Ohmic-Sticker: Force-to-Motion Type Input Device for Capacitive Touch Surface

Kaori Ikematsu
Ochanomizu University
Tokyo, Japan
ikematsu.kaori@is.ocha.ac.jp

Masaaki Fukumoto
Microsoft Research
Beijing, China
fukumoto@microsoft.com

Itiro Siio
Ochanomizu University
Tokyo, Japan
siio@acm.org

Figure 1: Ohmic-Sticker with 2.5 DoF comb electrodes pattern; Ohmic-Sticker works simply by attaching to a commercial touch surface.

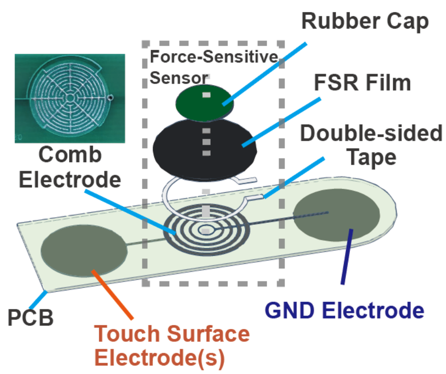

Figure 2: The simple FSR-based structure enables thin (the thinnest version is 1.68 mm thick) form factors and battery-less operation.

KEYWORDS
Capacitive Touch Surface; Force-to-Motion; Input Device.

ABSTRACT
We propose “Ohmic-Sticker”, a novel force-to-motion type input device to extend capacitive touch surfaces. It realizes various types of force-sensitive inputs by attaching on commercial capacitive touch surfaces. A simple force-sensitive-resistor (FSR)-based structure enables thin (less than 2 mm) form factors and battery-less operation. The applied force vector is detected as the leakage current from the corresponding touch surface electrodes by using “Ohmic-Touch” [5] technology. Ohmic-Sticker can be used for adding force-sensitive interactions to touch surfaces, such as analog push buttons, the TrackPoint-like pointing devices, and full 6 DoF controllers for navigating virtual spaces.

INTRODUCTION
Trackpad devices can be seen on most modern laptop PCs and 2-in-1s, whereas it is hard to find stick-type pointing devices (e.g., TrackPoint [6]). One possible reason is difficulty in assembling. “Thin” form factor and long battery life are most crucial element of modern laptop PCs, however, typical sensing mechanism of TrackPoint still requires thickness of 3 to 5mm and need to cut battery under the keyboard unit or increase body thickness. As a result, many PC makers abandon to adopt TrackPoint-like devices (even Lenovo does not use TrackPoint for much thinner series such as Miix). On the other hand, the force-to-motion type input device still has many advantages; small pointing-head does not consume “precious” surface area of portable devices, and the “isometric” pointing action does not require large finger movements . Therefore, it would be a promising add-on option if a force-to-motion type pointing device could be easily attached to the existing touch surfaces while retaining its thin form factors.

In this paper, we propose “Ohmic-Sticker”, a novel force-to-motion input device that provides 0.5 – 6.0 DoF (or more) operations. It realizes various force-sensitive interactions simply by attaching onto touch surfaces without any battery or active sensors (see Fig.1). The force-sensitive-resistor

CHI’19 Extended Abstracts, May 4–9, 2019, GLASGOW, Scotland UK
 The definitive Version of Record was published in *Proceedings of ACM Conference on Human Factors in Computing Systems (CHI’19 Extended Abstracts)*, https://doi.org/https://doi.org/10.1145/3290607.3312936.

