to name a few<sup>6-12</sup>.

The most fundamental and common component of a wearable device is the input control unit that senses

and distinguishes touch signals of users and relays them to the other part of the device as electric current. In addition, the input control unit should have the flexibility to be applied in textiles and clothing as well as sufficiently high sensitivity. There are two main types of wearable touch sensors for signal input. One type is on/off switching sensors, and the other is piezoelectric sensors, which generate charges and voltage in response to force and pressure applied to a piezoelectric component<sup>13-15</sup>. The actuation principle of both types of wearable touch sensors involves sensing the change in electric current or resistance arising at intersection points between conductive lines aligned in X- and Y-axis directions(Figure 1). Therefore, to fabricate many touch points on wear-

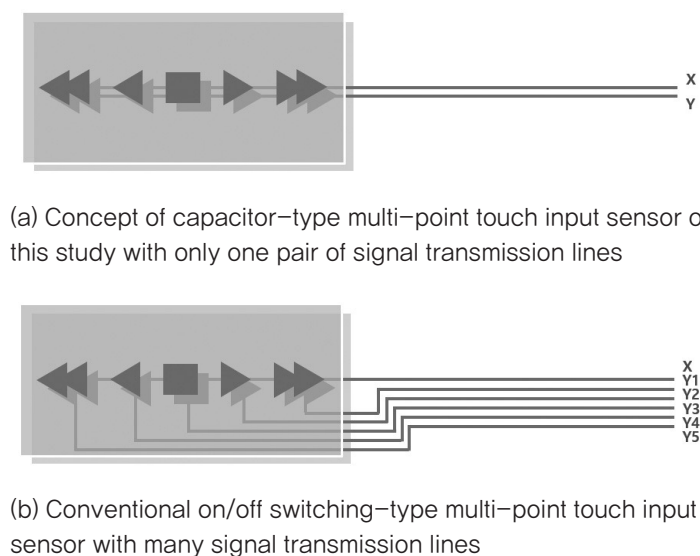


**Figure 1.** Conventional XY axes intersection-type on/off touch sensor.

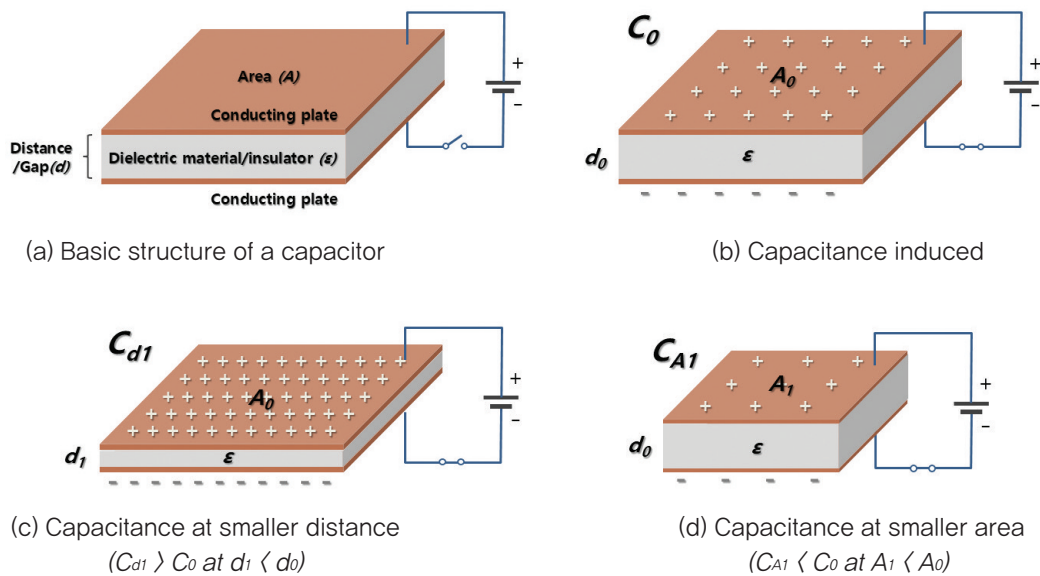
able input devices, the number of signal transmission lines must be increased in proportion to the touch points, which is an arduous and undesirable task in the field of wearable technology. Nevertheless, it is fundamentally and theoretically impossible to reduce the number of transmission lines while using conventional XY intersection touch sensors. Hence a new approach to touch sensors is required. In this study, several touch input signals were unambiguously distinguished using only one pair of signal transmission lines by using a capacitor made of a flexible polyimide film coated with a thin copper plate (Figure 2).

