Operation Guidance Method for Touch Devices by Direction Presentation Using Anisotropic Roughness

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Abstract. Most previous studies of tactile presentation for touch devices have presented tactile cues as a function of the position of the finger. In the current study, we examined whether directional information could be presented by modulating tactile cues depending on the direction of motion of the finger, using a new method called "anisotropic tactile presentation". Preliminary experiments confirmed that direction presentation and navigation to a goal could be achieved by decreasing the presentation of roughness when moving in the designated direction. In addition, we conducted two experiments comparing the proposed system with a conventional position-based guidance method. The results revealed that the proposed method enabled participants to search for the target more quickly and accurately compared with the conventional tactile presentation method.

Keywords: Anisotropic roughness · Direction presentation · Navigation · Touch device.

1 Introduction

Devices equipped with touchpad or touch panels have become widely used in recent years. The lack of haptic feedback, such as a clicking sensation, can lead to operational errors with these devices [1][2], and many tactile presentation methods for touch devices have been proposed. Fukumoto et al. developed a system called ActiveClick [3], which vibrates the entire surface using a transducer, enabling the presentation of a clicking sensation when an icon is pressed. In addition to this type of tapping operation, a method has been developed for providing tactile feedback while swiping the surface of a touch device. Bau et al. developed TeslaTouch[4], in which the frictional force between the touch device and the finger is changed using electrostatic attraction to modify the texture of the display surface. Several methods have proposed systems utilizing the manipulation friction and roughness via the ultrasonic vibration squeeze effect [5] [6] [7] or vibrotactile cues [8] [9].

The methods for the presentation of tactile stimulation for touch devices discussed above have largely aimed to convey the properties of the contact object, such as hardness, roughness and friction. However, some applications for touch devices require finger movement in a specific direction. For example, guidance systems that involve limiting movement to a single direction may be suitable for the operation of a scroll bar or volume control. In alphabet-learning applications for children, tactile stimulation may be useful for guiding fingers in a specific direction. In such situations, haptic feedback is required to move the finger in a specific direction. Many texture presentation displays provide texture feedback corresponding to the coordinates of the finger (i.e., position). However, in applications in which users are instructed to move a finger in a specific direction, texture feedback according to the direction of movement of the finger may be more suitable. Such a method could be used to indicate that one direction is the correct direction for moving the finger whereas another direction is incorrect. In the current study, we tested a direction-dependent texture presentation method called anisotropic texture presentation, and compared it with a conventional position-dependent texture presentation method called isotropic texture presentation.

We first describe our proposed navigation method using anisotropic texture presentation. We then tested participants' ability to move the cursor of the touch device to a specific point by using the proposed method, and compared navigation performance with the conventional isotropic texture presentation method. Third, a practical task was carried out, requiring participants to unlock the screen of a smartphone using a specific motion pattern, enabling a comparison between the proposed system and the conventional method.

2 Related Work

Several studies have presented directional cues to fingers. Ho et al. developed a system called Slip-Pad [10], which presents directions by providing a shearing force to the fingers using a two degrees of freedom belt mechanism. A method for directly driving the fingertip has also been proposed [11] [12]. Jung et al. developed Pinpad [13], which uses a pin array touchpad to assist the operation of a device by restricting the direction of finger movement. However, these approaches require additional hardware, and are difficult to apply in small devices, such as smartphones.

Klatzky et al. tested a system using a one-dimensional gradient on an electrostatic tactile display by gradually changing the concentration of the roughness of the electrostatic friction, and reported that the gradient direction was recognizable [14], which they suggested could be applied to navigation. However, this method has not been tested in two-dimensional space.

3 Method

3.1 Navigation Method Using Roughness

In the current study, we considered a situation requiring finger movement in a specific direction, such as a tracing task in an alphabet-learning application. We used the change of the roughness of the surface of the touch device to correct the movement of the finger and guide it in the correct direction. We call this method anisotropic roughness presentation, because the presented roughness is dependent on the instantaneous velocity vector.

When a finger is moved on the touch device, roughness is presented to the finger to correct the direction of movement. Thus, the user can reach the destination by continuously perceiving the correction signals, as shown in Fig. 1.

