Investigating Accuracy of Tilting Operation on Wrist-worn Devices with Touchscreens

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Abstract
Since the tilting operation has shown to be useful as a technique for expanding the input vocabulary to a small device, such operation could be also useful to expand input vocabulary of wrist-worn devices. In this study, in order to explore new design guidelines of GUI and operation methods for smartwatches, we have investigated the accuracy of the tilting operation in smartwatches. We conducted an experiment using a cursor whose position is determined according to the direction and the angle of tilt. The result of the experiment shows that the deviation in the x-axis (i.e., the inclination of the arm) direction distributes between -0.10 degrees and $+0.07$ degrees and between -0.10 degrees and $+0.07$ degrees under Seating condition and Standing condition, respectively; the deviation in the y-axis (i.e., the rotation of the wrist) direction distributes between -0.12 degrees and $+0.10$ degrees and between -0.12 degrees and $+0.09$ degrees.

Author Keywords
Smartwatch; pointing; cursor; motor skill; target acquisition accuracy.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: Interaction styles; Input devices and strategies; Benchmarking.

Introduction

Since the tilting operation has shown to be useful as a technique for expanding the input to the small device (e.g., PDA [9]), such operation could be also useful to expand input vocabulary of wrist-worn devices. There are smartwatches as one kind of wrist-worn devices. Among various wrist-worn devices such as UP2 [6], Surge [4], and SmartBand2 [5], smartwatches are used for a variety of applications, such as showing notification from a smartphone and health management. However input to the smartwatch with the ultra-small is limited due to "fat fingers" [10]. Therefore, using the tilting operation to expand input vocabulary is useful.

In this study, to explore new design guidelines of GUI and operation methods for smartwatches, we have investigated the accuracy of the tilting operation in smartwatches. We conducted an experiment using a cursor whose position is determined according to the direction and the angle of tilt. In addition, we implemented applications using the tilting operation based on the results of the experiment.

Related Work

In this section, we summarize the studies about the tilting operation and about the performance of the tilting operation.

In order to expand input vocabulary of mobile devices, various studies about the tilting operation has been conducted. Blowatch [1] and TiltType [8] used the tilting operation to expand input vocabulary of the device with an ultra-small screen, such as a smartwatch. In Blowatch, the user tilts a smartwatch to zoom-in or zoom-out a map or a camera after triggering the operation by blowing on the smartwatch. TiltType is a text entry technique using the tilting operation, with which the user tilts the device and presses one or more buttons to enter a character. The character depends on the direction of tilt, the angle of tilt, and the button pressed. Since the user uses both hands for operation in TiltType, it is necessary to remove the device from the wrist when the user inputs a text. The results of our study can be used in conjunction with these studies.

Performance of the tilting operation has been empirically investigated. Crossan et al. [3] investigated wrist rotation as a hands-free interaction with a mobile device. They conducted an experiment in pointing tasks using a cursor that moves one-dimensionally depending on the amount of rotation of the wrist. They applied Fitts' Law to the result and found that the correlation coefficient was above 0.5. Crossan et al. [2] evaluated the head tilting as an interaction with a mobile device. They compared two cursors (i.e., position-control and velocity-control) through pointing tasks in static condition and walking condition. As a result, the position-control showed higher performance than the velocity-control in static condition. In addition, the velocity-control showed higher performance than the position-control in walking condition. Teather et al. [11] evaluated the tilting operation on a tablet device. They conducted an experiment in 2D pointing task to compare position-control and velocity-control using the device's tilt to manipulate an on-screen cursor. As a result, position-control was about twice as fast as velocity-control. Similar to these studies, we investigated the accuracy of the tilting operation on wrist-worn devices through pointing tasks using a cursor whose position is determined according to the direction and the angle of tilt.

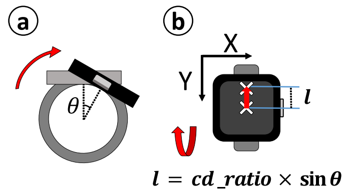

Figure 1: The movement of the cursor. (a) The rotation of smartwatch. (b) The amount of movement of cursor.

Figure 2: The screen of smartwatch in the experiment: (a) the standby screen; (b) the preparation screen; (c) the screen in the task.

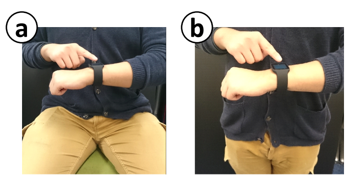

Figure 3: The pose conditions: (a) Seating; (b) Standing.

