Evaluation of a Soft-Surfaced Multi-touch Interface

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Abstract. "WrinkleSurface", which we developed by attaching a gel sheet to a FTIR-based touchscreen, enables a user to perform novel touch motions such as Push, Thrust, and Twist_CW (clockwise), and Twist_CCW (counterclockwise). Our research is focused on the evaluation of this soft-surfaced multi-touch interface. Specifically, to examine how a user can input our novel input methods precisely, we evaluated the user's performance of each method by two to nine levels of target acquisition task. As a result, we found some points to be improved in our recognition algorithm in order to increase the success rate of Push and Thrust. In addition, a user can input Twist before the level of six because the success rate of Twist was high up to that level.

Keywords: Touchscreen, tabletop, haptic interface, FTIR, tangential force sensing, pressure sensing.

1 Introduction

In conventional touchscreen interaction, input is limited to the coordinates of human fingers' contact areas. Recently, many researchers have worked on novel input that exceeds these coordinates to enrich touchscreen interaction [1, 2, 5, 6, 8, 10, 12]. We also developed "WrinkleSurface" to explore a wide variety of inputs in touchscreen interaction [9]. WrinkleSurface is a soft-surfaced touchscreen that enables a user to perform novel touch motions such as pushing, thrusting, and twisting (Fig. 1), in addition to conventional motions like drag and pinch. We named these input methods Push, Thrust, and Twist and presented some applications in touchscreen interaction. It is also possible to detect the strength and direction of the motion from the wrinkles caused by the motion.

Our research is focused on the evaluation of a soft-surfaced multi-touch interface. Specifically, to examine how a user can input our novel input methods precisely, we evaluated the user's performance of each method.

We begin by describing the previous works on input methods that achieved a variety of input in multi touch interfaces, and soft-surfaced touch interfaces. Next, we present the hardware design and recognition methods of our soft-surfaced touchscreen. We end with a user study that shows user's performance of our novel input methods using WrinkleSurface.

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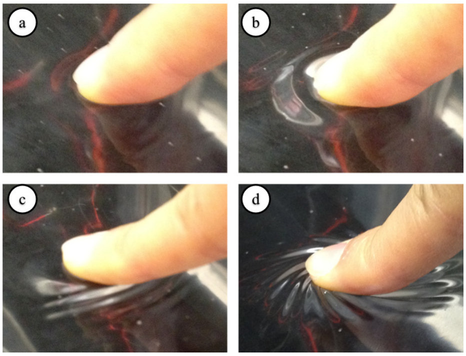

Fig. 1. a) Touch, b) Push, c) Thrust, and d) Twist

2 Related Work

Our research is focused on the evaluation of a soft-surfaced multi-touch interface. There are many works related to the research of this paper that have developed various of inputs in multi touch and soft-surfaced touch interfaces. However, few researchers have evaluated of their methods.

2.1 Input Methods in Touch Interaction

Some researches have attempted to obtain information other than coordinates by utilizing the shape of finger's contact area on the touchscreen surface in order to enrich interaction. Wang et al. and Dang et al. focused on oblique touch input and developed a way of detecting the finger orientation [1, 2, 12]. Our WrinkleSurface can sense the finger orientation as well, but our system is mainly intended not to utilize the information concomitant with finger's contact, but to develop novel input methods such as pushing, thrusting, and twisting.

Some have researched recognizing the finger posture above the touchscreen. Takeoka et al. proposed Z-touch, which utilizes the slant and direction of fingers in touchscreen interaction [10]. Z-touch uses infrared laser plane and a high-speed camera to recognize the finger posture in the space above the touchscreen. Our research is different from this because it is based on the force sense feedback deriving from direct contact with the input surface.

Heo et al. and Lee et al. enabled detection of horizontal movement on the surface of a device and recognized various types of inputs [6, 8]. They made a cover with sensors at the bottom and the side frame, enclosed a device within it, and detected the horizontal movement. Harrison et al. proposed Shear as a novel input that utilizes a tangential force to a screen's surface [5]. Shear is "a supplemental analog 2D input channel" and can be used with conventional touch input. Our WrinkleSurface detects the force through the deformation of the gel-sheet (i.e., wrinkles).

Wang et al., Dang et al., and Lee et al. evaluated their approaches on the ordinary touchscreens, but we focused on the evaluation of a soft-surfaced touchscreen.

