ThumbSlide: An Interaction Technique for Smartwatches using a Thumb Slide Movement

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Abstract
We present ThumbSlide, which is an interaction technique for a smartwatch that prevents occlusion caused by the user's finger; the technique realizes continuous manipulation by estimating the moving amount of the thumb. Combining with any determining operation (e.g., clench of the hand), our technique enables the user to select a target by only the hand that is wearing a smartwatch. Our system estimates the moving amount of the thumb by muscles' expansion caused by its movement. The muscle expansion is measured by a specially designed wrist-worn sensor device. Moreover, the device can recognize the clench of the hand as an instantaneous change of the wrist's contour. In this paper, we show the implementation of ThumbSlide and its example applications.

Author Keywords
Gestures; on-body interaction; wrist's contour; wearable computing; photo-reflectivity.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces - Interaction styles, Input devices & strategies.

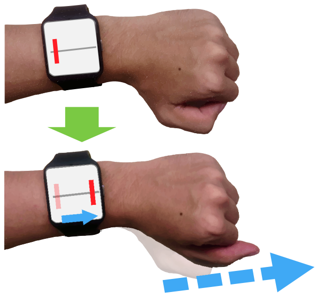

Figure 1: ThumbSlide.

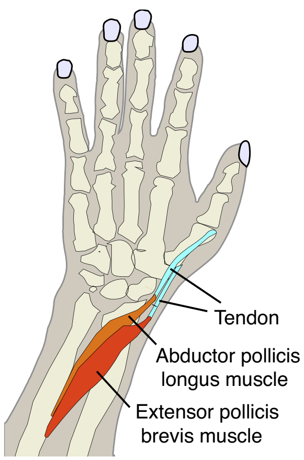

Figure 2: Muscles and tendons related to thumb slide movement.

Introduction

Smartwatches equipped with a touch screen have computational power sufficient enough to incorporate many functions, however, the touch screen severely limits its usage. This is because a touch screen requires touch interaction by a hand that is not wearing a smartwatch. In addition, the touch screen is so small that it causes the fat finger problem [12].

In this paper, we present an interaction technique for smartwatches to extend the interaction space outside the touch screen, and enable the user to control the smartwatch only by the hand that is wearing it. Specifically, this interaction technique enables continuous manipulation by recognizing the sliding movement of the thumb to the right or left direction on the side of the index finger. For example, when a user slides the thumb, the bar displayed on a smartwatch moves towards the same direction as the thumb (Figure 1). When our technique is combined with any determining operation, it enables the user to select a target only by the hand that is wearing a smartwatch. Furthermore, extending the interaction space exterior to the touch screen solves the fat finger problem.

This work provides the following contributions:

1. We present an interaction technique for a smartwatch that extends the interaction space exterior to the touch screen, and that enables the user to control the smartwatch only by the hand that is wearing it.
2. We present the algorithm for recognizing the thumb's sliding movement from muscles expansion without machine learning.
3. We present example applications of our interaction technique.

Related Work

There has been much work for extending the interaction space around a wearable wrist-worn device. For example, SkinWatch [9] uses skin as an input area by attaching Infrared (IR) proximity sensors at the back of the a smartwatch. Skin Buttons [8] projects icons on skin to use the skin as an input area by detecting touches on the icon with IR proximity sensors. Xiao et al. [14] use the watch's face as a mechanical interface to enable users to pan, twist, tilt, and click. In contrast to these work that requires the hand that is not wearing a smartwatch, we focused on designing an interaction technique that only uses the hand that is wearing it.

There is also much work for recognizing hand or finger gestures. For example, eRing [13] recognizes hand and finger gestures with a single ring. This work applies an electric field around the ring and measures the changes of the electric field caused by the other fingers and the hand itself. Magic Ring [7] recognizes finger gestures with the accelerometers embedded in the device on fingers. Hasan et al. [6] recognizes hand gestures with electromyography (EMG). While these work attaches the sensing device to the arm or finger, our work hides the sensing device inside a belt of the smartwatch.