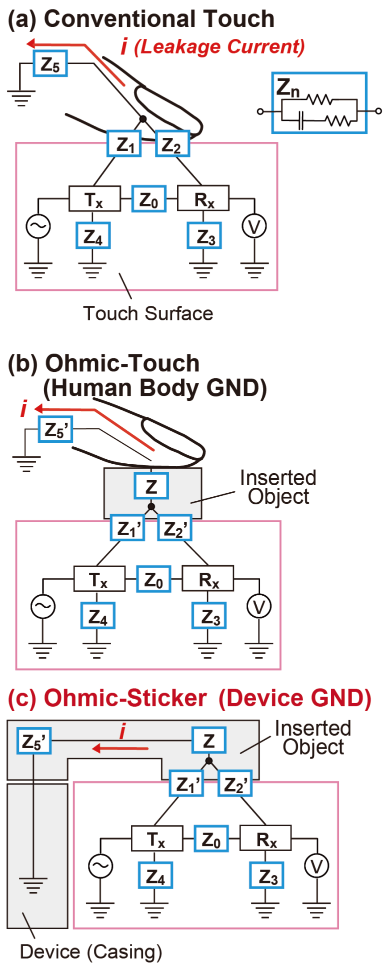

Figure 3: Equivalent circuit of capacitive touch surfaces. (a) Conventional touch; (b) Ohmic-Touch [5]: human body GND; (c) Ohmic-Sticker: connecting the object to the device casing.

[1]https://patents.google.com/patent/US6642857

[2]https://patents.google.com/patent/US6323840

(FSR)-based structure enables battery-less and thin (the thinnest version is 1.68 mm thick) form factors (see Fig.2). The applied force vector on the structure can be detected as a leakage current from the corresponding touch surface electrodes by using Ohmic-Touch [5] technology.

RELATED WORK

Force-to-Motion Type Inputs

Rutledge et al. [6] proposed an early form of an isometric joystick in 1990. Thereafter, IBM commercially introduced it as TrackPoint on its laptop PCs (ThinkPad 700C). TrackPoint senses the applied force and its direction by using resistive strain gauges. The stick-type pointing devices include capacitive pointing sticks (US Pat. 6642857) [1] or a surface-mounted pointing device (US Pat. 6323840) [2] are difficult to reduce the thickness of the above-mentioned structures, because the vertical space to mount a stick part is necessary. Researchers have also developed various interaction techniques using stick-type pointing devices. Wobbrock et al. [8] used an isometric joystick mounted on a mobile phone for text entry, Yamada et al. [9] used a stick-type pointing device attached on a rear camera bezel's of a smartphone to provide back-of-device interaction.

Extending Interaction on Capacitive Touch Surfaces

A capacitive touch surface has a structure in which two types of electrodes. The first type is the transmission electrode (T_x) group and the other is the receiving electrode (R_x) group; they are orthogonal to each other. Figure 3 (a) shows the equivalent circuit at the intersection of a pair of the electrodes. When the T_x is excited by a high-frequency signal, the R_x receives this signal through the impedance network. When a conductive and grounded object, such as a finger, approaches the intersection, a part of the signal from T_x leaks to the GND (i), and the signal received by R_x is attenuated. The touch surface determines the touching or non-touching states depending on whether the leakage current exceeds a certain threshold.

Researchers have developed attachments [11] or objects [2, 10] using conductive materials that can extend the touch areas to outside a touch surface. Clip-on Gadgets [11] provide simple on/off touch inputs from conductive buttons mounted on the object. ZebraWidgets [2] have alternating layers of conductive and nonconductive materials, similar to a striped pattern. They allow a user to swipe or touch inputs on the surface of the object. These approaches provides only discrete touch inputs (i.e., touching or non-touching at specific locations). Ohmic-Touch [5] and Flexibles [7] provide continuous inputs by using the leakage current from the touch surface electrodes. Ohmic-Sticker also uses it.

The leakage current changes according to the impedance of the path from the touch surface to the GND. Based on this, Ohmic-Touch [5] utilized the change in the resistance component (see Fig. 3 (b)) and Flexibles [7] utilized the change in the capacitance component of impedance. Similar to Ohmic-Touch [5], Ohmic-Sticker utilizes the change in the resistance component to realize continuous input (i.e., "analog" touch). However, in contrast to [5, 7], which use a human body as the GND,

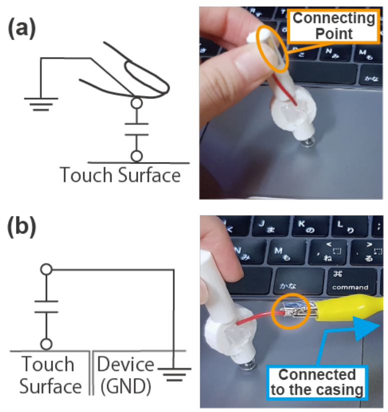

Figure 4: Touch pen used in the investigation; (a) the pen tip is electrically connected to the finger via the connecting point (human body GND); (b) connected to the casing (device GND).