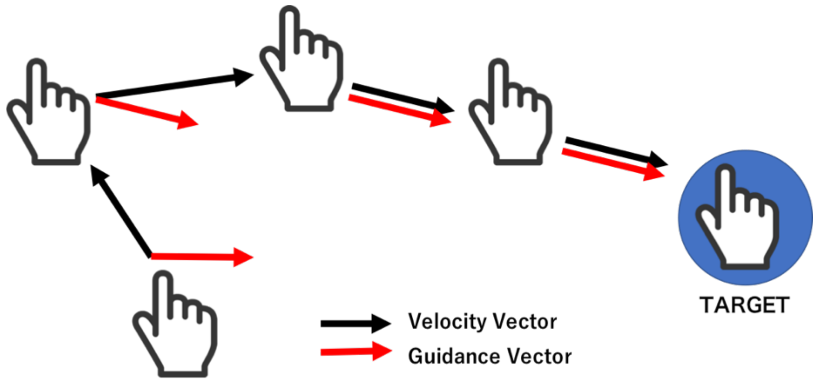

Fig. 1 Finger movement navigation method using direction presentation. The velocity vector indicates the correct movement direction of the finger, and the guidance vector indicates the direction of the target.

3.2 Direction Presentation Using Anisotropic Roughness

When the finger moves on the touch device, an angular difference is generated between the velocity vector indicating the movement direction and the guidance vector indicating the guidance direction (Fig. **2**). The direction-dependent texture is presented by modulating the magnitude of roughness corresponding to this angular difference. We speculated that it would be physically or mentally difficult to move in the direction in which the roughness becomes stronger, meaning that direction could be indicated naturally by presenting the lowest level of roughness when the finger moves in the designated correct direction, and the greatest level of roughness when moving in the opposite direction.

We propose an anisotropic texture method suitable for guiding in one direction, as shown in Fig. 3. Roughness is not generated when moving the finger in the direction along the background arrow of the figure, but increases when the finger moves against the flow of the background arrow. We used an anisotropic texture that mimics a texture flowing in a certain direction, similar to the sensation of touching animal fur. The magnitude $R(\theta)$ of the generated roughness is given by the following equation (1).

$$R(\theta) \propto |\sin(\theta/2)| \quad (1)$$

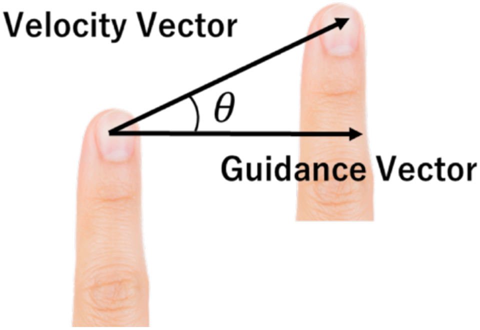

Fig. 2 Angle between the velocity vector and guidance vector.

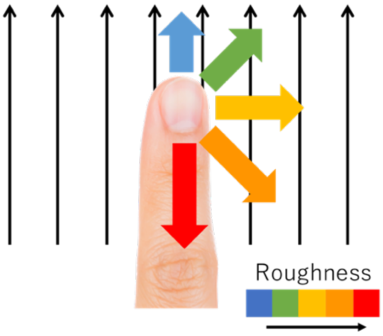

Fig. 3 Anisotropic texture suitable for guiding in one direction.

4 Hardware

4.1 Overview of the Roughness Presentation Touchpad System

Fig. 4(a) shows an overview of the experimental device. The device comprised a disassembled commercial touchpad (PERIPAD-501, Perixx Computer), audio speaker (NSW 1-205-8 A (2), AURASOUND), audio amplifier (M50, MUSE), texture signal source (Xperia arcS, SONY) and texture modulation circuit (MCP4018T-103E/LT and Arduino UNO, Arduino). Fig. 4(b) shows a side view of the touchpad. The audio speaker was attached below the touchpad, and the surface of the touchpad was vibrated by the speaker to present texture to the finger.

