A Pointing Method Using Accelerometers for Graphical User Interfaces

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ABSTRACT

Graphical User Interfaces (GUIs) are widely used and pointing devices are required to operate most of them. We have proposed Xangle, a pointing method using two accelerometers for wearable computing environments. The cursor is positioned at the intersection of two straight lines, which are synchronized with the angles of the accelerometers at fingers. However, Xangle is difficult to be used in daily-life, when the user frequently changes which part of the body they point with. Therefore, we propose a method of changing the body parts used for pointing according to the situation. Additionally, we proposed a method to accelerate the pointer and a method to layout menu items for Xangle since these methods are suitable for using GUI in wearable computing environments. We confirmed that the proposed method was effective from the results of evaluations.

General Terms

Human Factors

Keywords

Wearable Computing, Pointing Method, GUI

1. INTRODUCTION

Graphical User Interfaces (GUIs) are widely used to intutively operate a computer because of their high visibility and operability. In most GUIs, a user uses a pointing device to operate the target such as icons and buttons. Here, computers are used not only in desktop environments but also in wearable computing environments, where a user wears a computer and input/output devices and acquires various services anytime and anywhere. In wearable computing environments, there are many situations when we cannot use our hands freely and they require hands-free pointing methods.

Various conventional pointing devices such as mouses, track balls, and joysticks have been developed. However, they need to be held. Although there has been research on hands-free pointing including hand gesture and eye-gaze input, the number of operations are limited and they are difficult to use, and there is no method that is compatible with conventional systems.

In order to solve this problem, We have proposed Xangle[1], which is a pointing method with two small accelerometers on fingers. Xangle separates two axes that are needed to point on 2D GUI and each axis is controlled by an accelerometer. However, this method cannot be used in a hands-free environment. For example, when a user carries a pack by both hands, he/she cannot uses his/her hand freely. We investigated how to enable Xangle to be used in daily-life. We propose a method to change the body parts to be used for pointing according to the situation, and additionally we propose a new menu and icon layout that is suitable for Xangle but not so far from conventional GUIs. Evaluation results confirmed that our methods work effectively in pointing tasks.

This paper is organized as follows. Section 2 introduces related work and Section 3 explains Xangle. Section 4 describes a proposed method to switch the body parts to be used in Xangle and Section 5 describes the proposed menu structure. Section 6 describes further enhancements of out methods, and Section 7 summarizes the paper.

2. RELATED WORK

There are various input devices such as the trackball and joystick, which can be used in wearable computing environments because they do not need a table to be used. For example, Air mouse[2] operates the pointer with the tilt of user's wrist using gyro sensor. However, since these devices need to be held, they cannot be used where both hands are occupied with other operations.

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There has been many researches on hand gestures. In Gesture Pendant[3], a user inputs gestures in front of a camera and an infrared floodlight attached to the pendant. WearTrack[4] enables pointing by detecting the position of finger tips using ultrasonic waves and three microphones. Other finger-based pointing methods[5, 6, 7] use an accelerometer attached to the tip of the index finger. They cannot be used in a hands-free envitonment because they require hand-operations.

There has also been much research on pointing with eye-gazes such as small-target selection with gaze alone[8] and effective-eye-gaze input into Windows[9]. Eye-Tracking[10] is a device that controls the pointer through eye-gaze. Eye-gaze pointing is not sufficient for pointing at small targets such as desktop icons. Moreover, to achieve clicking by eye movement, the system must select one of two ways: using a camera to detect the specific motion of eyes or using other sensors. The former burdens the user due to unusual eye motions, and the latter needs additional devices such as microphones that make the system complex and too heavy to wear.

There are researches on evaluation of input methods. There is a research that compares menu configurations in changing pointing devices[11]. Furthermore, there is a research exploring how to develop a pointing system for truly wearable[12]. As a research on multitasking, Ease of Juggling[13] evaluates the effect of operation in multitasking situations.

3. XANGLE

We have proposed Xangle, a pointing method with two accelerometers. Xangle is designed on the assumption that people can precisely and quickly control only one axis by moving a body part. Therefore, Xangle uses right and left straight lines, and the angle for each line is calculated from the gravitation of accelerometer that is attached on the body where the angle is almost equal to the angle of the fixed points. Xangle achieves intuitive operation because of direct mapping from angle to angle instead of from angle to speed.

An image of how the system is used in shown in Figure 1. A straight line (line A) is extended from the lower left of the screen (point A), and another straight line (line B) is extended from the lower right of the screen (point B). The slopes of two lines correspond to the tilt of these two accelerometers. The cursor appears on the intersection of these two lines. When one slope changes, the cursor moves along the other line. The slopes change with the tilt of accelerometer, and the cursor moves with the slopes. As a result, pointing is achieved by part of the body.