Experiment

We conducted an experiment in order to investigate the accuracy of the tilting operation on smartwatches.

Participants

The participants were eight university undergraduates / graduates (21–24 years old, M = 22.5). They had been using mobile devices for 0 to 71 months (M = 40.6). All of them had never used a smartwatch. They were all right-handed. We instructed them to wear a smartwatch on their left wrist and touch the screen by their right hand.

Apparatus and Software

The study was conducted using a SONY SmartWatch 3 SWR50 (Android Wear 1.1.1, 1.6-inch screen with a resolution of 320 px × 320 px). For investigating the accuracy of the tilting operation through pointing tasks, we implemented a cursor whose position is determined according to the direction and the angle of tilt. Figure 1 shows the movement of the cursor when the smartwatch is tilted at θ degrees. Since the amount of the movement is determined by $cd\_ratio \times \sin\theta$, the more the smartwatch tilts, the more the cursor will move widely. In other words, the position of the cursor by tilting at θ_x degrees in the x-axis (i.e., the inclination of the arm) and θ_y degrees in the y-axis (i.e., the rotation of the wrist) is $(x, y) = (160 + cd\_ratio \times \sin\theta_x, 160 + cd\_ratio \times \sin\theta_y)$. In this study, we experimentally determined the cd_ratio as 2300. Since the screen size of the smartwatch is 320 px × 320 px, the user can move the cursor in the entire screen by tilting the smartwatch at $3.99\ (= \arcsin(160/2300))$ degrees in each direction. We store the angle of the screen when the task starts as the reference angle ($\theta = 0$).

Task

Participants had to select the target displayed on the screen of the smartwatch. Figure 2 shows the screen of the smartwatch in this experiment. They, first of all, was holding the smartwatch to naturally watch the screen during the standby screen (Figure 2a). The angle of the screen at this time was recorded as the reference angle, and then preparation screen (Figure 2b) was shown. They started a task by tapping the preparation screen. Figure 2c shows the screen in the task. "×" in the screen is the cursor; "○" is the target.

As a trial, participants moved the cursor to the target by using the tilting operation, and tapped an arbitrary position of the screen when the cursor overlaps the target. A session consisted of 25 trials. We instructed participants to prioritize accuracy rather than time, i.e. to match the cursor and the target as well as possible. The target was displayed at a random position each time participants tapped once. Participants carried out the task in two poses conditions: Seating (sitting down on a chair) and Standing. Each pose condition is shown in Figure 3. During the session, they floated their left arm in the air. Each participant carried out six sessions (two practices and four sessions) in each pose condition. In total, each participant conducted 300 trials (25 trials × 6 sessions × 2 poses). After the experiment, the participants filled out a questionnaire. The experiment took about one hour per participant, including the prior explanation and answering the questionnaires. All participants were paid 820 JPY for their time.

Results

Before analyzing the data in detail, we removed 37 trials in which the position of the cursor was more than three standard deviations away from the average as outliers, because some participants performed pointing to unintended locations by tapping accidentally during the experiment.

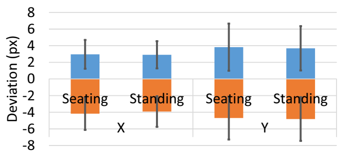

Figure 4: The deviation of the cursors' positions from the center of targets.

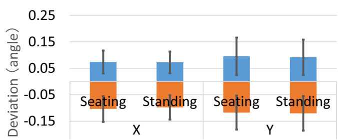

Figure 5: The angle of the deviation.

Deviation from the Target
Figure 4 shows the deviation of the cursors' positions from the center of targets in the x-axis and y-axis direction when the targets were selected under each pose condition. The deviation in the x-axis direction distributes between -4.17 px and $+2.96$ px and between -3.92 px and $+2.91$ px under Seating and Standing, respectively; the deviation in the y-axis direction distributes between -4.70 px and $+3.83$ px and between -4.82 px and $+3.83$ px.

Figure 5 shows the result of converting the unit of deviation from px to angle. The deviation in the x-axis direction distributes between -0.10 degrees and $+0.07$ degrees and between -0.10 degrees and $+0.07$ degrees under Seating and Standing, respectively; the deviation in the y-axis direction distributes between -0.12 degrees and $+0.10$ degrees and between -0.12 degrees and $+0.09$ degrees.