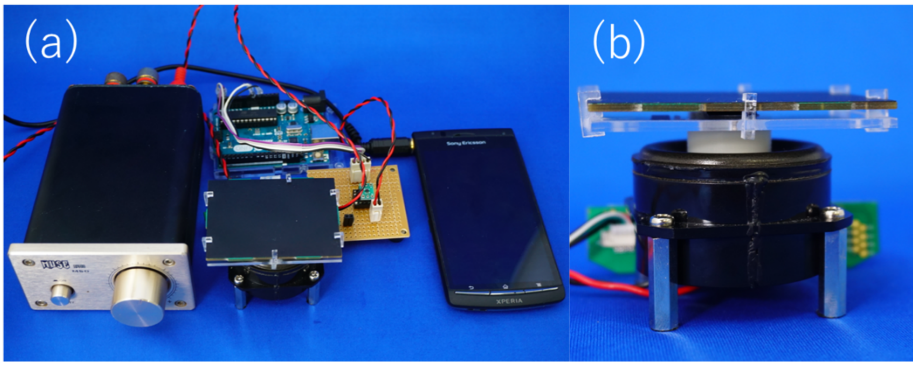

Fig. 4 Roughness presentation touchpad system: (a) Overview of the device; (b) Side view of the touchpad.

4.2 System Configuration

The system configuration of the device is shown in Fig. **5**. The touch pad is connected to a PC via USB, and operates as a normal external connection touch pad. Using software running on the PC, the magnitude of the roughness for presenting the direction could be calculated and transmitted to the amplitude modulation circuit as a control signal. By inputting the control signal and the texture signal to the amplitude modulation circuit, the amplitude-modulated texture signal is then output. The original texture signal was band-limited white noise with its upper limit set to 200 Hz. Preliminary testing revealed that there was a latency of approximately 50 ms between the actual motion of the finger and the presentation of vibration.

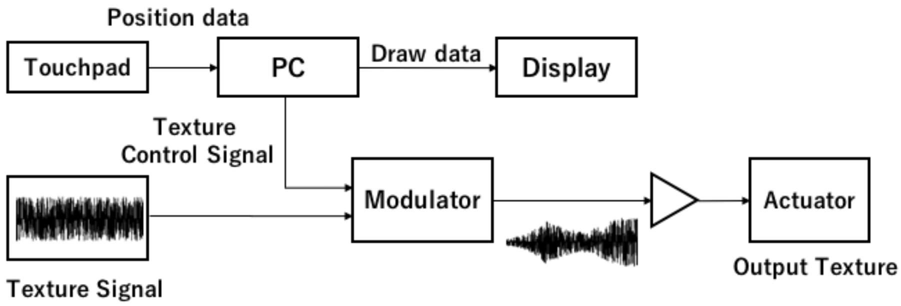

Fig. 5 System configuration of the roughness presentation touchpad.

5 Experiment

5.1 Preliminary Experiment: Comparison of Increase and Decrease in Roughness

Procedures and Tasks. In the proposed method, we hypothesized that it would be difficult to move the fingers physically or mentally under conditions of high roughness, and that natural guidance can be performed by setting the direction with low roughness as the guidance direction. To test this hypothesis, we conducted an experiment comparing a direction presentation method using two types of anisotropic roughness: the method of minimizing roughness and the method of maximizing roughness when the guidance direction and motion direction matched.

Participants performed a task involving searching for a correct target using direction information based on anisotropic roughness. Participants were required to find one target among four potential targets, arranged as shown in Fig. 6 (b) (Fig. 6 (a) was used in a subsequent experiment described below). We measured the time spent searching and the correct response rate.

The process of starting the movement and selecting the target constituted one trial. A total of 20 trials (five trials for each of the four targets) was considered to constitute one measurement period. The trials were performed in a random order, and each participant performed a total of two measurement periods (i.e., one for each method).

We recruited four participants (right-handed males, 21–25 years old). Participants were divided into two groups. The first group was first presented with the condition in which roughness decreased when the direction matched, then the condition in which roughness increased when the direction matched. The second group experienced the conditions in the reverse order. Three exercise tasks were performed before each measurement period, and experiments were conducted after the method was explained in detail. Participants performed the experiments with their hearing blocked, to prevent them hearing the sound generated by the device.