The capacitor is an electronic component with the ability to accumulate electric charges when voltage is

applied to two thin conducting plates separated by a dielectric material (Figure 3 (a)). The capacitance of a capacitor is related to its geometry and is given by the equation  $C = \epsilon A/d$ , where  $C$  is the capacitance,  $A$  is the area of the thin conducting plates connected to electric power,  $\epsilon$  is the dielectric constant of the dielectric material inserted between the two conducting plates, and  $d$  is the distance between the two conducting plates separated by a dielectric material<sup>16-20</sup>. According to the equation, the larger the surface area ( $A$ ) of the conducting plates, the narrower the inter-plate distance ( $d$ ), and the higher the dielectric constant ( $\epsilon$ ), the higher is the resulting capacitance ( $C$ ). Using the above, a capacitor-type touch input device can be



**Figure 2.** Capacitor-type multi-point touch input sensor of this study with only one pair of signal transmission lines (a) different from conventional on/off switching-type sensors with many signal lines (b).



**Figure 3.** Basic structure of a capacitor (a) and its capacitance induced under different conditions (b) ~ (d).

fabricated. For example, when a user presses a specific touch point with a certain area ( $A_0$ ) of conducting plates, the distance ( $d_0$ ) become narrower ( $d_1$ ) and then a higher capacitance ( $C_{d1}$ ) is induced in a sensor than that ( $C_0$ ) in the unpressed condition (Figure 3 (b) and (c)). If a smaller area ( $A_1 < A_0$ ) of the conducting plates is pressed, much smaller capacitance ( $C_{A1} < C_0$ ) is induced in the sensor than when a larger area ( $A_0$ ) is pressed (Figure 3 (b) and (d)).

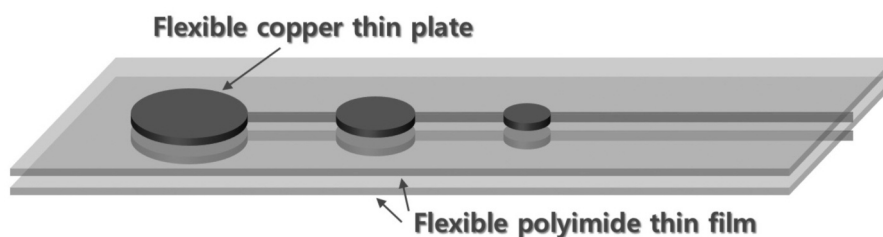
By connecting the capacitors having different areas of conducting plates and resulting different capacitances with only one pair of signal transmission lines, an input device that can sense and distinguish multi-point touch can be fabricated with the least number of transmission lines. In addition, by using flexible ma-

terials such as a thin polyimide film coated with copper plate, a wearable application can be designed as shown in Figure 4<sup>21)</sup>.

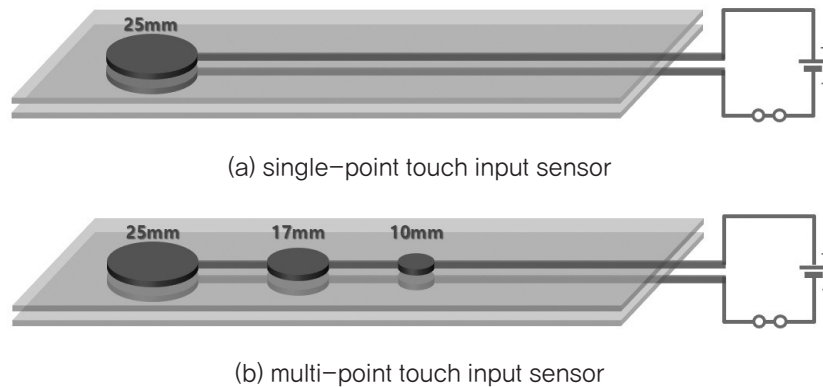
## 2. Experimental

### 2.1 Materials

A thin polyimide film (30 $\mu$ m) coated with a copper plate of thickness of 40 $\mu$ m on one side was used to fabricate the capacitor-type touch input sensors. To etch out the copper plate from the film as designed, iron (III) chloride hexahydrate was used. For use of flexible spacers between two conducting plates of capacitors, standard textile fabrics such as polyester (ISO 105-F04 Adjacent fabric, thickness 350 $\mu$ m) and cotton (KS K 0905, thickness 280 $\mu$ m) were used.



**Figure 4.** Concept of capacitor-type multi-point touch input sensor of this study having conducting plates of different areas or different capacitances with only one pair of signal transmission lines.



**Figure 5.** A single-point touch input sensor having a 25 mm touch point (a) and a multi-point touch input sensor having three different-sized touch points of 10, 17, and 25mm (b).

## 2.2 Design and implementation of a circuit pattern of touch input sensors

A circuit pattern design of touch input sensors with three round-shaped interconnected touch points with diameters of 10, 17 and 25mm was printed on wax-coated paper using a desktop laser printer. The black toner of the printed circuit pattern on the wax-coated paper was transferred thermally to the copper plates coated on the polyimide film. Subsequently, the pattern-transferred film was chemically etched in a 40% iron (III) chloride hexahydrate aqueous solution at 40°C for 60 min to remove the copper plate on the unprinted area and to keep it as pattern-designed. Finally, a flexible circuit pattern of the touch input sensor was obtained after washing the film with tap water.