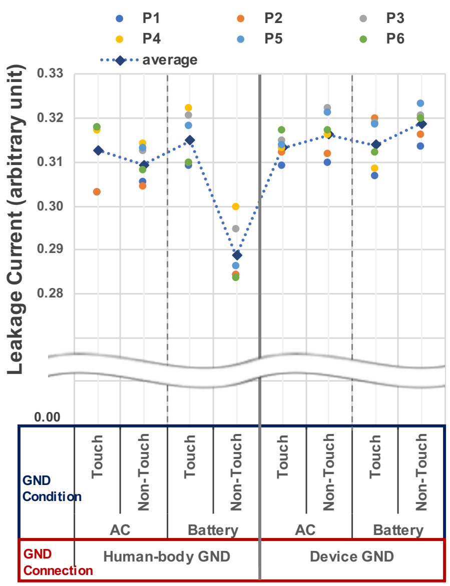

Figure 5: Mean leakage current for each GND condition and GND connection method. (P: participant)

Ohmic-Sticker utilizes a touch surface device (casing) as the GND to increase stability by reducing the noise from the leakage current (see Fig.3(c)) . Generally speaking, circuit boards inside a touch surface are electrically connected to the device casing. As shown in Fig. 3 (c), the device GND is the method of connecting one end of the conductive part of Ohmic-Sticker onto the touch surface and the other end to the casing of the touch surface.

As shown in Fig.2, Ohmic-Sticker has a simple FSR-based structure that changes its resistance value according to the applied force. When the structure is put into the path from a touch point to the GND, the amount of leakage current changes according to the applied force. By detecting the applied force vector, Ohmic-Sticker realizes various force-sensitive inputs onto the touch surface.

INVESTIGATIONS FOR GND CONNECTION METHOD

We investigated how the GND connection methods described in Fig. 3 affect stability for the leakage current measurement. In this experiment, we selected the following GND conditions.

(1) Touching or non-touching between a user's body to the casing (*touching/non-touching* condition)
(2) Connecting the touch surface to the AC adapter or battery-powered (*AC/battery* condition)

Regarding (1), when a user uses a laptop PC, the condition frequently changes (e.g., putting/leaving hands on the palm rests or putting a laptop PC on his/her lap/on a table) and it affects the leakage current measurement. Regarding (2), the leakage current is stable when the laptop is connected to the GND through the AC adapter. However, it is unstable for battery-powered devices, which often rely on a weakly coupled GND reference.

Six participants (four females and two males, aged 23 to 57) were invited to participate in the experiment. The participants touched the touch surface with a touch pen object (see Fig. 4 (a)). As shown in Fig. 4, the touch pen object can switch the device GND and the human-body GND. The touch operation was performed at the center of the touch surface with the four types of combined GND conditions and the two types of GND connection methods. We used a 12 inch MacBook (Apple, macOS 10.13). As refereed to Ohmic-Touch [5], we utilized the size property value of MTDeviceDeclarations [3] (third-party library for MultitouchSupport.framework) that is in correlation with leakage current. We recorded five seconds of leakage current value, with a sampling rate of 120 Hz.

Result

The mean leakage current for each GND condition and GND connection method is shown in Fig. 5. In the device GND method, the leakage current was stable in all GND conditions (the mean fluctuation was less than 1.0 %). In the human body GND method, the leakage current was stable in the *AC adapter* condition regardless of the *touching/non-touching* conditions. However, in the *battery* condition, the *touching* condition tended to increase the leakage current compared to the *non-touching* condition (the mean fluctuation was less than 9.0 %). We confirmed the device GND method is more stable than the human GND, therefore, we selected the device GND method.