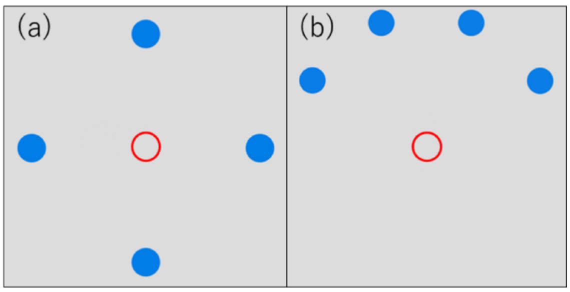

Fig. 6 Arrangement of the target point; in both position conditions, the target was located equidistant from the starting point (red circle): (a) CROSS; (b) SPREAD

Result. Fig. 7 shows the results of the preliminary experiment. The horizontal axis shows two types of presentation methods of anisotropic roughness. In the DECREASE method, roughness decreases in the guidance direction. In the INCREASE method, roughness increases in the guidance direction.

The response times are shown in Fig. 7 (a). The vertical axis shows the time taken to respond, and the horizontal axis shows the two types of presentation method for anisotropic roughness. Error bars indicate the standard deviation. The search time was shorter when searching with the DECREASE method compared with the INCREASE method ($p < .001$, t-test).

Participants' response accuracy is shown in Fig. 7(b). The vertical axis shows the average correct response rate, and the horizontal axis shows the two kinds of presentation methods of anisotropic roughness. The results revealed that the DECREASE method resulted in a higher correct answer rate, but the difference did not reach statistical significance.

The results described above confirmed that the method in which the roughness decreased towards the guidance direction was more appropriate. Based on these findings, we used this method in subsequent experiments.

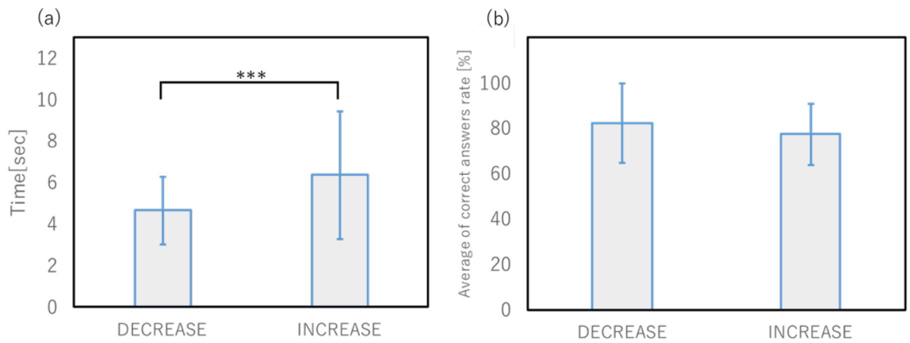

Fig. 7 Measurement result of preliminary experiment: (a) answer time for each guidance direction presentation method; (b) correct answer rate for each guidance direction presentation method. (*** $p < .001$)

5.2 Experiment 1: Comparison of Isotropic Roughness and Anisotropic Roughness

Procedures and Tasks. We conducted experiments comparing our proposed anisotropic roughness presentation method with an isotropic roughness presentation method, which depends on positional information. As in the preliminary experiments, participants were required to search for one correct target among four targets, as shown in Fig. 6. For isotropic (position-based) roughness presentation, we used a method that was dependent on the distance to the target. In this method, roughness decreases as the cursor approaches the correct target, and increases as the cursor gets farther away. In other words, by searching for a position with low roughness, it is possible to identify the correct target. The vibration is presented only while the finger moves, because continuous vibration is impractical.

In this experiment, we tested a CROSS (Fig. 6 (a)) configuration, in which the targets were placed at the four sides, and a SPREAD (Fig. 6 (b)) configuration, in which the targets are gathered in a narrower configuration than the CROSS. The SPREAD configuration is assumed to be more difficult to navigate. In both target arrangement conditions, the targets were equidistant from the starting point (red circle).

As in the preliminary experiment, each trial was defined as the selection of one target from the starting point. Each measurement period involved 20 trials (five trials for each of the four targets). Participants performed four measurements involving two types of arrangement conditions × two types of induction methods, in a random order.

We recruited seven participants (seven right-handed males, 21–25 years old). Three exercise tasks were performed before each measurement, and experiments were conducted after the method was explained in detail.