## 2.3 Measurement of capacitance induced on touch input sensors

The obtained pair of touch sensor films were stacked up and overlapped perfectly for inducing capacitance. Figure 5 shows a single-point touch sensor circuit (a) having a 25mm diameter touch point, and a multi-point touch sensor circuit (b) having three different diameter touch points connected in one pair of signal transmission lines. The obtained pair of touch sensor films were stacked up and overlapped perfectly and then wrapped tightly with polyethylene film membranes to protect and not to move the sen-

sor films inside. A 100g standard metal weight of cylindrical shape with 20mm diameter was used to press the touch points for inducing capacitance except for reliability tests by a lot of human testers. When buttons and switches were pushed by human fingertips, its pressure forces range within 50~150gf in general, which was previously investigated. The capacitance was measured using a multi-meter (FLUKE 8846A 6-1/2 Digit Precision Multi-meter). As needed, the capacitance was measured with or without flexible fabric spacers inserted between a pair of flexible touch input sensors.

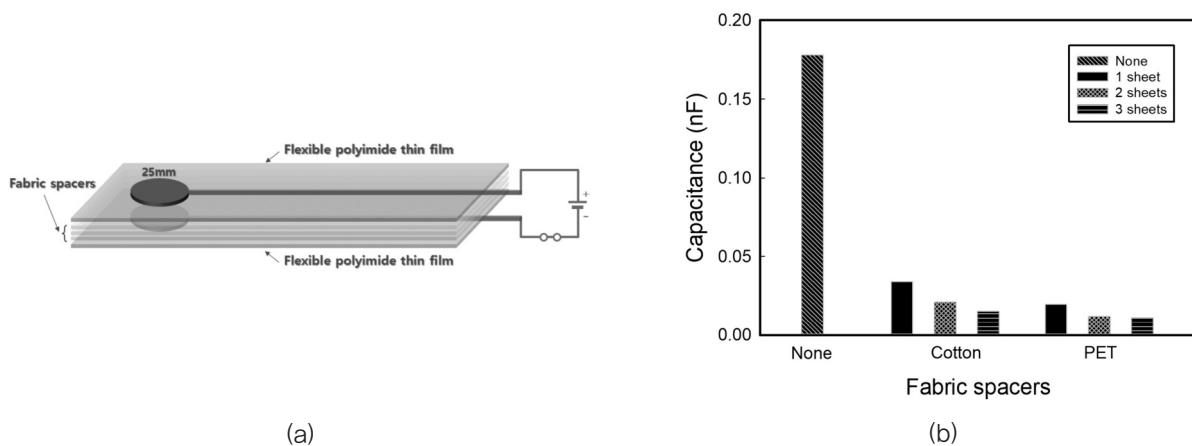
## 2.4 Performance reliability of the touch input sensors

For practical applications, the capacitance should be measured reliably and consistently over multiple pushing trials for different magnitudes and patterns of applied force. Therefore, in this research, the experimental results of 30 testers were collected on the same touch input sensor with each tester performing three trials. The average and deviation of the 90 data values were plotted in the Figures.

# 3. Results and Discussion

## 3.1 Effect of fabric spacers on capacitance

Even when a touch point is unpressed, a small capacitance is induced. This is because regardless of



**Figure 6.** A single-point touch input sensors having fabric spacers inserted (a) and its capacitance change according to the number of the spacer sheets under the pressure of a 100g standard metal weight (b).