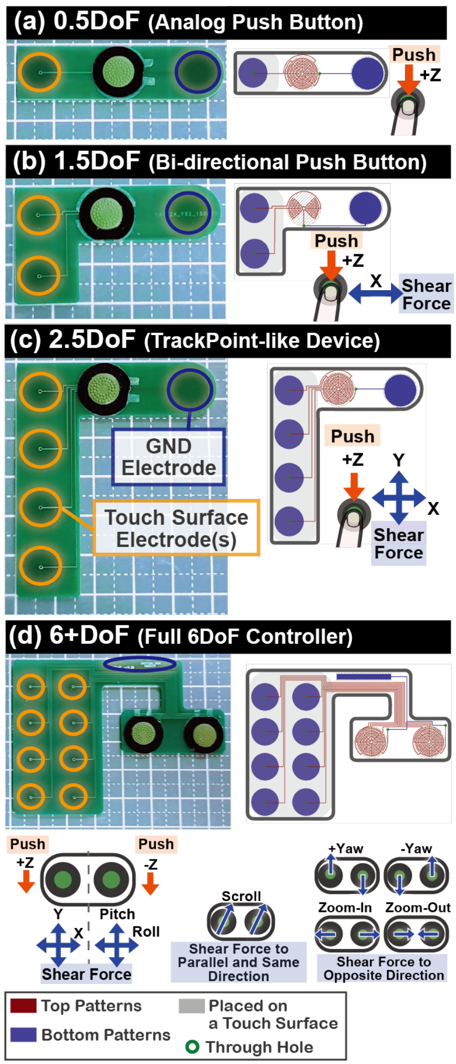

Figure 6: Ohmic-Sticker with electrode patterns for 0.5–6+ DoF.

OHMIC-STICKER

Figure 2 shows the basic structure of Ohmic-Sticker. The sensor structure was designed with reference to MicroNav 360 (Interlink Electronics). Ohmic-Sticker consists of a rubber cap (1.0 mm thick, 8.0 mm diameter), a FSR film (0.12 mm thick, 14.0 mm diameter, a plastic film with carbon powder applied to one side), and circular double-sided tape (0.16 mm thick, 14 mm diameter, with a small gap for a pressure vent) and a two-layered printed circuit board (PCB, 0.6 mm thick). The FSR film is attached on a comb electrode installed on the PCB by the double-sided tape. The rubber cap is attached on the film with an adhesive. One end of the comb electrode is connected to an electrode to be placed on a touch surface (touch surface electrode) and the opposite is connected to an electrode to be placed on a device casing (GND electrode).

The conductive side of the film faces the comb electrode. The circular double-sided tape acts as a spacer. When an external force is applied to the film, the contact area between the film and the comb electrode is changed such that the resistance value is changed, and thus it works as a force sensor. The more of the electrode area is in contact with the film, the lower the resistance. A touch surface detects the change in the resistance value of the force sensor as a change in the leakage current. Therefore, the proposed device works simply passively attaching to a touch surface. Based on the structure, the proposed device realizes a variety of interactions.

Layout Patterns of the Electrodes and Corresponding operations

Figure 6 shows the electrode patterns of Ohmic-Stickers that realize 0.5 DoF–6+ DoF operations.

0.5 DoF Pattern has one touch surface electrode connected to a GND electrode via a comb electrode. When an external force is applied to the force sensor, a touch surface detects the change in the resistance value. It provides simple one-directional (0.5 DoF) pressing operations.

1.5 DoF Pattern has two touch surface electrodes connected to a GND electrode via a two-divided comb electrode. When a shear force is applied to the right or left side of the force sensor, a touch surface detects the change in the resistance value of one part of the sensor. It provides bi-directional (1.0 DoF) pressing operations. When applying vertical pressure force on the sensor, the resistance value in both parts of force sensor change simultaneously. This adds 0.5 DoF pressing operations.

2.5 DoF Pattern has four touch surface electrodes connected to a GND electrode via a four-divided comb electrode. When a shear force is applied to the right, left, up, or down side of the force sensor, a touch surface detects a change in the resistance value of one part of the sensor. In a case of applying a shear force in an oblique direction, the resistive values of the two adjacent parts of the force sensor are changed. This provides two-dimensional (2.0 DoF) operations. In addition, when applying vertical pressure force on the sensor, more than two parts of the resistance value of the force sensor change simultaneously. This is utilized as a 0.5 DoF pressing input.