The following four steps explain pointing operations when the accelerometers are attached on both hands of user as shown in Figure 1:

1. By moving the accelerometer attached to the right hand, line B moves, and the cursor moves along the line A.

2. Line B arrives at the target.

3. Line A moves along with the movement of the left hand, and the cursor moves along straight line B.

4. When line A arrives at the target, the cursor reaches the target.

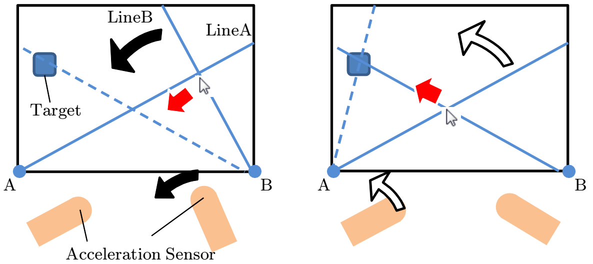


Figure 1: Pointing operations with our method

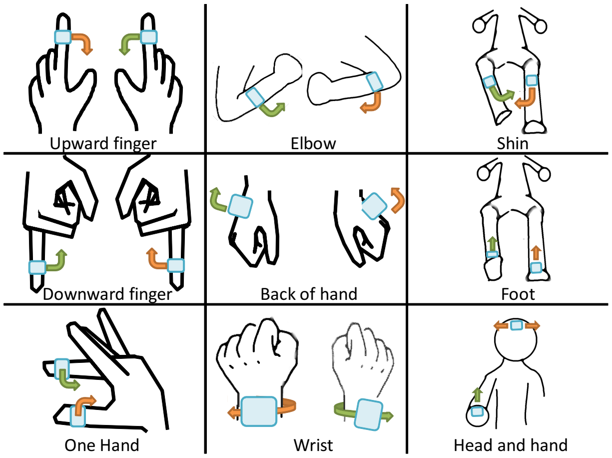


Figure 2: Fixed points

4. SWITCHING OF OPERATING PARTS

4.1 Body parts used in the method

To use Xangle in various situations, a user wears accelerometers on various parts on the body, which are used for pointing. Moreover, to switch the body parts to be used, the pivot points of straight lines should be modified in response to the range and direction of movement for the fixed points. We suppose nine fixed points as shown in Figure 2. These points use either the Pitch or Roll angle to calculate the cursor movement. We give a detailed description of the fixed points as follows:

Upward finger: Pointing is done with accelerometers on the upward finger. Pivot points of lines are located at 200 pixels downward from the bottom edge and at 100pixels outside from either side edge. These positions are decided by a preliminary evaluation of how easy it is to point.

Downward finger: Pointing is done with accelerometers on the downward finger. Pivot points are located at 200 pixels upward from the top edge and at 100 pixels outside from either side edge.

One hand: Pointing is done with accelerometers on the thumb and middle finger. Pivot points are located at 100 pixels outside from the top, bottom, and right edge. The accelerometer on the thumb correspond to

Figure 3: Snapshots of users in experiment

the line extending from right-bottom pivot point, and the accelerometer on the middle finger correspond to the line extending from the right-top pivot point.

Elbow: With accelerometers that are worn on elbows, pointing is done as the user opens and closes the armpit. Pivot points are located at 100 pixels outside from the bottom and either side edge.

Back of hand: With accelerometers which are worn on back of the hands, pointing is done as the user flexes the wrist back. Pivot points are located at 100 pixels outside from the bottom and either side edge.

Wrist: With accelerometers which are worn on wrist, pointing is done as the user rotates the wrists. Pivot points are located at 100 pixels outside from the bottom and either side edge.

Shin: With accelerometers which are worn on the shin, pointing is done as the user crosses the feet. Pivot points are located at 700 pixels outside from the top edge and at 300 pixels outside from either side edge.

Foot: With accelerometers which are worn on the instep, pointing is done as the user moves the insteps up and down after the user lifts his/her feet. Pivot points are located at 100 pixels outside from bottom and either side edge.

Head and hand: With accelerometers which are worn on the head and hand, pointing is done as the user flexes the wrist up and down and tilts the head left and right. There are one line extending from the pivot point and the other line horizontal line. Pivot point is located at 300 pixels downward from the bottom edge and at the center of side. The tilt of head correspond to the line extending from the pivot point. The other line on the wrist flexion corresponds to the height of the horizontal line.

4.2 Evaluation of pointing

We evaluated the pointing time for each fixed point in the three situations shown in Figure 3. Participants used a head mounted display (HMD). The available fixed points for each situation are listed as follows.