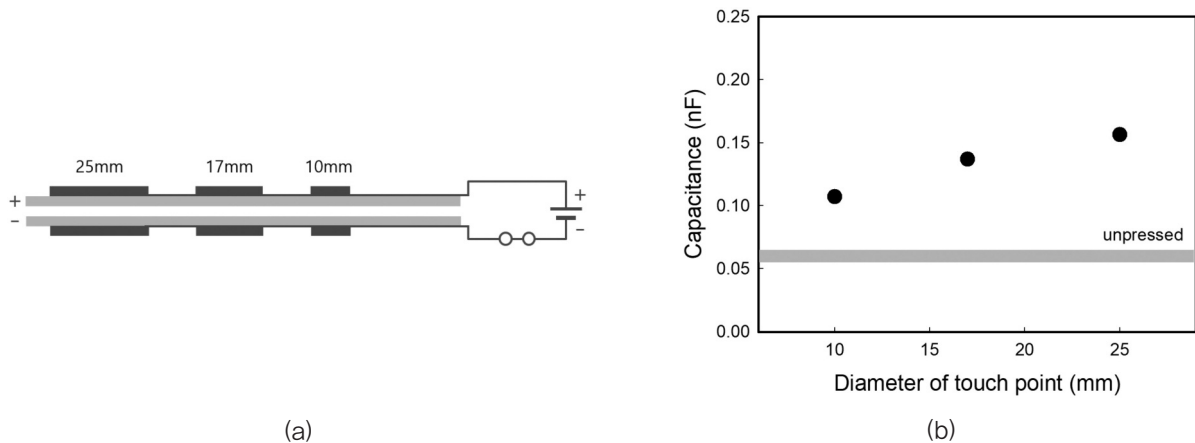
whether a touch point is pressed or not, the touch input sensor still has a capacitor structure with some distance between a pair of sensor sheets. When unpressed, a small initial capacitance ( $C_0$ ) is induced by the initial distance ( $d_0$ ), but when pressed, a larger capacitance ( $C_1 > C_0$ ) is induced by the smaller distance ( $d_1 < d_0$ ). It is important to make the difference of capacitances in the pressed and unpressed conditions large. To make the initial capacitance as small and constant as possible, the effect of fabric spacers such as cotton and polyester on the capacitance was investigated. In turn, 1, 2 and 3 sheets of fabric spacers were inserted between a pair of single-point touch input sensors with a conducting plate of 25mm diameter. The capacitance was measured by applying a constant pressure on the touch point using a 100g standard metal weight and the results are shown in Figure 6.

According to the capacitance equation presented earlier, the capacitance is affected by the dielectric constant ( $\epsilon$ ) of inserted materials, distance ( $d$ ) between the two conducting plates, and surface area ( $A$ ) of the plates. In this experiment, since the surface area ( $A$ ) is maintained constant at 25mm, the capacitance is determined by  $\epsilon$  and  $d$ . According to Figure 6, the capacitance with the cotton fabric spacer was higher than that with polyester spacers. This is attributed to

the higher dielectric constant and smaller thickness (distance) of cotton fabric spacers. The dielectric constant and thickness were 3.2~3.5F/m and 280 $\mu$ m for cotton spacer and 2.0~2.2F/m and 350 $\mu$ m for polyester spacer. More importantly the capacitance becomes higher with the decrease in the number of sheets of fabric spacers. This means that the touch input sensor without fabric spacers might be inducing higher capacitance than that with the spacers-inserted. Fortunately, the polyimide thin film used as a substrate of the copper plate could function as a dielectric material separating the conducting plates. Therefore, the capacitance without fabric spacers was measured and consequently, a higher value of 0.18nF was obtained compared to the value less than 0.03nF with the spacer-inserted. This is considered to be because of a narrow natural gap between two sensor sheets to be pressed, since the two sheets of touch input sensors made of thin copper-plated polyimide films are not ideal flat planes. This gap is thought to become narrower when pressed by the standard weight and restored when the pressure is removed.

### 3.2 Capacitance of multi-point touch sensors

According to the capacitance equation, it is natural that capacitance increases with the increase in the surface area of a touch point which is a conducting



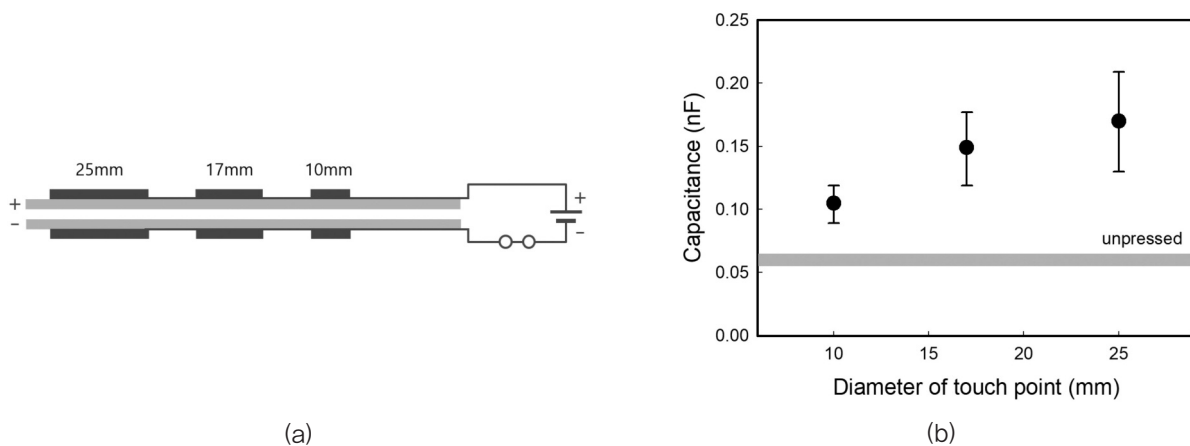
**Figure 7.** A multi-point touch input sensor (a) and its capacitance according to the diameter of the touch points under the pressure of a 100g standard metal weight (b).

plate collecting electric charges on it. The aim of this study is to connect the different-sized touch points together with only one pair of signal transmission lines and to distinguish the point from which the capacitance signal originated. Therefore, as shown in Figure 5 (b) previously, the capacitance of two perfectly overlapped sheets of multi-point sensors having round-shaped touch points with three different diameters of 10, 17 and 25mm connected to only one pair of signal transmission lines was measured by applying constant pressure using the standard weight. Since higher capacitance was induced when no spacer was inserted as shown in Figure 6, no additional spacer was inserted in this experiment. The polyimide thin film itself, which is used as a substrate of the copper plate, plays the role of a dielectric material in this sensor structure.

