A Touchpad for Force and Location Sensing

Dong-Ki Kim, Jong-Ho Kim, Hyun-Joon Kwon, and Young-Ha Kwon

This paper presents the design and fabrication model of a touchpad based on a contact-resistance-type force sensor. The touchpad works as a touch input device, which can sense contact location and contact force simultaneously. The touchpad is 40 mm wide and 40 mm long. The touchpad is fabricated by using a simple screen printing technique. The contact location is evaluated by the calibration setup, which has a load cell and three-axis stages. The location error is approximately 4 mm with respect to x-axis and y-axis directions. The force response of the fabricated touchpad is obtained at three points by loading and unloading of the probe. The touchpad can detect loads from 0 N to 2 N. The touchpad shows a hysteresis error rate of about 11% and uniformity error rate of about 3%.

Keywords: Touch input device, touchscreen, touchpad, contact-resistance-type force sensor, contact force, contact location.

I. Introduction

Recently, personal computers, mobile phones, and other multimedia devices have evolved to become user-friendly even though they cover an increasing number of functions. Additionally, their structures and sizes are becoming more slim and miniaturized. Thus, the user requires a greater variety of user-friendly input devices, such as a mouse, keyboard, touchpad, and touchscreen. In particular, touchscreens and touchpads have developed rapidly for mobile phones and MP3 players because of their limitations regarding size. Since its use in the military in the 1970s, the touchpad has become an important part of the main input interface of mobile devices. After GlidePoint was commercialized in 1994, Apple adopted a touchpad as an input device for its ‘power book’ laptop computer. Touchpads have mostly developed through the improvements to its design and sensor.

Meanwhile, since Apple launched the smart phone, IPhone, the user interface (UI) is considered an important parameter that can appeal to users. However, most touch input devices, such as touchpad and touchscreen, can measure only contact location when a user touches the device. From the viewpoint of UI, the forthcoming touchpads and touchscreens require a force component and, if possible, a contact location. If an input device can sense force and position by contact and touch, some handset manufacturers can release a variety of mobile devices that can be used for communications and games. Particularly, when a human finger makes contact with a device, the intensity of the force can be used as a new function within the contents of a game player and mobile phone. Research on contact position and force using force/pressure sensors has been conducted in the fields of robotics and medical instruments [1]-[8]. In the case of a tactile sensor based on an array of force sensors, it is easy to simultaneously acquire the contact location and force by a scanning process using input and output signal

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lines [9]. However, it is difficult to apply a tactile sensor having many signal lines to a mobile device because of a phone's limited size. Therefore, it is necessary to decrease the number of signal lines in order to apply the tactile sensor to a mobile phone. On the other hand, in the case of an existing capacitive touchpad, it can also sense the position and force simultaneously. However, the force is essentially caused by changing the contact area when human fingers make contact with the device. Thus, it is not easy to sense the force of a pen because its contact area does not change with respect to touch. Additionally, the capacitive touchpad needs many signal lines related to an array of unit sensors to obtain the position and force. This paper presents an opaque input device similar to a laptop's touchpad using a contact-resistance-type force sensor, which can simultaneously sense a contact position and force.

II. Touchpad Design

Figure 1(a) shows the schematic drawing of a touchpad using a contact-resistance-type force sensor to obtain a contact location and force simultaneously. The sensor has two resistive layers and four conductive layers for signal lines. The design is similar to a 4-wire type touchscreen. When a contact point (CP) within the upper substrate, for example, CP 1, is pressed by a finger or pen at a certain pressure, the resistive layer of the upper substrate touches with CP 2 of the resistive layer within the lower substrate. When a resistive layer connects to two conductive layers, such as silver and copper layers, the resistive layer becomes a one-dimensional resistor in x-axis or y-axis direction. Thus, the upper and lower substrates have four electrodes: a, b, c, and d. Figure 1(b) shows the line resistances of x-axis and y-axis components and a contact resistance between CPs. The line resistances of an x-axis near electrodes are R_{x1} and R_{x2}. Meanwhile, the line resistances of y-axis near electrodes are, R_{y1} and R_{y2}. The contact resistance across CPs is R_z, which is caused by a change of the contact area under loading conditions. The contact location and force are obtained by measuring each line resistance in x-axis and y-axis and contact resistance. In order to measure the location component of x-axis, input voltage (V_{in}) is applied to electrode b, and electrode a is set to ground. Then, the output voltage (V_{out}) is measured at either electrode c or d. Thus, output voltage $V_{\text{out},x}$ can be expressed by