2.2 Soft-Surface Touch Interactions

Vlack et al. proposed GelForce, which detects strength and direction of forces applied to the surface of an elastic material [11]. It consists of a CCD camera and two layers of colored markers embedded in a transparent silicone rubber. This research developed soft-surface touch interactions. In contrast, our research focused not only the development but also evaluation of soft-surface touch interaction.

Kakei et al. proposed a tabletop tangible interface, ForceTile [7]. The tile interface consists of an elastic body and markers. Cameras and infrared transmitters are placed underneath the tabletop, and they sense the position, rotation, and ID of interface and calculate the force vector of deformation. WrinkleSurface recognizes the input strength without any markers. Therefore, rear projection is possible, which is an advantage for a touchscreen. Our novel input Push, Thrust, and Twist are recognized by the wrinkles caused on the touchscreen, which is a novel recognition method.

Sato et al. showed PhotoelasticTouch, which recognized deformation of transparent elastic material as an input without using visual markers. It is made from transparent elastic material and consists of an LCD and an overhead camera both fitted with a quarter-wavelength filter. When force was applied to the elastic material, the deformed area transforms incoming light into elliptically polarized light, which is captured by the camera. Position and size of the deformed area and direction of the force can be calculated, and interactions such as pinching, pushing, and pulling became recognizable. Its weakness was the positioning of the camera. It was placed above the touchscreen and sometimes users' body parts (e.g., head) interfered with capturing hand images. In the case of WrinkleSurface, the IR camera is placed under the panel, and we can utilize the wrinkles caused on the touchscreen without such interruptions. In addition, WrinkeSurface enabled us to recognize novel input (thrusting and twisting) without any occlusions.

Fukumoto attached a soft-gel based transparent film named "PuyoSheet" onto the surface of the touchscreen. PuyoSheet, combined with soft-gel based small dots "PuyoDots", provided a button-push feeling to the fingertips [3]. WrinkleSurface provides novel input utilizing the softness of its surface in addition to tactile feedback by the restitution of the soft-gel surface. Fukumoto evaluated the performance and impressions of PuyoSheet and PuyoDots with a handheld device, but WrinkleSurface is a multi-touch tabletop interface.

3 WrinkleSurface

WrinkleSurface is a touchscreen based on frustrated total internal reflection (FTIR) [4]. A transparent urethane soft gel sheet (hereinafter gel sheet) about

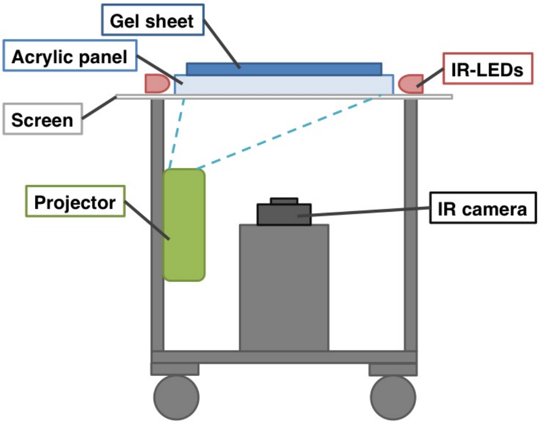

Fig. 2. Hardware setup of WrinkleSurface

3.5 mm thick is attached onto the surface of an acrylic panel (Fig. 2). Each touch motion, such as pushing, thrusting, and twisting, makes characteristic wrinkles on the surface. Utilizing this, we have extracted the features of these wrinkles to detect three novel input methods. Moreover, the strength of each input can be detected. Fig. 1 shows the ordinary Touch and our input methods: Push, Thrust, and Twist. When a user pushes vertically into the panel with a certain strength, it results in Push (Fig. 1b). Wrinkles do not appear on the gel sheet in both Touch and Push. When a user slides the finger while Pushing, wrinkles appear in the direction in which a user slides the finger (Fig. 1c). When a user rotates the finger while Pushing, wrinkles appear around the finger (Fig. 1d).

3.1 Hardware Setup

As shown in Fig. 2, WrinkleSurface consists of an acrylic panel attached to a gel sheet, 28 infrared LEDs, an infrared camera, a projector, and a screen for projection. WrinkleSurface is placed 1100 mm above floor level. The acrylic panel is 590 × 450 × 10 mm, and the gel sheet is 500 × 400 × 3.5 mm. 14 IR LEDs (OPTOELECTRONICS CO., LTD., SFH4550) are attached lengthways along the acrylic panel. We also placed the IR camera (Point Grey Research, Dragonfly2) and the projector underneath the panel. The bottom of the acrylic panel and the camera lens are 330 mm apart. Under the acrylic panel, we put a tracing paper of 40 g/m^2 paper density as a screen for projection.