Figure 7 displays the measured capacitance for a multi-point touch sensor. In spite of pressing by the equal standard weight, higher capacitance was obtained when pressing wider-area touch points, showing approximately 0.11nF at 10mm point, 0.13nF at 17mm, and 0.16nF at 25mm on average. Even when any touch point was unpressed, a small initial capacitance ( $C_0$ ) of approximately 0.055~0.065nF was induced because of the natural gap ( $d_0$ ) between the two sheets of touch sensor films. Because the touch

sensor thin film is not an ideally perfect flat plane, the natural gap always exists even when the touch points are unpressed. However, when one of the three touch points is pressed, the gap between the two sheets of sensor films at that position become narrower ( $d_1 < d_0$ ) than in the unpressed condition. This induces a higher capacitance ( $C_1 > C_0$ ) according to the equation.

For practical applications requiring reliability, the measured values of capacitance should be within a limited narrow range for a given touch-point, regardless of the force magnitude and push patterns applied by users. In this experiment, each of the 30 testers tested the multi-point touch sensor by pressing each point three times without any preconception. According to Figure 8, the linear relationship between the diameter of the touch points and the capacitance induced is identical to the results shown in Figure 7, which were obtained from one tester. However, every value of the capacitance obtained from 30 testers, that is 90 data values for each touch point, was significantly deviated from the others and, moreover, the range of deviation overlapped with the data of adjacent touch points, making it difficult to distinguish which point the capacitance signal originated from. For example, for the measured capacitance of 0.15nF, it was impossible to determine which touch point was pushed. This is because 0.15nF can be obtained from



**Figure 8.** A multi-point touch input sensor (a) and its performance reliability of capacitance by 30 testers according to the diameter of the touch points (b).

both 17mm and 25mm points shown in Figure 8.

To manufacture reliable wearable touch input sensors practically, the slope of the linear relationship between the diameter and capacitance must be as large as possible and the deviation of data at each point must be as small as possible.

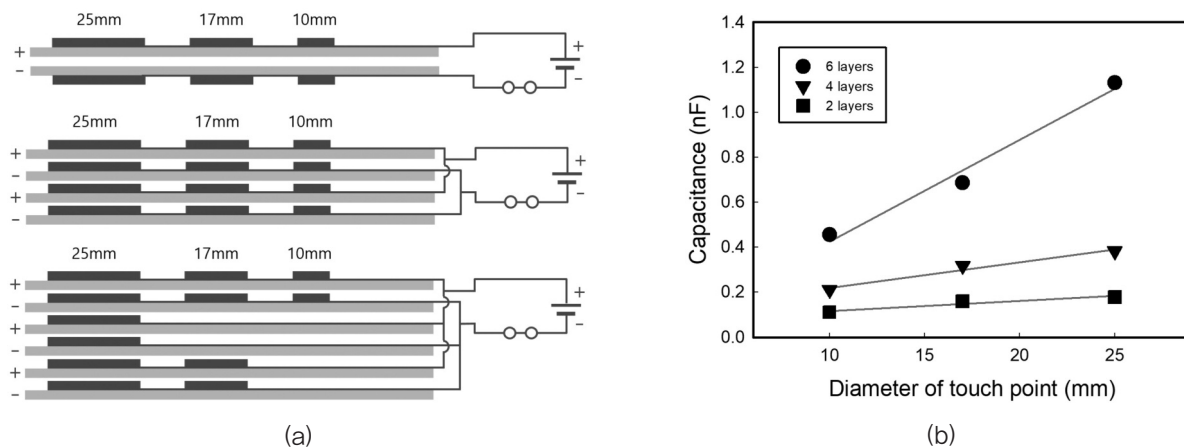
### 3.3 Enhancement of capacitance by multiple stacking of sensor sheets

The easiest method to enhance capacitance is to increase the surface area ( $A$ ) of touch points. In addition, to obtain a considerable difference between the capacitance values induced at the three touch points, it is possible to make the 10mm touch point as small as possible and to make the 25mm touch point as large as possible. However, there are some problems associated with increasing the touch-point diameter above 25mm and with decreasing it below 10mm. First, the size of a fingertip that pushes a touch point is limited to 10~15mm in most people. Second, a wearable sensor and the corresponding wearable device will increase in size if the touch-point diameter exceeds 25mm and this would make the device unattractive aesthetically. Finally, decreasing the size below 10mm would not distinguish the capacitance signals from those obtained in the unpressed condition.