Result. Fig. 8 shows the results of Experiment 1. The response times in each measurement condition are shown in Fig. 8(a). The vertical axis shows time, and the horizontal axis shows the condition. Error bars indicate standard deviation. The results of a two-factor analysis of variance (two target arrangement conditions × two guidance methods) revealed a significant main effect of arrangement condition (F [1, 1] = 21.472, $p < .001$). In addition, we found a significant main effect of guidance method (F [1, 1] = 8.258, $p < .01$), indicating that anisotropic roughness presentation enabled participants to respond in a shorter time than isotropic roughness presentation.

Fig. 8 (b) shows the average correct response rate in each measurement condition. The vertical axis shows the average correct response rate, and the horizontal axis shows each measurement condition. The results of a two-factor analysis of variance (two target arrangement conditions × 2 derivation method conditions) revealed no main effects in any condition.

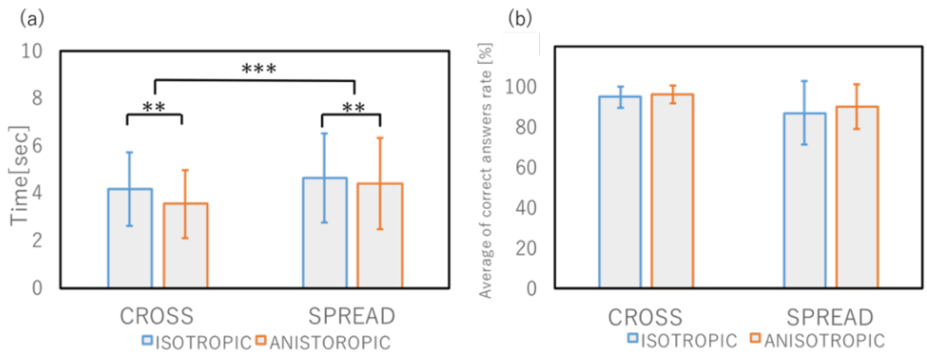

Fig. 8 Results of Experiment 1: (a) response times in each measurement condition; (b) correct response rate for each measurement condition. (** $p < .01$, *** $p < .001$)

5.3 Experiment 2: Comparison in Complex Guided Tasks

Procedure and Tasks. As an advanced version of the experiment described in Section 5.2, we conducted an experiment requiring participants to unlock a pattern formula lock on a smartphone lock screen using roughness guidance. As shown in Fig. 9 (a), one of the nine targets was set as the starting point. The measurement began when the participant tapped the starting point. In the search phase, the two types of roughness change were used to guide the finger (Fig. 9(b)). By tapping the target, the target was registered as a passing point, and the route was drawn. At this time, if an erroneous target was tapped, it was not registered, but was recorded as a miss tap, and search was restarted. This process was repeated in four trials. When a pattern was drawn by four routes, the trial ended (Fig. 9 (c)). The whole duration and the number of miss taps were recorded. The starting point and the route were generated randomly for each trial.

In each measurement period, the unlocking task was performed 20 times. Participants performed two measurements under two conditions: isotropic roughness and anisotropic roughness. We recruited six participants (three males and three females, 21–24 years old, five right-handed and one left handed). Participants were divided into two groups. The first group was presented with the isotropic roughness condition first, followed by the anisotropic roughness condition. The second group was presented with the conditions in the reverse order. Participants performed three practice trials before each measurement period, and began the experiment after a full explanation of the method. In addition, participants performed experiments while their hearing was blocked so they could not hear the sound generated by the device.

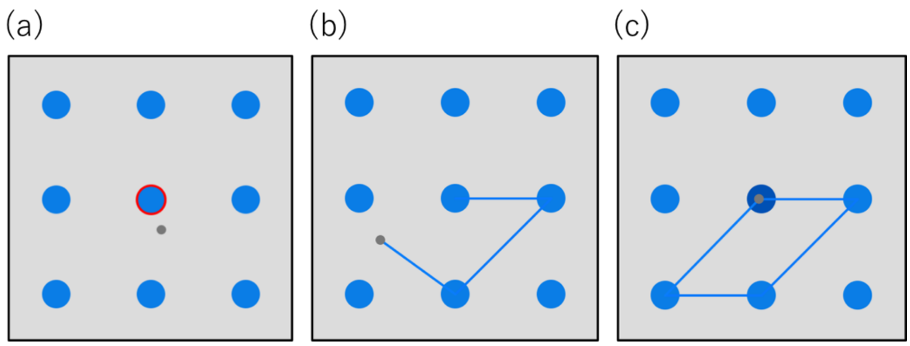

Fig. 9 Pattern formula unlocking task: (a) Standby phase: the starting point (red circle) is set to a random position; (b) Search phase: participants search for the target according to guidance cues; (c) Exit phase: The fourth target is selected, and the participant exits the task.