Figure 6 and Figure 7 show plots of the deviation and the time of each trial. According to these, it can be seen that the more time participant carry out, the shorter the deviation is. The average of the time of the one trial when the cursor is distributed within $1 \times \sigma$ is $3.95\ s$ under Seating and $4.08\ s$ under Standing.

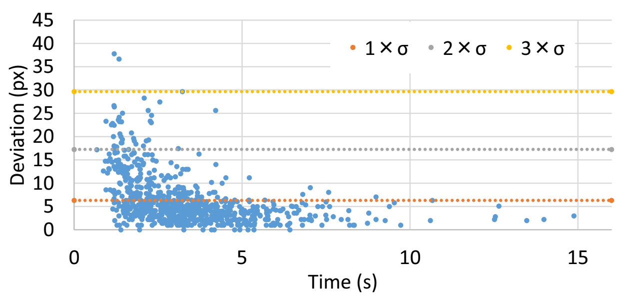

Figure 6: Plots of the deviation and the time under Seating.

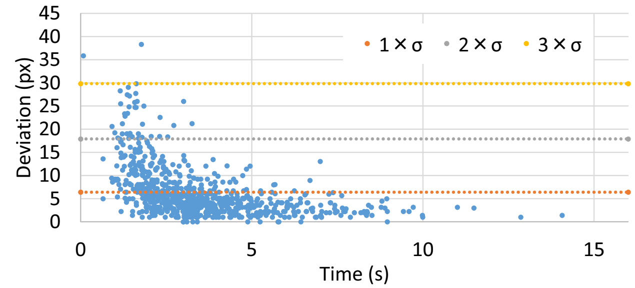

Figure 7: Plots of the deviation and the time under Standing.

Consideration

Figure 8 shows the distribution of the cursors' position from the center of the targets. The ellipses are the standard deviation. Figure 8 shows the results that the cursors' positions were distributed in a long elliptic in the y-axis direction. This indicates that the accuracy of the tilting operation of the x-axis direction was higher than that of the y-axis direction. In the participants' opinions, P8 commented about difficulty of the tilting operation in the y-axis direction, "Tilting operation in the direction of the wrist axis (i.e., in the y-axis direction) is the asymmetry in positive and negative direction. "

From Figure 8, it was seen that the density of the distribution of the cursors' position within $1 \times \sigma$ was high. On the other hand, the distribution of the pointing position was seen also outside $3 \times \sigma$. In order to investigate the reason, we investigated the distribution of the cursors' position from the center of the targets for each participant. The result is shown in Figure 10. The distribution of P1 and P3 was large compared to other participants. Since our instruction has been based on the subjectivity of the participants, the differences had appeared in each participant. According to Figure 9 illustrating the time of the one trial of each participant, the time of P1 and P3 is shorter than that of other participants under each pose condition. That is to say, there is a possibility that the distribution become equivalent that of other participants by putting more time.

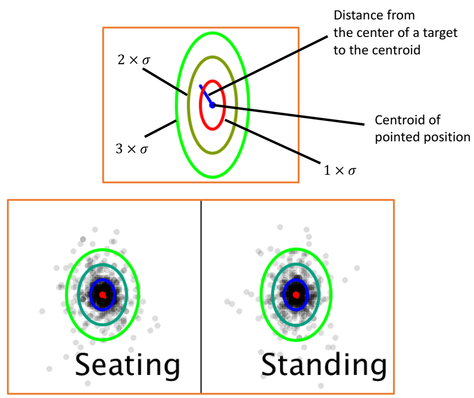

Figure 8: The distribution of the cursors' position from the center of targets.

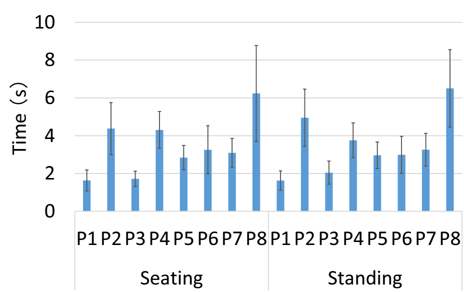

Figure 9: The time of the one trial of each participant.