To increase the effective surface area of touch

points without increasing the apparent diameter, the touch sensor sheets were stacked in four to six layers with complete overlapping rather than in two layers, as done before. This configuration yields results that would be obtained for touch points with diameters scaled by a factor of two to three. In particular, in the case of a stack of six sheets, the smallest 10mm touch point was stacked in two effective sheets, the touch point with a diameter of 17mm was stacked in four effective sheets and the largest 25mm point was stacked in six effective sheets, for maximizing the slope of capacitance change. The “effective sheets” means the number of sheets of copper plates not polyimide films. Even though six sheets of polyimide films were stacked, the number of sheets of copper plates could be two, four, and six as necessary (Figure 9 (a)). In this stacked configuration, electrodes must be connected alternatively (+ - + -), as concluded by preliminary experiments. Figure 9 (a) shows the structure configuration of touch sensor sheets and (b) shows that the increase in the absolute magnitude and the slope of capacitance change with the increase in the number of sheets in the touch sensor from two to six sheets.

By stacking sensor sheets, it was possible to enhance the capacitance and its slope of change according to the diameter of touch points. Therefore, a



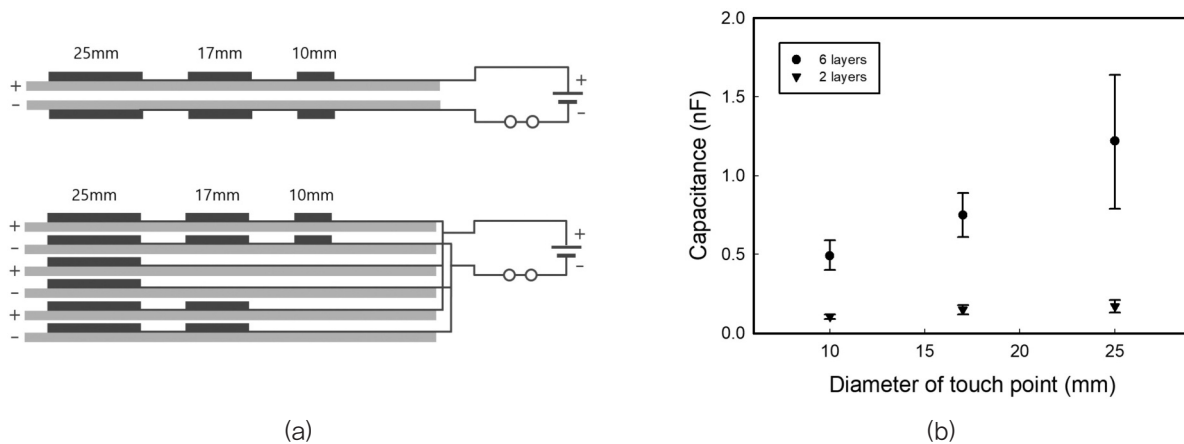
**Figure 9.** Multi-point touch input sensors layered by 2, 4, and 6 sheets (a) and their capacitances according to the diameters of the touch points under the pressure of a 100g standard metal weight (b).

reliability test was also performed here again. Figure 10 shows the results of the reliability test for the touch sensor with a stack of six sheets compared with the results with two sheets of sensors obtained at Figure 8. This test was also conducted by 30 different testers with each person pressing three times at each point. Figure 10 shows that the touch sensor with a stack of six sheets induces a significantly higher magnitude and slope of capacitance change compared with the prior touch sensor with a stack of two sheets. However, there was still a measureable overlap between the capacitances of different touch points, which was manifested in a severely wide deviation of capaci-