$$V_{\text{out},x} = \frac{R_{x1}}{\left(R_{x2} + R_{x1}\right)} V_{\text{in}}. \tag{1}$$

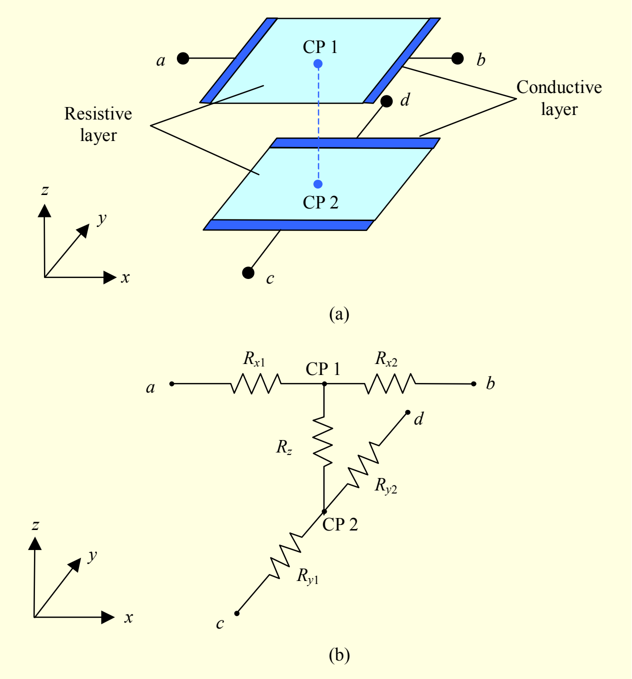


Fig. 1. (a) Schematic diagram of touchpad using contact-resistance-type force sensor and (b) its equivalent circuit composed of four line resistances and one contact resistance.

In the case of the y-axis component, an input voltage is applied to electrode d, and electrode c is set to ground. The output voltage $V_{\text{out},y}$ is measured at either electrode a or b and expressed by

$$V_{\text{out},y} = \frac{R_{y1}}{\left(R_{y2} + R_{y1}\right)} V_{\text{in}}. \tag{2}$$

The contact load can be obtained by using the contact resistance R_z between CP 1 and CP 2. An input voltage is applied to electrode a, and electrode c is set to ground. The output voltage V_{CP1} is measured by electrode b while electrode d is open. In a similar way, the output voltage V_{CP2} is obtained by signal line d while the other signal line b is open. The V_{CP1} and V_{CP2} output voltages can be expressed by

$$V_{\text{CP1}} = \frac{\left(R_z + R_{y1}\right)}{\left(R_{x1} + R_z + R_{y1}\right)} V_{\text{in}}, \tag{3}$$

$$V_{\text{CP2}} = \frac{R_{y1}}{\left(R_{x1} + R_z + R_{y1}\right)} V_{\text{in}}. \tag{4}$$

Finally, the voltage difference ΔV between V_{CP1} and V_{CP2} is obtained by

$$\Delta V = V_{\text{CP1}} - V_{\text{CP2}} = \frac{R_z}{\left(R_{x1} + R_z + R_{y1}\right)} V_{\text{in}}. \tag{5}$$