Applications

QWERTY Keyboard

We implemented QWERTY Keyboard as shown in Figure 11. By tilting the user's arm wearing a smartwatch, the user can select a key that corresponds to the tilt. The key that has been selected is displayed in red, and the detailed position of the cursor is displayed as "$\times$". Another key is selected each time the user tilt the smartwatch at 0.80 degrees in the x-axis direction and at 1.00 degree in the y-axis direction. This value is used the result that the participants were able to select with 100 % accuracy in the experiment. When the user tap an arbitrary position of the screen, the character corresponding to the selected key is input. Since QWERTY Keyboard is longer in the x-axis direction, it match the properties of the tilting operation.

Game

We implemented a game using the tilting operation. The user moves the red circle (player character) by the tilting operation. The time kept avoiding the yellow circle is score. The position of the player character is $(x, y) = (160+cd\_ratio_x \times \sin\theta_x, 160+cd\_ratio_y \times \sin\theta_y)$. We determined the cd_ratio_x as 2300 and the cd_ratio_y as 1756 based on the aspect ratio of the ellipse of Figure 8,. We used the angle of the screen when the game starts as the reference angle ($\theta = 0$).

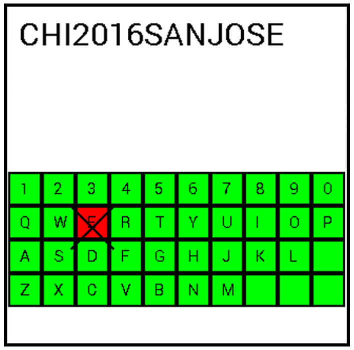

Figure 11: The QWERTY keyboard using the tilting operation.

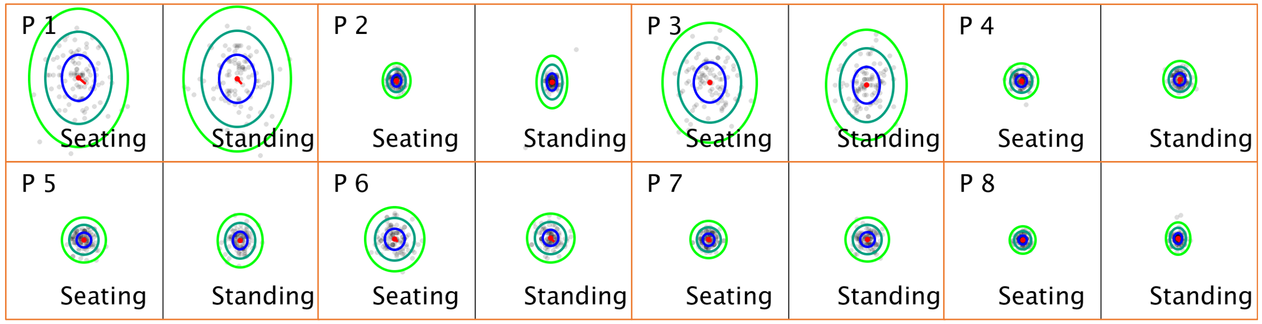

Figure 10: The distribution of the cursors' position from the center of the targets for each participant.

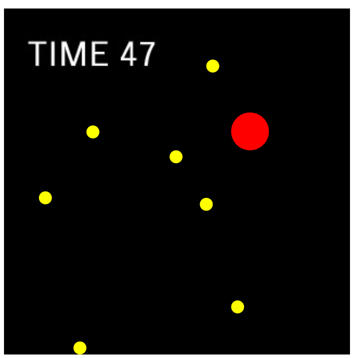

Figure 12: The game using the tilting operation.

Conclusion and Future work

In order to explore new design guidelines of GUI and operation methods for smartwatches, we have investigated the accuracy of the tilting operation in smartwatches. We conducted an experiment using a cursor that decides its position according to the direction and the angle of tilt. The results of the experiment shows that the deviation in the x-axis direction distributes between -0.10 degrees and $+0.07$ degrees and between -0.10 degrees and $+0.07$ degrees under Seating and Standing, respectively; the deviation in the y-axis direction distributes between -0.12 degrees and $+0.10$ degrees and between -0.12 degrees and $+0.09$ degrees. The accuracy of the tilting operation of the x-axis direction was higher than that of the y-axis direction. Based on these findings, we implemented applications using the tilting operation.

In future work, in order to investigate the user's feeling and workload, we should conduct further experiment through keyboard input tasks. We also plan to allow for one-handed operation using gestures of hand wearing the smartwatch. In order to recognize gestures, we should combine the smartwatch with a muscle potential measurement device (e.g., MYO [7]).

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