The idea to use the change of the wrist's contour to recognize hand gestures already exists. For example, Fukui et al. [2] and Ortega-Avila et al. [11] constructed wristbands with IR proximity sensors to recognize hand gestures by measuring the wrist's contour. WristFlex [1] recognizes hand gestures by measuring the wrist's contour using the wrist-worn pressure sensors. In contrast to these work that uses the change of the wrist's contour for recognizing static gestures, our work uses it for estimating the moving amount of the thumb.

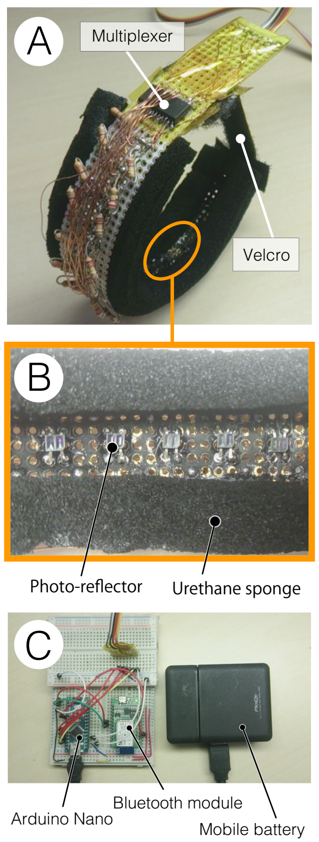

Figure 3: Hardware.
A) Experimental wrist-worn sensor device, B) photo-reflectors surrounded by a frame made of urethane sponge, C) the microcontroller and the Bluetooth module on the breadboard.

ThumbSlide

ThumbSlide is an interaction technique for a smartwatch that prevents occlusion caused by the user's finger by enabling the user to control it by the hand where the user is wearing it. ThumbSlide uses the thumb's sliding movement to the right or left direction on the side of the index finger (thumb slide movement).That is, when a user performs a thumb slide movement, ThumbSlide system estimates the moving amount of the thumb (Figure 1); the system can use them for continuous manipulation (e.g., moving a cursor displayed on a smartwatch). To recognize a thumb slide movement, we use a wrist-worn sensor device. In this section, we describe our implementation of ThumbSlide system.

Recognizing thumb slide movement

We use the change of the wrist's contour for recognizing the thumb slide movement. Such change is caused by the movement of the muscles and tendons with the movement of the fingers, which Figure 2 shows. The abductor pollicis longus muscle and the extensor pollicis brevis muscle are the muscles for abducting the thumb. These muscles expand when a thumb slide movement is performed, resulting in the expansion of the wrist's contour. Our approach to recognize the moving amount of the thumb is to measure this expansion by a wrist-worn sensor device.

Experimental wrist-worn sensor device

To examine how the wrist's contour changes when a thumb slide movement is performed, we constructed an experimental wrist-worn sensor device. In the same way as [2], this device measures the wrist's contour using an array of photo-reflectors, each of which measures the distance from the sensor to the skin's surface. To measure the whole circumference of wrist's contours, we designed the device to cover the whole wrist.

Figure 3 shows the hardware which we constructed. The hardware consists of the wrist-worn device, a microcontroller, and a Bluetooth module (RN-42, Microchip). The wrist-worn device was constructed on a flexible circuit board (230 mm $\times$ 21 mm $\times$ 0.4 mm). There are 16 photo-reflectors (TPR-105F, GENIXTEK) and a multiplexer (CD74HC4067, Texas Instruments) on the circuit board. Furthermore, the photo-reflectors are surrounded by a frame made of urethane sponge to make space between the photo-reflectors and skin surface and also to prevent the photo-reflectors from being exposed to ambient lighting. The height of the sponge is 10 mm; its inside area is 140 mm $\times$ 10 mm. The wrist-worn device is attached to the wrist by Velcro. The microcontroller and the Bluetooth module are on the breadboard. The Bluetooth module transmits sensing data to a smartphone connected with the smartwatch.

Hypothesis on the change of wrist's contour

Our hypothesis on the change of wrist's contour is that the total value of sensors above the abductor pollicis longus muscle and the extensor pollicis brevis muscle increases in proportion to the thumb slide movement towards the wrist. We call the total value "expansion amount." If the hypothesis is supported, the system can use this expansion amount for estimating the moving amount of the thumb. Moreover, by using the total value of sensors above the muscles, the system absorbs individual differences such as the thickness of the arm because, even if the sensor position shift slightly, any of these sensors can cover the muscles.