Figure 2 shows a design of a touchpad to measure contact position and force simultaneously. The input device is 40 mm wide and 40 mm long. Dot spacers are needed to maintain some distance between the upper and the lower substrate layers. The dot spacers (0.3 mm in diameter and 0.01 mm in height)

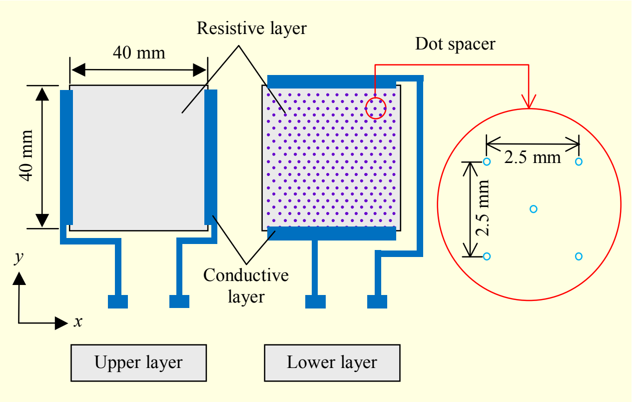


Fig. 2. Schematic design of touchpad having resistive layers and dot spacers.

are formed on a resistive layer of the lower substrate. The distance between spacers is 2.5 mm.

III. Touchpad Fabrication

Figure 3 presents the fabrication process of a touchpad using a silk screening technique. We use 50 µm polyethylene terephthalate film as the substrate of sensor (Fig. 3(a)). Before processing, the film is soaked in acetone for 10 min to get rid of organic debris. Next, the film is rinsed with methanol for 5 min to remove acetone. Methanol is rinsed with the DI-water. Then, the film is dried. The conductive layer, resistive layer, and dot spacer are coated by a screen printing technique. We use a semi-automatic printing machine by Linesystem Co., which uses a square-edge type squeegee. The hard squeegee is of polyurethane material having shore hardness (Hs) of 70 durometers because it is necessary to spread ink onto the screen mask. A conductive layer is formed on the rinsed film by using a silver ink (CMI Co.) (Fig. 3(b)). The mesh for silver printing is 300-mesh size. The coated film needs to be level at room temperature for 30 min. Next, the film is cured in an oven at 140°C for 10 min. A resistive layer using a carbon paste (CMI Co.) is coated one time (Fig. 3(c)). The mesh for printing is 250-mesh size. The coated film is cured in an oven at 150°C for 60 min after being leveled at room temperature for 30 min. Next, dot spacers using an UV ink (CMI Co.) are formed on the resistive layer (Fig. 3(d)). The mesh is 325-mesh size. The coated UV ink is cured in a UV light system for 1 min. We use a double-coated adhesive tape to bond both upper and lower substrates (Fig. 3(e)).

Figure 4 shows a touchpad using the fabrication process. The active area of the touchpad is 36 mm×36 mm because the coated width of the conductive layer is 4 mm. The line resistance between conductive layers is about 1.9 MΩ because the surface resistivity of the carbon ink is about 2 MΩ/□.

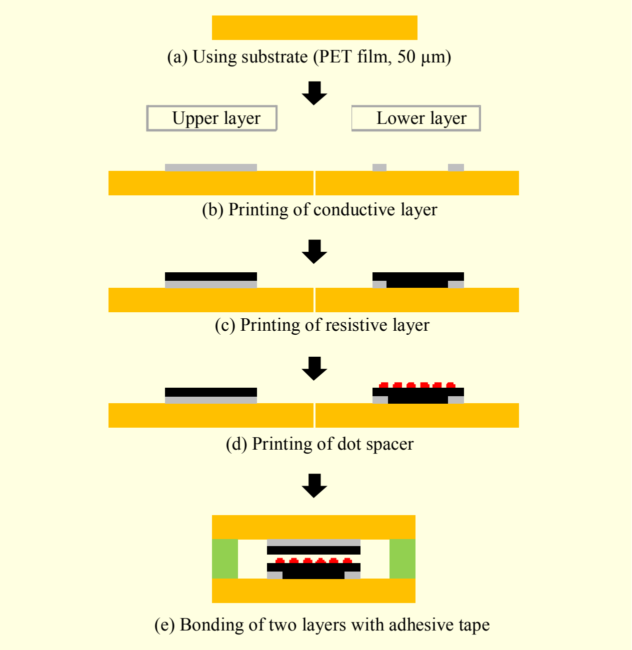


Fig. 3. Fabrication process of contact location and force sensing touchpad.