In this system, we used FTIR to detect input. After attaching the gel sheet to the FTIR touchscreen, we checked and confirmed that the FTIR mechanism worked properly. FTIR-based touchscreen and WrinkleSurface differ in diffuse reflection. In the case of WrinkleSurface, the diffuse reflection takes place not only in the finger contact area like for FTIR-based touchscreen but also in the wrinkled area. By capturing the diffuse reflection image with an IR camera, we can obtain the shape and angles of the wrinkles appearing on the gel sheet.

3.2 Recognition Techniques

In this section, we describe the recognition technique of our novel inputs and the strength of these inputs. WrinkleSurface recognizes each input by means of the following process.

1. Extracting three characteristic parameters from the image processing: “roundness”, “magnitude of the wrinkle vector”, and “rotation degree”.
2. Defining the likelihood function associated with each input and the characteristic parameters.

“Roundness” is the roundness of the combined area consisting of the finger’s contact area and the wrinkled area. “Magnitude of the wrinkle vector” is expressed by the Euclidean distance between the gravity centers of the finger’s contact area and the wrinkled area. “Rotation degree” is obtained by comparing the inter frame differences of the finger direction calculated using the algorithm developed by Wang et al [12]. “Rotation degree” is only used for the Twist. To recognize three input methods, we experimentally developed a likelihood function that uses these characteristics as its parameters. The system also recognized the strength of each input from the parameters listed in Table. 1.

Table 1. Range of parameters for each input method

Input	parameter	range
Push	luminance value	50-110
Thrust	moving distance	0-60 (pixel)
Twist_CW	rotation angle	20-80 (degree)
Twist_CCW	rotation angle	20-80 (degree)

4 Applications

We developed three applications taking advantage of the features of WrinkleSurface. WrinkleGeo edits the geographical terrain utilizing wrinkles that appear on WrinkleSurface. WrinkleMesh distorts the image into the spiral pattern, utilizing the Twist. WrinkleIcon operates icons making good use of the repulsion of the gel sheet. Using WrinkleIcon, a user can flick out or gather icons.

5 Evaluation

To examine how a user can perform input precisely using our novel input methods, we evaluated the user’s resolution of each method’s parameter such as the strength of Push, the moving distance of Thrust, and the rotation angle of Twist_CW (Twist clockwise) and Twist_CCW (Twist counterclockwise). To simplify the experimental setup, we did not use the projector or the screen for projection in this experiment (Fig. 3) and covered the frame of WrinkleSurface with a blackout curtain in order to block out sunlight from the camera (Fig. 4).

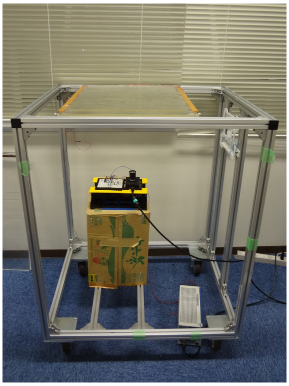

Fig. 3. Experiment environment

Fig. 4. WrinkleSurface surrounded by the blackout curtain

5.1 Participants

We recruited seven male and five female participants, aged 21-24, who were university (undergraduate and graduate) students majoring in computer science. All 12 participants were right-handed, and we asked them to use only their right index finger to complete the task to make the experiment conditions identical.

5.2 Task

Each participant engaged in a target acquisition task (Fig. 5). They were asked to adjust the size of the yellow circle (i.e., cursor) by controlling the parameter of an input method between two green circles (i.e., target). The cursor and the target were shown on the display. When a particitant kept the cursor within the target for 1000 ms, the trial was a success. When 5000 ms elapsed after a participant had started a trial, the trial was a failure.

For each method, the range of the parameter was divided into two to nine levels and represented as a target (Fig. 6). Therefore, the experimental application provided 44 types of targets (2+3+....+9) for each parameter. For each target, the inner and outer circle of the target represented the minimum and maximum values of the target, respectively (e.g., 50 and 80 when the range of Push was divided into two levels). In this experiment, six sets of trials were given for each target. Thus, each participant had 1056 trials:

$$\begin{aligned}&Target\ type: 44\\&\times Set: 6\\&\times Input\ method: 4\\&= 1056.\end{aligned}$$

In total, this experiment had 12672 trials.