Measurement the Wrist's Contour

We conducted a preliminary experiment to collect wrists' contour data during thumb slide movement. The purpose of this data collection is to test the hypothesis that the expansion amount increases in proportion to the thumb slide movement towards the wrist.

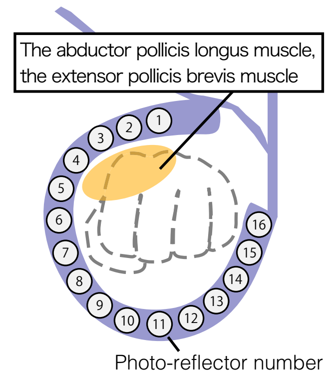

Figure 4: The positional relationship between the device and the wrist.

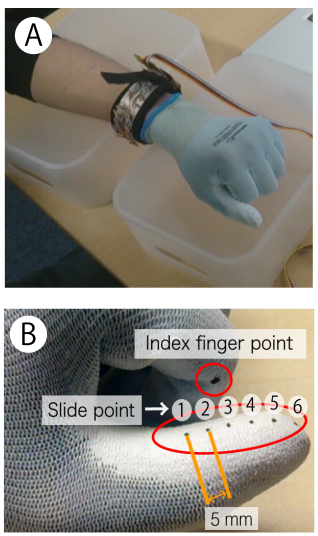

Figure 5: Experimental condition. A) Posture and B) slide points and the index finger point on the glove.

Setup

5 volunteers (all male, aged from 21 to 23) participated in this experiment. We asked the participants to wear the experimental wrist-worn sensor device on their left wrist as shown in Figure 4. In addition, we asked them to wear the nylon glove coated with polyurethane on their left hand. As shown in the Figure 5, the thumb of this glove is marked with 5 points at an interval of 5 mm. We call each point a "slide point." Furthermore, the side of the index finger of this glove is marked with a point. We call this point the "index finger point." The purpose of wearing the glove is to make the moving amount of the thumb the same among participants. Moreover, as the position of the thumb and the index finger is the same among participants, we can compare the sensor values for each thumb's position for all participants. We also asked them to clench their fist and rest the hand and the arm on the base. We did this to measure the expansion amount under the condition where the position of the arm, the bending angle of the wrist, and the bending angles of the finger were stabilized, preventing the influence of individual difference in the position of the arm and finger. Moreover, by stabilizing them, we can collect only the data with respect to a thumb slide movement.

Task

Initially, we asked the participants to overlap the index finger point with slide point 1. Next, the participants slid the thumb to overlap the index finger point with slide point 2. The participants repeated sliding the thumb until the index finger point overlapped with slide point 6. The participants performed this procedure 5 times. We recorded wrist's contour data when each slide point overlapped with the index finger point.

Results

The change of wrist's contour by thumb slide movement

Figure 6 shows the change of each sensor value caused by sliding the thumb from slide point 1 to slide point 6. In this figure we subtracted the sensor value of slide point 1 from the sensor value of slide point 6. Figure 7 shows the average of the 5 participants's data. These two figures show that, when the thumb is slid towards a wrist, the wrist surface swells around the position where photo-reflector 4 is. Since there are the abductor pollicis longus muscle and the extensor pollicis brevis muscle at the position as shown in Figure 4, this result show that our device can measure the expansion amount.

The proportional relationship between the moving amount of the thumb and the expansion amount

Figure 8 shows how much the expansion amount at each slide point changes from the sensor value of slide point 1. This graph shows the proportional relationship between the moving amount of the thumb and the expansion amount.

The algorithm to estimate a thumb slide movement

The above result supports the hypothesis. As a result, we can built a simple algorithm to estimate thumb slide movement: the moving amount is estimated by comparing the current expansion amount with the minimum value and maximum value of the expansion amount; it is calculated as $(cur - min)/(max - min)$, where min and max represents the minimum value and maximum value of expansion amount, and cur represents the expansion amount which is used for estimation. These min and max can be obtained by a simple calibration process in which the user performs a thumb slide movement once. By this, ThumbSlide system can obtain the minimum and maximum of the expansion amount.