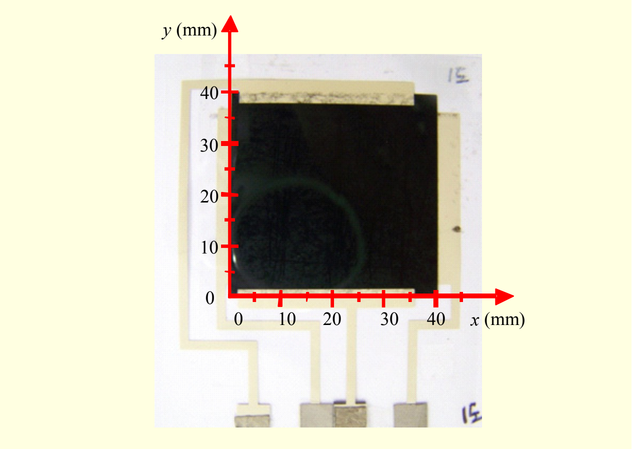


Fig. 4. Fabricated touchpad (40 mm wide and 40 mm long).

IV. Evaluation Setup

We use an evaluation system to obtain the location deviation of a touchpad and its force response under static load. Figure 5 shows the evaluation system that has a 3-axis load cell and 3-axis linear stages. The vertical force component, F_z (of the 3-axis load cell), is employed to measure the force response of a touchpad. The other components, F_x and F_y, are used to check the alignment between touchpad and the load cell under loading and unloading conditions. The capacity of a load cell is 50 N in F_x, F_y, and F_z components. The 3-axis linear stages can make the stage move in *x*-axis or *y*-axis directions and translate the stage to apply some load in the *z*-axis direction. We use a

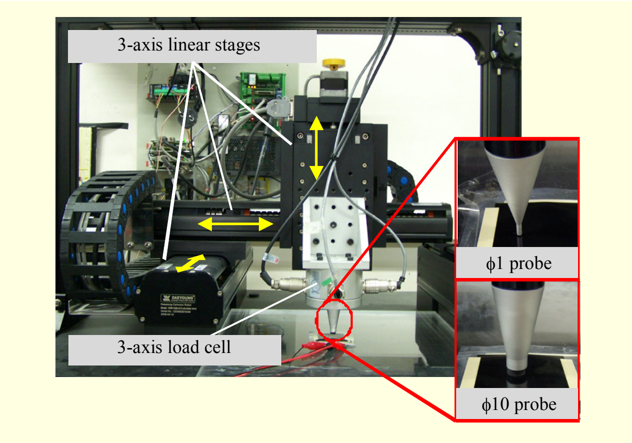
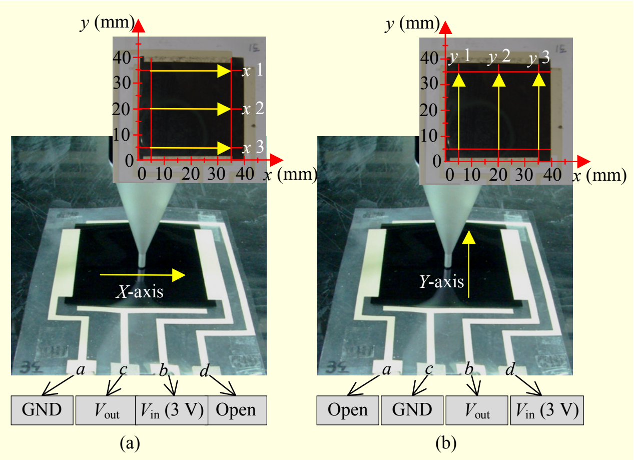


Fig. 5. Calibration setup having 3-axis load cell and 3-axis linear stages to evaluate contact location and force sensitivity of touchpad.