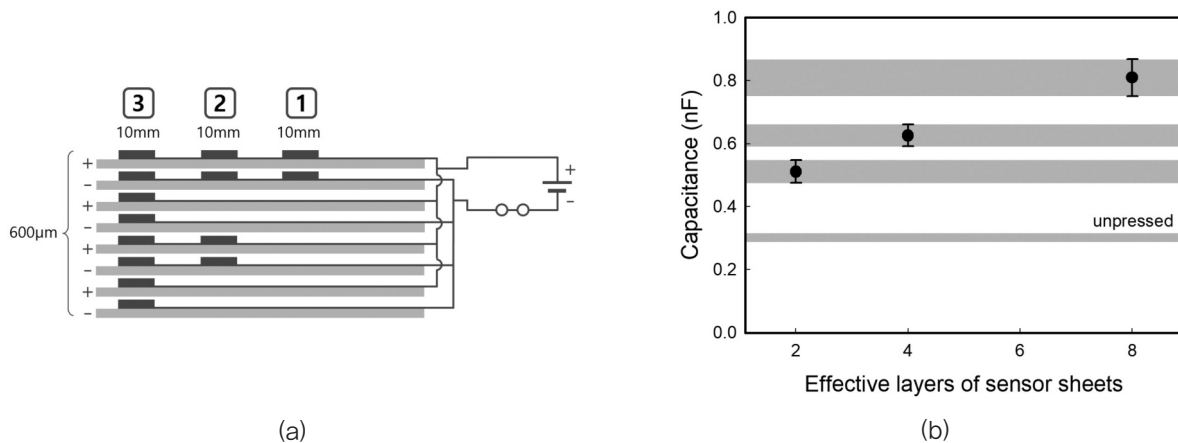
tances especially at larger touch points such as 17mm and 25mm. To manufacture reliable touch sensors, it is very essential to eliminate this overlap between the capacitance readings of different touch points.

### 3.4 Reducing deviation of capacitance data

According to the reliability tests in Figures 8 and 10, the larger the size of touch points, the wider is the deviation of capacitance resulting in an unwanted overlap of data. The deviation of capacitance is also affected by the force magnitude and the pattern of force application. For example, some testers pressed the touch points using their fingertips, while others



**Figure 10.** Multi-point touch input sensors layered by 2 and 6 sheets (a) and the performance reliability of capacitances by 30 testers according to the diameters of the touch points (b).

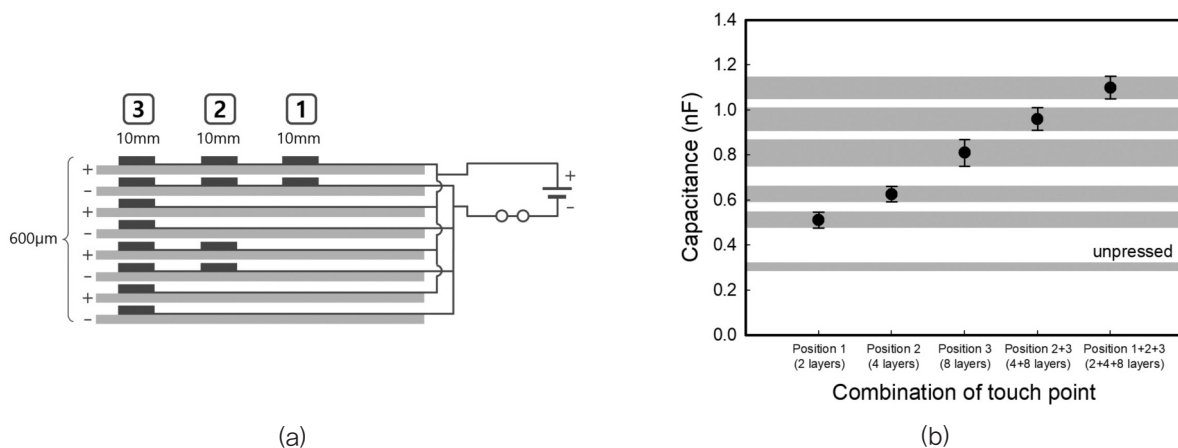


**Figure 11.** A multi-point touch input sensor layered by 8 sheets (a) and its performance reliability of capacitance by 30 testers according to the touch points (b).

applied pressure using the entire finger cushion. As seen from Figure 8 and Figure 10, the 10mm diameter touch point was least affected by the pushing pattern, because this touch point was very small, thus precluding any possible spatial effects. In contrast, the data of the 25mm diameter touch point was strongly affected by the pushing pattern. Therefore, in Figure 11 the diameters of all touch points were set to 10mm for minimizing their effect on the deviation of capacitance. In addition, the first touch point was stacked in two effective sheets, the second point was stacked in four effective sheets, and the third one was stacked in eight sheets, to yield a clear big difference in capac-

itance. Although eight sheets of touch sensors were stacked, the structure was still flexible and thin enough, with a thickness of less than 600µm. Thus, the structure is still suited for use in wearable devices. Each of the thirty testers tested the eight-layered multi-point touch sensor three times at each point, without any preconception, and the results are presented in Figure 11.

Even though the absolute capacitance values become lower than those of the structure with six-layers shown in Figure 9 or Figure 10, the measurements show no overlap with the data of adjacent touch points, and show a significant reduction in the devia-



**Figure 12.** A multi-point touch input sensor layered by 8 sheets (a) and its multi-touch effect on capacitance by combination of touch points by 30 testers (b).

tion of capacitance values.