- Standing with both hands occupied:
  downward finger, back of hand
- Standing with one-hand occupied:
  upward finger, one hand, elbow, head and hand
- Sitting with both hands occupied:
  upward finger, wrist, elbow, shin, foot

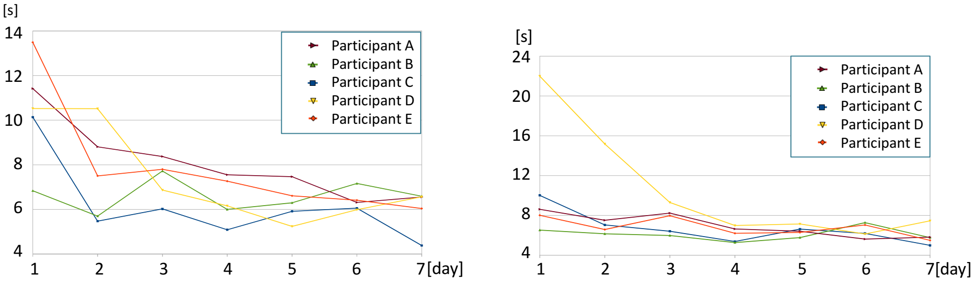
To reproduce the situation where the user is standing with both hands occupied, we had participants hold bags with both hands during the evaluation. Similarly, to reproduce the situation where the user is standing with one hand occupied, we made participants hang on to something like a strap with one hand during evaluation. Furthermore, to reproduce the situation where the user is sitting with both hands occupied, we had participants hold a book with both hands during evaluation. For the upward finger, the participants used the index finger. In downward finger, the participants use the little finger, and one hand of fixed points uses the thumb and the middle finger of right hand.

A click operation is executed if the cursor stays within 30 pixels during one second. As a comparison target from existing methods, we used an IR sensor and trackball. The IR sensor of Wii remote [14] is worn on the head and was used for when the user was standing with both hands occupied. The click of Wii remote is the same as the proposed method. We got the Wii remote under control by using the WiiRemote. In the situation when the user seated with one hand occupied, participants used the trackball. Participants clicked 50 pixels icon 5 times on HMD which had a 800 × 600-px screen. One set is consisted of 5 clicks, and participants performed 3 sets per a day. In a total of 15 clicks, the icon is arranged randomly in area a randomly chosen from the parts of screen divided into 5 × 3 equal parts. We measured the elapsed time of one set and calculate the average time of a click. There were five participants and the experimental period was 7 days.

4.3 Result

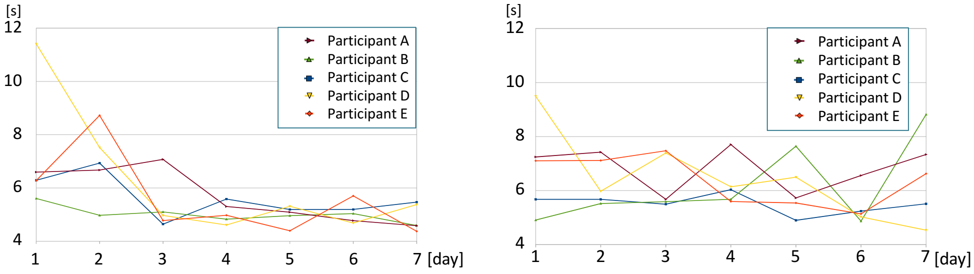
Level of proficiency

The elapsed time for each of participants in evaluation is shows in Figures 4-7. The y-axis shows the elapsed time of a click and the x-axis shows the number of evaluation times. As shown in Figure 5, we confirmed that the participants mastered this method before the 3rd or 4th day with the exception of when the shin or wrist was used. The cause of thses areas taking longer to master is the non-straightforward mapping from left-right rotation to up-down

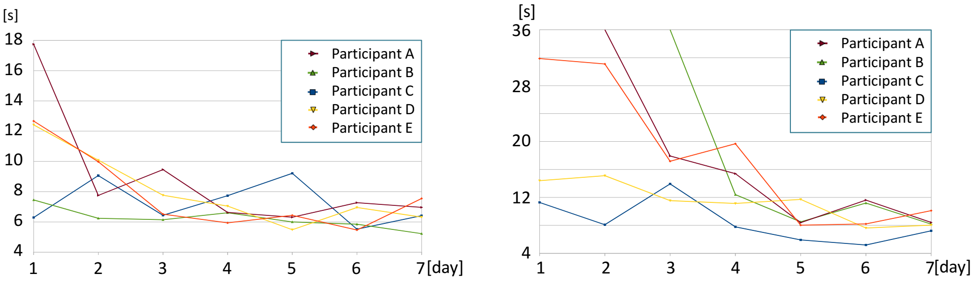


(a) Downward finger (b) Back of hand

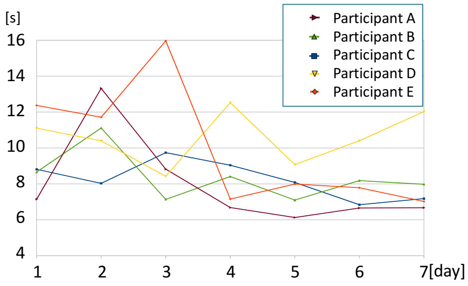
Figure 4: Elapsed time in standing with both hands occupied