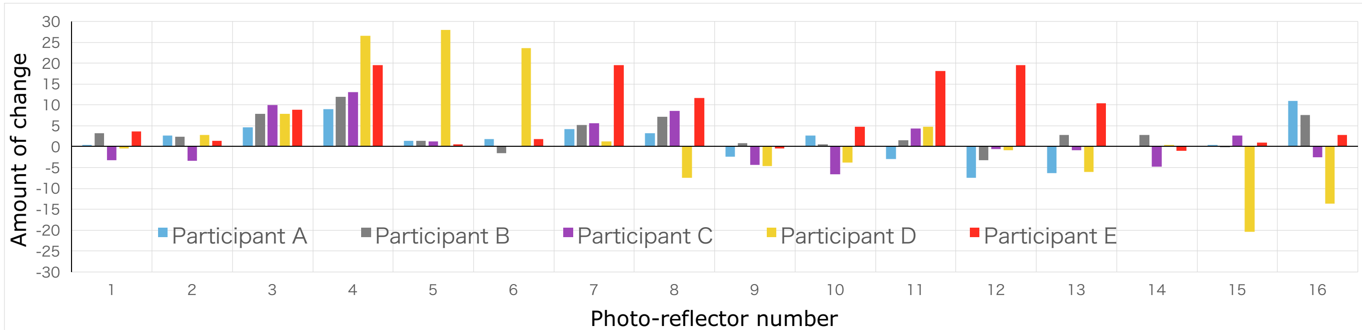

Figure 6: The change of sensor values by thumb slide movement.

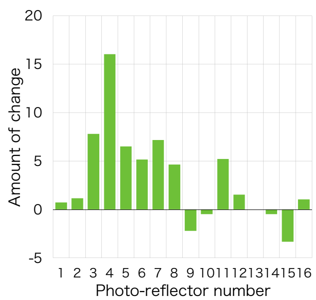

Figure 7: The average of the 5 participants's data.

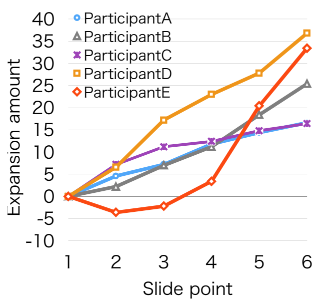

Figure 8: The change of the total value of 1 – 4 photo-reflectors (expansion amount).

Example Applications

To implement applications of ThumbSlide, we constructed a compact wrist-worn sensor device that a user attaches inside of the belt of a smartwatch. Figure 9 shows this device. In this device, the circuit board was divided into pieces, each of which has a photo-reflector and is attached to rubber cloth. Thereby, we made the device more flexible and fit to the wrist. Additionally, we lowered the height of the frame surrounding photo-reflectors as much as possible to make the device compact. We made the height 3 mm, as the photo-reflector's (TPR-105F) detective distance is 1 mm – 10 mm. We attached the device inside of the belt of a Sony SmartWatch 3 to test our example applications.

Invaders Game

We developed "Invaders Game" (Figure 10A) played with ThumbSlide. In this game, the laser cannon shoots continuously. The user controls the space ship only horizontally. A game played with ThumbSlide enables the user to play by only the hand that is wearing a smartwatch. In addition, ThumbSlide allows the user to enjoy a game that needs continuous manipulation, without occlusion.

Image Gallery

We developed "Image Gallery" (Figure 10B) manipulated with ThumbSlide and the determining operation. The user selects an image from the thumbnail menu using the ThumbSlide and the clench of the hand as the determining operation. Then, the selected image is expanded. This example shows that ThumbSlide can be applied to a variety of applications when combined with any determining operation.