(a) (b)

Fig. 6. Electrical circuits for measurement of output voltage according to change of contact position: (a) *x*-axis direction and (b) *y*-axis direction.

probe of 1 mm in diameter to evaluate the resolution of the contact location. In case of a large probe, it is not easy to measure the exact resolution of a position because the error of the resolution tends to be large in proportion to the size of the probe. In the case of force response under static load, another probe of 10 mm in diameter is used. The range of motion of a linear stage in *z*-axis direction is 50 mm, and its position resolution is 1 μm. The calibration setup obtains the signal of the load cell and controls the motion of the linear stage to maintain an applying load. The amplifier (Instrument Division Co., Model 2310) amplifies the force signal and transmits it to a data acquisition board (National Instrument Co., Model PXI-6251). The software, LabVIEW, is employed to control the linear stage and obtain the sensor signal.

1. Evaluation of Deviation Error for a Touchpad

The touchpad is attached to the stage to measure the deviation of contact location in *x*-axis direction. Figure 6(a) shows an electrical circuit for evaluation of output voltage in the *x*-axis direction according to a change of contact position. First, an input voltage of 3 V is applied to the electrode *b* of the upper layer. The opposite electrode *a* is set to ground. When electrode *d* of the lower layer is opened, the output voltage is measured at electrode *c*. The stage moves vertically at a speed of 1 mm/min, and the probe of load cell makes contact with the upper layer of touchpad. As soon as the probe touches the surface of the touchpad, the load is increased until the signal of load cell shows 0.2 N. While the evaluation system maintains a constant load of 0.2 N, the data acquisition board records the output voltage related to the contact position of the touchpad. Next, the stage moves upward at a speed of 1 mm/min, and the load is finally removed. The stage moves 1 mm in the *x*-axis direction to evaluate a new contact position. The output voltage of path 1 shown in Fig. 6(a) is recorded in a similar way. The initial CP for the evaluation is 5 mm away from electrode *a*. Output voltages are measured every 1 mm until the final CP at 35 mm is reached. Additionally, path 2 and path 3 are also evaluated to check the deviation error of the contact location. Figure 6(b) shows another electrical circuit with respect to three contact paths in the *y*-axis direction. As in Fig. 6(a), an input voltage of 3 V is applied to electrode *d* of the lower layer. The opposite electrode *c* is set to ground. After electrode *a* of the upper layer is opened, the output voltage is measured at electrode *b*. The initial CP in *y*-axis direction is 5 mm from electrode *c*. The output voltages are measured every 1 mm until the final CP at 35 mm is reached.

2. Evaluation of Force Response for Touchpad

The calibration setup shown in Fig. 5 evaluates the force response under a static loading condition. Figure 7 presents an electrical circuit to measure the output voltage caused by contact resistance, R_z. The force response is calculated by (5) using V_{CP1} and V_{CP2}. In the case of output voltage V_{CP2}, an input voltage of 3 V is applied to electrode *b* of the upper layer, and then *a* opens. Output voltage V_{CP2} is measured at electrode *c* of the lower layer, and then electrode *d* sets to ground. In case of V_{CP1}, an input voltage of 3 V is applied to electrode *b* of the upper layer, and then electrode *c* of the lower layer opens. Output voltage V_{CP1} is measured at electrode *a* of the upper layer, and then electrode *d* of the lower layer is set to ground. The touchpad aligns with the probe of the load cell. The stage moves vertically at a speed of 1 mm/min until a load is reached to 2 N. The stage moves upward to remove the contact load. At the same time, the output voltage is recorded under loading and