### 3.5 Multi-touch effect by simultaneous pushing of touch points

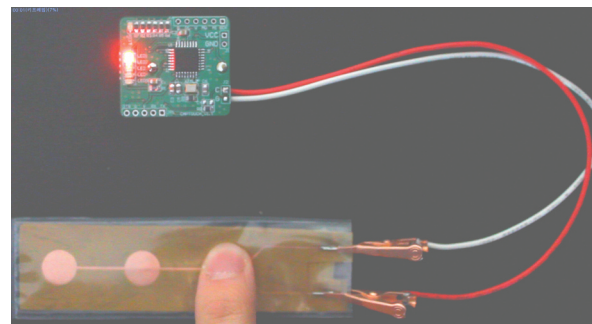
We were aware of the possibility of obtaining more capacitance signals without addition of any other touch point to the initial three. This can be done by pushing touch points simultaneously. For example, the second and the third touch points or all the three touch points can be pushed at the same time to induce much higher capacitance than that induced when pushing the points one by one. Consequently, five different capacitance signals could be obtained.

Figure 12 shows the reliability test results for these five combinations using three touch points obtained from 30 testers. The first three signals correspond to pressing the touch point one by one. The fourth signal was induced by pushing 4-effective-layered touch point of 2-position and 8-effective-layered touch point of 3-position simultaneously. The final fifth signal was obtained by simultaneously pushing all three touch points at once and this induced the highest capacitance. Pushing the 2-effective-layered touch point of 1-position and 4-effective-layered of 2-position together is not allowed because its capacitance is very similar to that of 8-layered touch point of 3-position. By the same reason, pushing the 2-effective-layered touch point of 1-position and 8-effective-layered of 3-position together is not allowed, either. The “effective layers” means the number of layers of copper plates not polyimide films. Even though eight sheets of polyimide films were stacked, the number of layers of copper plates could be two, four, and eight as necessary (Figure 11 and Figure 12). Consequently, five capacitance signals could be obtained with three touch points from the stacking structure of selectively etched copper-plated polyimide films connected by only one pair of signal transmission lines.

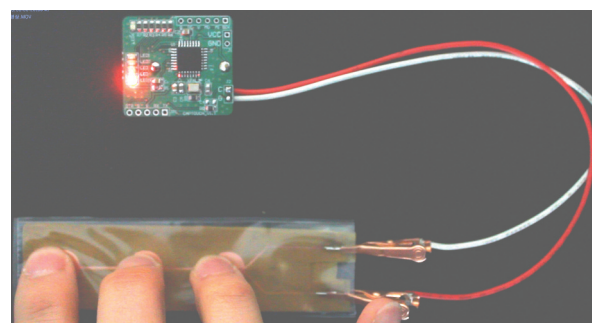
### 3.6 Actuating the final multi-touch input sensor

The optimized multi-touch input sensor was ob-

tained. From wearable point of view, application is the ultimate goal for commercializing. The multi-touch input sensor was demonstrated by actuating five LED lights of corresponding to five different signals only having one pair of signal transmission lines. The first, second, and third LED lights are activated by responding to press the first (2-effective-layered touch point of 1-position), the second (4-effective-layered touch point of 2-position) and the third touch point (8-effective-layered touch point of 3-position) one by one. It causes activation the fourth LED light that the second and the third touch points are pushed simultaneously. The fifth LED light is actuated by pressing all the three touch points. Figure 13 illustrate two cases of actuating the multi-touch input sensor on behalf of five cases of actuations. Figure 13 (a) shows that the first LED light is activated by pushing the first touch point, and figure 13 (b) shows that the fifth LED light is activated by pushing all the three touch points.



(a)



(b)

**Figure 13.** Actuation the first LED light by pressing the first touch point (a) and the fifth LED light by pressing all the touch points simultaneously (b).

## 4. Conclusions

A multi-point touch sensor consisting of touch points of different sizes or different capacitances with all touch points connected by only one pair of signal transmission lines was fabricated in this study. From the results of the effect of fabric spacers, it is clarified that the capacitance becomes higher with the decrease in the number of sheets of fabric spacers. This means that in the touch input sensor without fabric spacers inserted, the capacitance induced can be higher than that in a sensor with spacers-inserted.

In the fabricated multi-point touch sensors, a higher capacitance was obtained when pressing wider-area touch points, showing approximately 0.11nF at the 10mm point, 0.14nF at 17mm, and 0.17nF at 25mm on average. However, the capacitance of a system comprising two sheets of touch sensors was considerably low, leading to a serious overlap of the capacitance values according to the data collected from the reliability test.

By selective stacking of several sheets of touch sensors, it was possible to increase the absolute magnitude and the slope of capacitance change with the increase of the diameter of touch points from 10mm to 25mm. However, the overlap of capacitance values was still observed. After reducing the size of all touch points to 10mm and stacking up to eight sheets of sensors, reliable and consistent capacitance data was obtained.

Five different capacitance signals could be induced without addition of any other touch point to the initial three by pushing touch points simultaneously.

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