Discussion and Future Work

Recognizing the determining operation

In Image Gallery, the determining operation is recognized by instantaneous change of the wrist's contour caused by the clench of the user's hand; it is recognized by examining whether the instantaneous change of the sum of 16 photo-reflectors sensor value is larger than a threshold. In this method, clenching user's hand influences estimating the moving amount of the thumb. However, it is not a problem for selecting a target because the determining operation is recognized before such influence is given. As another approach, we plan to use accelerometers to recognize a thumb's tap on the side of the index finger as shown in [3].

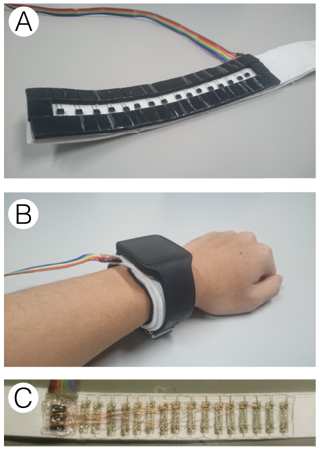

Figure 9: Compact wrist-worn sensor device, A) Overview, B) Usage, C) The inside of the device.

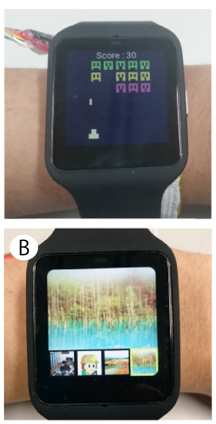

Figure 10: Example applications, A) Invaders Game, B) Image Gallery.

The influence by the movement or twist of the arm
In our example applications, when the movement or twist of the arm is detected by the embedded accelerometer, our applications stop until the arm is stabilized. This is because the movement or twist of the arm affects the wrist's contour, resulting in the changes in the minimum value and maximum value of expansion amount. Thus, our system initializes the calibration data when the smartwatch detects movement or twist; when the applications restart, the calibration is conducted again.

Discriminating between an input state and a non-input state.
As a smartwatch is always worn, ThumbSlide system has to discriminate between the input state and the non-input state. To distinguish these states, we plan to use a specific action. Twisting an arm quickly will be an approach that activates ThumbSlide system, and allows the user to perform a thumb slide movement as the calibration. This process switch the system to the input state. On the other hand, if the system detects the movement or twist of the arm in the input state, the system goes into the non-input state. Another approach for discriminating will be that the system only accepts input on condition that user's fist is clenched.

Conducting further experiments
In our experiment, the participants were all males of similar age group and there was no variety in the experimental condition such as the thickness of the arm. Therefore, as future work, we plan to conduct experiments involving variety of participants such as women and children to investigate the influence of difference in thickness of the arm.

As a smartwatch is worn even in mobile conditions such as walking, it is essential to investigate the usability of ThumbSlide when the user is moving. However, the current implementation setup is not suitable to carry smartwatches while moving because the microcontroller and the Bluetooth module are on the breadboard and not on the wrist-worn sensor device. As future work, we plan to incorporate such elements into the wrist-worn sensor device, and conduct experiments to investigate the influence by moving.

Furthermore, we plan to conduct experiments to compare ThumbSlide against other input techniques (e.g., touch input and accelerometer-based input).

Applying ThumbSlide to more applications
In addition to the applications we have developed, we think that ThumbSlide can also be applied to other applications. For example, text entry on a smartwatch such as [10, 4, 5] will be a possibility. In contrast to these work which requires a hand that is not wearing a smartwatch, it is possible to enter text with one hand by applying ThumbSlide to it. As future work, we plan to study text entry using ThumbSlide. Additionally, ThumbSlide can be applied for authentication. For example, an application that uses the moving pattern of the thumb to release screen lock can be developed.

Conclusions

In this paper, we have presented ThumbSlide, a novel interaction technique for smartwatches based on thumb slide movement. To implement the technique, we constructed a wrist-worn sensor device and estimated thumb movements by comparing the sensor value with the calibration data (the minimum and maximum of sensor value in the thumb slide movement). The estimation is based on the hypothesis that the expansion amount (the total value of sensors above the abductor pollicis longus muscle and the extensor pollicis brevis muscle) increases in proportion to the thumb slide movement towards the wrist. Furthermore, we constructed a compact wrist-worn sensor device which enable a user to attach inside of a smartwatch, and show two example applications using it.

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