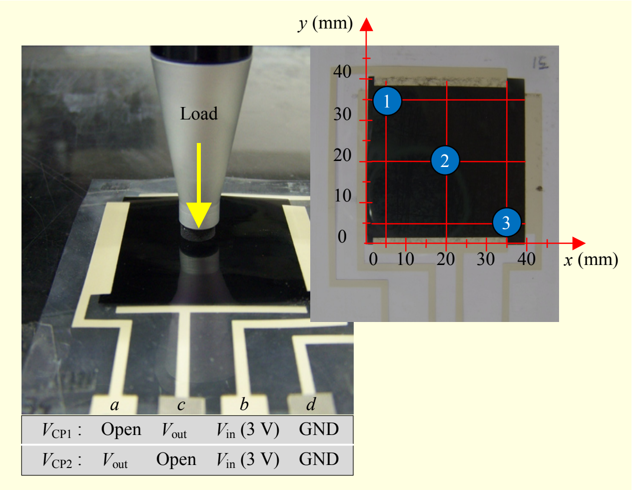


Fig. 7. Electrical circuit for measurement of force response and the coordinates of three contact points.

unloading conditions. Figure 7 also shows the coordinates of points 1, 2, and 3.

V. Results and Discussion

1. Contact Position of Touchpad

Figure 8(a) presents the output voltage $V_{out,x}$ according to three contact paths in the x-axis direction. A fitting curve using the least-square method is calculated by using output voltages obtained from the three paths. The fitting curve has a slope of 0.049 with respect to contact position X, and its intercept is 0.025. The output voltages show a good coincidence with the fitting curve. This means the output is linearly well distributed. Figure 8(b) shows the output voltage $V_{out,y}$ according to the three paths with respect to contact position Y. A fitting curve using linear regression is obtained by averaging the data of the three paths. The fitting curve has a slope of 0.047 with respect to contact position Y, and its intercept is –0.044. As with the x-axis, the output voltages also show a good coincidence with the fitting curve. The slope of the x-axis is little different from that of the y-axis. The deviation error of the contact location shows approximately 4 mm according to the results obtained from x-axis and y-axis directions. Meanwhile, the touchpad shows high noise level because it has high line resistance comparable to the input impedance of the data acquisition board. Therefore, the high noise causes a difference of slope between the x-axis and y-axis. The high impedance of the touchpad also makes the output voltage decrease. Thus, the measured voltages are lower than the theoretical output voltage according to (1) and (2). The line resistance should be a few KΩ to decrease the noise level and lower the deviation error of contact location.