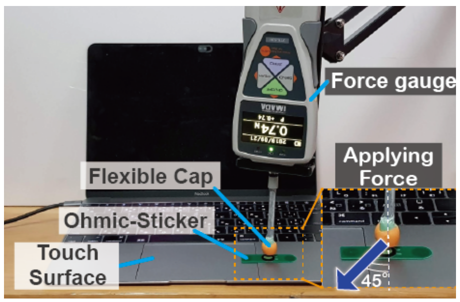

Figure 7: Experimental setup.

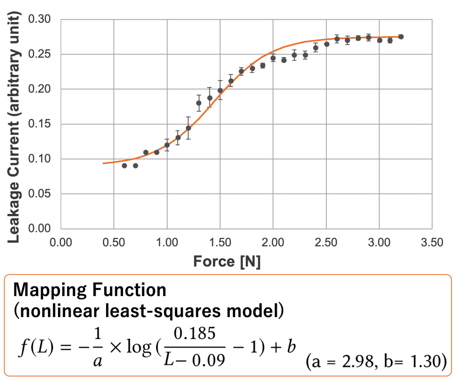

Figure 8: Mean leakage current for press input; Orange line: The mapping function.

6 DoF + Zoom + Scroll Pattern has eight touch surface electrodes connected to a GND electrode via two four-divided comb electrodes. The left column of the touch surface electrodes is connected to the four-divided comb electrode installed on the right side. The right column of the touch surface electrodes is connected to the four-divided comb electrode installed on the left side. The operations of the force sensor on the left side are the same as the 2.5 DoF pattern operations. The force sensor on the right side are similar to the operations on the left side; applying shear force to each direction is used as pitch/roll operations and applying pressure force is used for -Z operation. In addition, applying a shear force to the opposite direction on both sensors is used as yaw operation.

One concern for the 6+ DoF Ohmic-Sticker is assigning both +Z and -Z operations to a pressing movement towards the same direction. The Z-axis operations are not orthogonal compared with X/Y-axis operations, and not very intuitive. This issue can be solved by introducing Flip-Flop Sticker [4] mechanism. Basically, Flip-Flop Sticker has same device structure as the 6+ DoF Ohmic-Sticker. However, it has a pivot point that is attached to the bottom of the device. When pressure force is applied to the -Z pointing head, the device is slanted around the pivot point. The small seesaw movements generate flip-flop (upward) movements toward a operation finger and provide the user with a mental image of a stepping-up motion.

CHARACTERISTICS AND SPECIFICATION

To implement a software that provides TrackPoint-like force-to-motion operations, we firstly investigated the mapping between the force and the leakage current of Ohmic-Sticker. Then we investigated the mapping between the force and the cursor speed of the commercial TrackPoint.

Mapping Between Force and the Leakage Current

Our experiment was conducted as shown in Fig. 7. We used the Ohmic-Sticker having one direction of 2.5DoF pattern attached to the touch surface of the 12 inch MacBook (Apple, OS X 10.13) by using the double-sided Z-axis conductive tape (M3, 9703). We performed each press onto the Ohmic-Sticker with a continuously increasing applied force by using a digital force gauge (IMADA, ZTS-50N). We logged the leakage current and the applied force simultaneously. As shown in Fig. 8, Ohmic-Sticker is capable of sensing continuous intensities of applied force (from 0.6 to 2.5[N]).

Mapping Between Force and the Cursor Speed

We used a ThinkPad Bluetooth Keyboard with TrackPoint (driver version 1.5.6.0, Lenovo) and Vaio Ultrabook SVT13139CJS (SONY, Windows8). We set the cursor speed as the TrackPoint default speed in the driver. Similar to the above task, we used the digital force gauge. In order to exclude the effect of the dynamic acceleration [1], the cursor speed was measured for a total of seven seconds, of which the data for the first two seconds were excluded. The cursor speed is measured as px/s on the display (Iiyama, ProLite B2712HDS, 1920 × 1080 px).

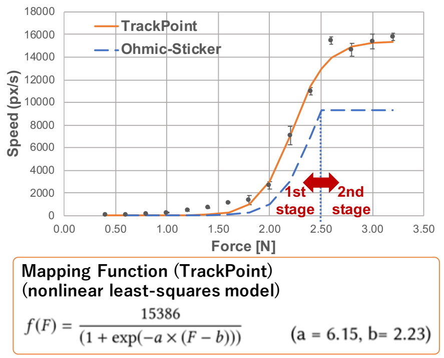

Figure 9: Orange: mean cursor speed and the mapping function of TrackPoint. Blue: the mapping function for Ohmic-Sticker divided into two stages.