Result. Fig. 10 shows the results of Experiment 2. Fig. 10 (a) shows the response time for one task. The vertical axis shows time, and the horizontal axis shows the guidance method condition. Error bars indicate standard deviation. It was confirmed that using anisotropic roughness required a shorter time compared with isotropic roughness ($p < .001$, t-test).

Fig. 10 (b) shows the number of miss taps per trial. The vertical axis shows the number of miss taps that occurred per trial, and the horizontal axis shows the guidance method. The results confirmed that the number of miss taps was lower when anisotropic roughness presentation was used ($p < .05$, t-test).

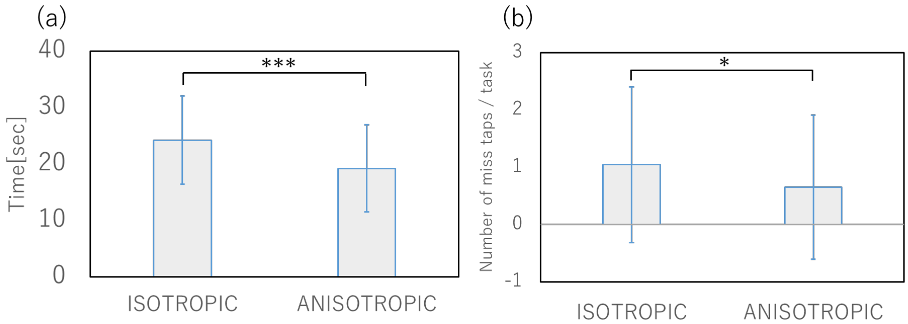

Fig. 10 Results of Experiment 2: (a) Response time for each guidance method condition; (b) Number of miss taps per task in each guidance method condition. (* $p < .05$, *** $p < .001$)

6 Discussion

In the preliminary experiment, we compared two roughness reduction methods: a method in which roughness was decreased, and a method in which roughness was increased, when the finger moved towards the target. The results revealed that the method of decreasing roughness was more suitable for guidance, as originally hypothesized. Many participants commented that decreasing roughness was easier to understand, largely because the upper limit of vibration was difficult to understand in the increasing roughness method; thus, the lower bound with no roughness was relatively easy to understand. We originally speculated that it might be perceived physically or mentally more difficult to move in a direction if roughness increased. However, no participant mentioned difficulty in finger movement. Rather, participants appeared to perceive the tactile presentation as a simple symbolic tactile cue.

In Experiment 1, the cursor was haptically guided to the correct target among several candidates, using two methods: the proposed anisotropic texture presentation method, and the isotropic texture presentation method. It should be noted that isotropic texture presentation is easier to implement, because it only requires positional information. In contrast, anisotropic texture presentation requires a velocity vector, which necessitates fast-response touch sensing. In the present case, this was achieved using a stable 50 ms latency in our system configuration. The experimental results revealed that the method using anisotropic roughness presentation resulted in shorter response times than the conventional distance-dependent isotropic method. Isotropic roughness presentation requires searching around each target, whereas anisotropic roughness presentation can provide guidance direction with less movement. Furthermore, because isotropic roughness presentation depends on the location, many participants searched exhaustively for the target and were unable to search using the optimal route. In contrast, there was no significant difference in the correct response rate, and both methods can be considered sufficient for guiding search.

Experiment 2 was an advanced version of Experiment 1, with a task involving unlocking a pattern formula lock. As in Experiment 1, the response time was shorter when guidance was provided via anisotropic roughness. Similar to Experiment 1, some participants used brute-force search in the isotropic roughness presentation condition. This tendency was not observed when anisotropic roughness was presented, and most participants connected the targets with straight lines. These results indicate that the anisotropic roughness method was able to present the route by limiting the movement direction.

The number of miss taps was also reduced when the anisotropic roughness method was used, which may have also contributed to the decreased response time.