It took about three hours for each participant to complete the task. The experiment was conducted in a casual atmosphere. The participants could rest between the trials and talk freely to the other members including the experimenter in the laboratory.

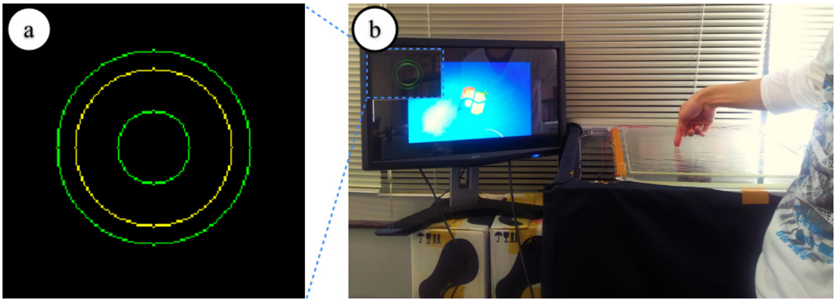

Fig. 5. a) Screen used in the task with cursor (yellow circle) and target (two green circles). b) Participant operating WrinkleSurface.

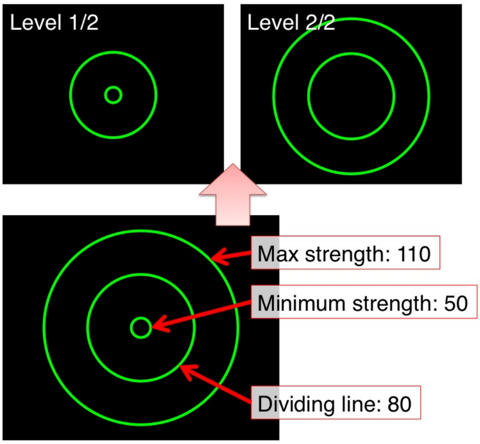

Fig. 6. Two targets when the range of Push was divided into two levels

6 Result and Discussion

Fig. 7 shows the average success rate of each method. Due to a system error, we could not use one participant's results. Thus, we had to calculate the average from the other 11 participants' results. The grand average was 27.2% in Push, 57.9% in Thrust, 49.9% in Twist_CW, and 50.5% in Twist_CCW.

From these results, we also identified some points to be improved in our recognition algorithm. One drawback of our algorithm is that the overall success rate of Push was too low. This was because when the target was small, the luminance value was high enough, but other elements caused the failure. We found out that WrinkleSurface was mistaking Push for Thrust when a participant pushed the gel sheet strongly. To solve this failure, we could stop distinguishing Push from Thrust or only recognize strong Thrust as Thrust.

The success rate of Thrust was higher than those of the other three inputs in the levels over four. However, the error rate of Thrust increased as the level increased. By examining of the error of Thrust, we found that there were two causes. First, WrinkleSurface had mistaken Thrust as Push or Twist because the movement of wrinkle vector is small. Second, the system changed the recognition into Touch when the force applied to WrinkleSurface was weakening while a user was performing Thrust. Both causes occurred when a participant was moving his/her fingers. Moreover, in the case of Thrust, the success rate of females was lower than that of males. This is because women are physically weaker than men in general. From the experimental observation and participants' comment, it seemed that it was difficult for female participants to keep their initial strength of Push to the end of the movement. Both male and female participants also commented that they had pain in their fingers, especially doing Thrust. To solve these problems, we believe that the elapsed time of thrusting is a possible parameter to improve the accuracy of Thrust recognition.

As shown in Fig. 7, the success rates of Twist_CW and Twist_CCW did not differ much. Both varied inversely to the levels except the sixth. The major cause

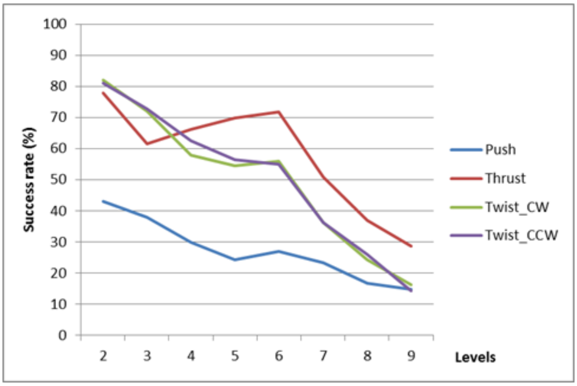

Fig. 7. Average success rate of each input

of failure of Twist was due to the trembling of the rotation angle; we observed that a user found it difficult to keep the target angle stable. This result indicates that Twist (both CW and CCW) is suitable for continuous input, or a use in rough situation.