Figure 9 shows the mapping between force and the cursor speed of the TrackPoint. Based on it, we implemented the force-speed function for two-dimensional operations of Ohmic-Sticker. Owing to the differences in the detectable force range between the TrackPoint (0.4–3.0 [N]) and Ohmic-Sticker (0.6–2.5 [N]), we modified the transfer function as follows:

$$(F < 2.5[N]) : f'(F) = \frac{15386}{(1 + \exp(-a \times (F - b + 0.2)))} \quad (1)$$

$$(F >= 2.5[N]) : f'(F) = 9324 \quad (2)$$

Regarding the range of F < 2.5 [N], the modified function used the same slope of the curve as the original function, except for moving parallel to the x-axis direction by +0.2 (differences in the required force to detect the input). Regarding the range of F >= 2.5 [N], the change in the leakage current is indistinguishable, therefore, we use a constant value for this range.

CONCLUSION

We proposed a force-to-motion type input device that realizes various types of force-sensitive inputs simply by attaching to commercial capacitive touch surfaces. The simple FSR-based structure enables thin (less than 2 mm) form factors and battery-less operation. We reported a series of investigations that are based on the characteristics of modern touch surfaces.

REFERENCES

[1] R. C. Barrett, E. J. Selker, and J. D. Rutledge. 1995. Negative Inertia: A Dynamic Pointing Function. In *Proc. of CHI'95*. 2.
[2] Liwei Chan, Stefanie Müller, Anne Roudaut, and Patrick Baudisch. 2012. CapStones and ZebraWidgets: Sensing Stacks of Building Blocks, Dials and Sliders on Capacitive Touch Screens. In *Proc. of CHI'12*. 2189–2192.
[3] The Media Computing Group. 2011. MTDeviceDeclarations. http://hci.rwth-aachen.de/guide_trackpad
[4] Kaori Ikematsu, Masaaki Fukumoto, and Itiro Siio. 2018. Flip-Flop Sticker: Force-to-Motion Type 3DoF Input Device for Capacitive Touch Surface. In *Proc. of SUI '18*. 169–169.
[5] Kaori Ikematsu and Itiro Siio. 2018. Ohmic-Touch: Extending Touch Interaction by Indirect Touch Through Resistive Objects. In *Proc. of CHI '18*. Article 521, 8 pages.
[6] Joseph D. Rutledge and Ted Selker. 1990. Force-to-motion Functions for Pointing. In *Proc. of INTERACT '90*. 701–706.
[7] Martin Schmitz, Jürgen Steimle, Jochen Huber, Niloofar Dezfuli, and Max Mühlhäuser. 2017. Flexibles: Deformation-Aware 3D-Printed Tangibles for Capacitive Touchscreens. In *Proc. of CHI '17*. 1001–1014.
[8] Jacob O. Wobbrock, Duen Horng Chau, and Brad A. Myers. 2007. An Alternative to Push, Press, and Tap-tap-tap: Gesturing on an Isometric Joystick for Mobile Phone Text Entry. In *Proc. of CHI '07*. 667–676.
[9] Wataru Yamada, Hiroyuki Manabe, and Daizo Ikeda. 2018. CamTrackPoint: Camera-Based Pointing Stick Using Transmitted Light Through Finger. In *Proc. of UIST'18*. 313–320.
[10] Yuko Yanagawa, Kaori Ikematsu, Chihiro Suga, Mana Sasagawa, Yasushi Matoba, and Itiro Siio. 2017. Anamorphicons: An Extended Display Utilizing a Cylindrical Mirror Widget. In *Proc. of OZCHI '17*. 457–461.
[11] Neng-Hao Yu, Sung-Sheng Tsai, I-Chun Hsiao, Dian-Je Tsai, Meng-Han Lee, Mike Y. Chen, and Yi-Ping Hung. 2011. Clip-on Gadgets: Expanding Multi-touch Interaction Area with Unpowered Tactile Controls. In *Proc of UIST '11*. 367–372.