7 Conclusion

In the current study, we developed a system to guide a finger in a specific direction on a touch device by presenting tactile cues, named anisotropic roughness presentation. This method was achieved by vibrotactile presentation that depended on the direction of motion of the finger with respect to the designated direction. We initially hypothesized that increasing the roughness of a surface would make it more difficult for users to move. Our preliminary experiment showed, however, that while decreasing roughness presentation along the designated direction was effective, users comprehended the stimuli symbolically. Subsequently, in Experiments 1 and 2, we compared isotropic roughness presentation with our proposed direction-dependent anisotropic roughness presentation. In both experiments, anisotropic roughness presentation significantly shortened the response time.

In Experiment 2, participants were required to search for an unknown unlocking-pattern. When anisotropic roughness presentation was used, many participants searched along the path of the pattern. This result suggests that the proposed method could be used not only for presenting a target destination, but also for presenting a route (i.e., navigation).

All experiments in the present study were conducted under conditions in which the route was invisible. However, in some applications it is appropriate for the route to be visible, such as in alphabet-learning for infants. In future experiments, we plan to test our method in such applications.

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References

1. A. Sears, "Improving touchscreen keyboards: Design issues and a comparison with other devices", Interacting with Computers, 1991, pp. 253–269.
2. A. Hasegawa, T. Yamazumi, S. Hasegawa, and M. Miyano, "Evaluating the input of characters using software keyboards in a mobile learning environment", Wireless, Mobile and Ubiquitous Technology in Education, 2012 pp. 214–217.
3. M. Fukumoto and T. Sugimura, "Active click tactile feedback for touch panels", SIGCHI Conference on Human Factors in computing Systems, 2001, pp.121–122.
4. O. Bau, I. Poupyrev, and C. Harrison, "TeslaTouch: Electrovibration for touch surfaces," in UIST '10 Proc. of the 23nd Annual ACM Symposium on User Interface Software and Technology, 2010, pp.283–292.
5. T. Watanabe and S. Fukui, "A method for controlling tactile sensation of surface roughness using ultrasonic vibration", IEEE International Conference on Robotics and Automation, 1995, pp.1134–1139.
6. M. Takasaki, H. Kotani, T. Mizuno, and T. Nara, "Transparent surface acoustic wave tactile display", Intelligent Robots and Systems (IROS), 2005, pp. 3354–3359
7. L. Winfield, J. Glassmire, J. E. Colgate, and M. Peshkin, "T-Pad: tactile pattern display through variable friction reduction", EuroHaptics Conference 2007 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, IEEE World Haptics Conference, 2007, pp.421–426.
8. S. Asano, S. Okamoto and Y. Yamada, "Toward quality texture display:Vibrotactile stimuli to modify material roughness sensations", Advance Robotics, 2014, pp.1079-1089.
9. T. Yamauchi, S. Okamoto, M. Konyo and S. Tadokoro, "Realtime remote transmission of multiple tactile properties through master-slave robot system", Proceedings of IEEE International Conference on Robotics and Automation, 2010, pp. 1753-1760.
10. C. Ho, J. Kim, S. Patil, and K. Goldberg, "The Slip-Pad: A haptic display using interleaved belts to simulate lateral and rotational slip", IEEE World Haptics Conference, 2016, pp.189–195.
11. A. Roudaut, A. Rau, C. Strez, M. Plauth, P. Lopes, and P. Baudisch, "Gesture output: eyes-free output using a force feedback touch surface", SIGCHI Conference on Human Factors in computing Systems, 2013, pp.2547–2556.
12. S. Saga and K. Deguchi, "Lateral-force-based 2.5-dimensional tactile display for touch screen", IEEE Haptics Symposium, 2012, pp.15–22.
13. J. Jung, E. Youn and G. Lee, "PinPad: Touchpad Interaction with Fast and High-Resolution Tactile Output", SIGCHI Conference on Human Factors in computing Systems, 2017, pp.2416-2425.
14. R. L. Klatzky, S. Adkins, P. Bodas, R. Haghighi Osgouei, S. Choi and H. Z. Tan, "Perceiving Texture Gradients on an Electrostatic Friction Display", IEEE World Haptics Conference, 2017, pp.154-158.