Some participants made positive statements about WrinkleSurface. Many said that they would prefer a much softer surface. The softness depends on gel sheets, so we plan to experiment with another softer gel sheet. Some participants suggested CG modeling and paint application for WrinkleSurface. We will continue to evaluate and improve both the software and hardware of WrinkleSurface.

7 Conclusion

Our research is focused on the evaluation of a soft-surface multi-touch interface. To this end, we presented an evaluation of "WrinkleSurface", which we developed by attaching a gel sheet to a FTIR-based touchscreen. In the evaluation, we obtained the grand average of 27.2% in Push, 57.9% in Thrust, 49.9% in Twist_CW, and 50.5% in Twist_CCW, and positive statements for WrinkleSurface from some participants. From these results, we found some points to be improved in our recognition algorithm in order to increase the success rate of Push and Thrust. The results also suggest that a user can input Twist before the level of six. We plan to continue to evaluate and improve both the software and hardware of WrinkleSurface.

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References

1. Dang, C.T., André, E.: Usage and recognition of finger orientation for multi-touch tabletop interaction. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) INTERACT 2011, Part III. LNCS, vol. 6948, pp. 409–426. Springer, Heidelberg (2011)
2. Dang, C.T., Straub, M., André, E.: Hand distinction for multi-touch tabletop interaction. In: Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, ITS 2009, pp. 101–108 (2009)
3. Fukumoto, M.: Puyosheet and puyodots: simple techniques for adding "button-push" feeling to touch panels. In: CHI 2009 Extended Abstracts on Human Factors in Computing Systems, CHI EA 2009, pp. 3925–3930 (2009)
4. Han, J.Y.: Low-cost multi-touch sensing through frustrated total internal reflection. In: Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology, UIST 2005, pp. 115–118 (2005)

5. Harrison, C., Hudson, S.: Using shear as a supplemental two-dimensional input channel for rich touchscreen interaction. In: Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems, CHI 2012, pp. 3149–3152 (2012)
6. Heo, S., Lee, G.: Force gestures: augmented touch screen gestures using normal and tangential force. In: Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems, CHI EA 2011, pp. 1909–1914 (2011)
7. Kakehi, Y., Jo, K., Sato, K., Minamizawa, K., Nii, H., Kawakami, N., Naemura, T., Tachi, S.: Forcetile: tabletop tangible interface with vision-based force distribution sensing. In: ACM SIGGRAPH 2008 New Tech Demos, SIGGRAPH 2008, p. 17:1 (2008)
8. Lee, B., Lee, H., Lim, S.-C., Lee, H., Han, S., Park, J.: Evaluation of human tangential force input performance. In: Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems, CHI 2012, pp. 3121–3130 (2012)
9. Sakamoto, Y., Yoshikawa, T., Oe, T., Shizuki, B., Fukumoto, M., Tanaka, J.: Wrinklesurface: A wrinklable soft-surfaced multi-touch interface. In: Proceedings of the 19th Workshop on Interactive Systems and Software, WISS 2011, pp. 7–12 (2011) (in Japanese)
10. Takeoka, Y., Miyaki, T., Rekimoto, J.: Z-touch: an infrastructure for 3d gesture interaction in the proximity of tabletop surfaces. In: ACM International Conference on Interactive Tabletops and Surfaces, ITS 2010, pp. 91–94 (2010)
11. Vlack, K., Mizota, T., Kawakami, N., Kamiyama, K., Kajimoto, H., Tachi, S.: Gelforce: a vision-based traction field computer interface. In: CHI 2005 Extended Abstracts on Human Factors in Computing Systems, CHI EA 2005, pp. 1154–1155 (2005)
12. Wang, F., Cao, X., Ren, X., Irani, P.: Detecting and leveraging finger orientation for interaction with direct-touch surfaces. In: Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology, UIST 2009, pp. 23–32 (2009)