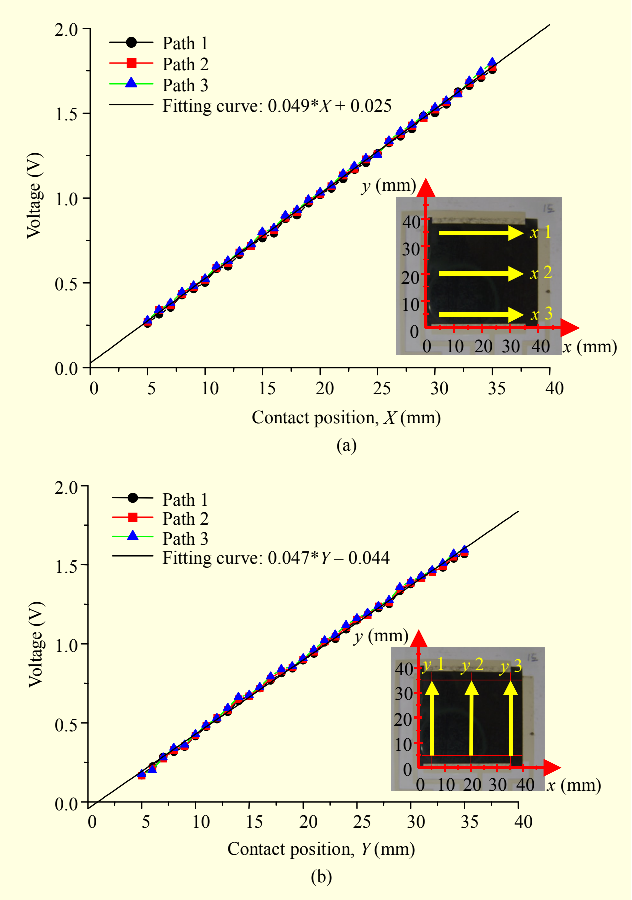


Fig. 8. Output voltage of touchpad according to three paths: (a) x-axis direction and (b) y-axis direction.

2. Force Response of Touchpad

Considering the size of a human fingertip, we used a probe with a diameter of 10 mm to obtain the sensitivity of a touchpad with respect to contact force. In the case of output voltage V_{CP1}, (3) shows the output voltage decreases according to an increasing contact load. For example, when the contact resistance R_z has an infinite value, the output voltage is theoretically equal to the input voltage. In the case of output voltage V_{CP2}, (4) shows the output voltage increases according to an increasing contact load. For example, the output voltage has zero value when the contact resistance has an infinite value. Thus, the output voltage ΔV in (5) always has a positive value with respect to the contact load. However, the output voltage decreases exponentially with increasing contact load. Figure 9 presents the final output voltage calculated by using voltages V_{CP1} and V_{CP2}. The output voltages of three points show that the contact occurs at a load of 0.2 N. The touchpad shows a hysteresis error rate of about 11% and uniformity error rate of about 3%. In the region below 1 N, the sensitivity is approximately 0.12 ΔV/N, and above 1 N, the sensitivity is

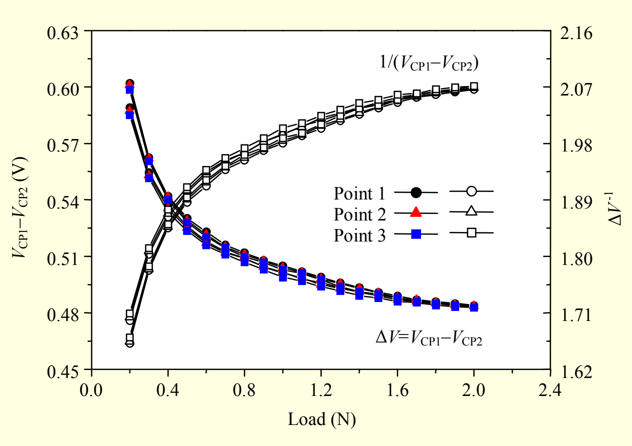


Fig. 9. Loading and unloading response of touchpad at three points.

roughly 0.02 ΔV/N. However, the nonlinearity in the region below 1 N is 36.5%. In the region above 1 N, it is roughly 16.3%. The output voltages show almost the same behavior regardless of the contact positions. Figure 9 also presents the inverse of output voltage ΔV^{-1} at three points to show the behavior of the output voltage according to the increasing contact load.

VI. Conclusion

In this paper, we have proposed a touchpad that can measure contact location and force simultaneously. We have used a contact-resistance-type force sensor using two resistive layers. The touch input device has four signal lines. It is 40 mm in width and 40 mm in length. The deviation error of the contact location was approximately 4 mm considering the evaluation results of contact locations in *x*-axis and *y*-axis directions. The force sensitivity of the touchpad is obtained using a calibration setup. In the region below 1 N, the sensitivity was approximately 0.12 ΔV/N. Above 1 N, the sensitivity was roughly 0.02 ΔV/N. The force response showed a hysteresis error rate of about 11% and uniformity error rate of about 3%. We have confirmed that the touchpad is applicable as a touch input device for contact location and force sensing.

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