(a) Upward finger (b) Wrist



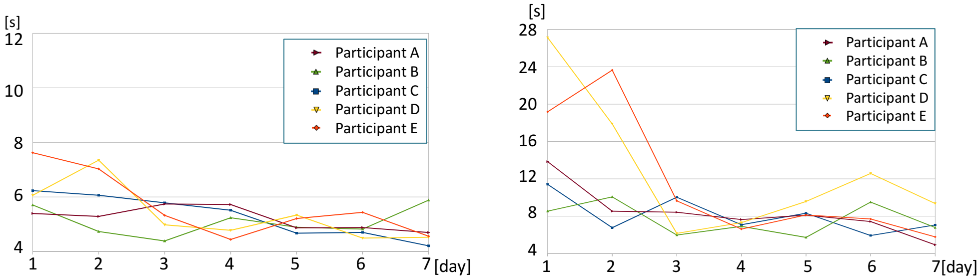
(c) Elbow (d) Shin



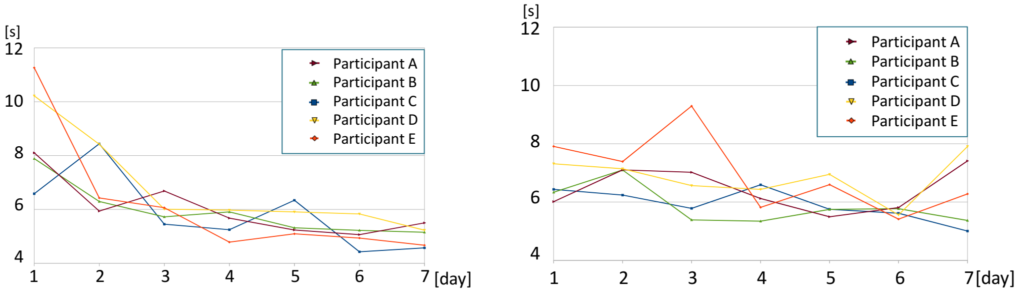
(e) Foot

Figure 5: Elapsed time when sitting with both hands occupied

rotation on the foot. Conversely, the other fixed points can be operated intuitively. The range of wrist movement is 180 ° , thus the participants sometimes rotated their wrist too much, which caused the angle to be lost and retarded the pointing time. Figure 7 shows elapsed time in the existing method. The level of proficiency of trackball converged at the first day, however the Wii remote needed three or four days to master due to a difference from usual operation method as is the case in the proposal method. Figure 4, 5, 6, and 7 show that the pointing time stays within 4 ∼ 8 seconds, so pointing can be done with all of fixed points as the situation demands.

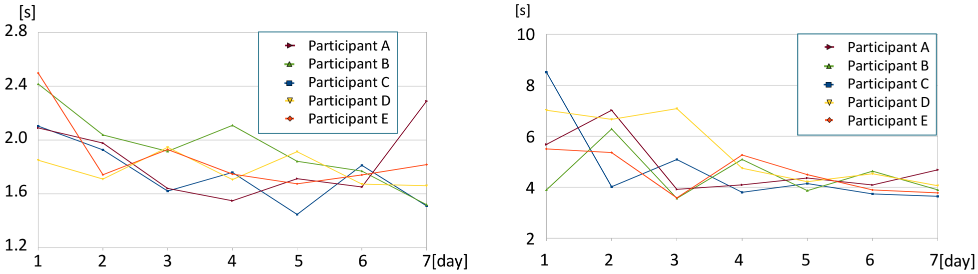


(a) Upward finger (b) One hand



(c) Elbow (d) Head and hand

Figure 6: Elapsed time in standing with one hand occupied



(a) Trackball (b) Wii remote

Figure 7: Elapsed time with existing devices

Influence of fixed points

Elapsed time per a click which are observed at the last day by proposal systems and existing devices is shown in Figure 8. The elapsed time of when the elbow was used and the participant iwas seated with both hands occupied is 2 seconds slower than that of the elbow where the participant was standing with both hands occupied. This is because the users cannot move the elbow freely when they have something in both hands. The movement range of fingers in one hand is too wide to shorten the pointing time. Furthermore, the factors of slow pointing time in one hand are that a finger movement affects the movement of the other fingers and that distance is far from the target of pointing which is located on the left edge of the screen because pivot points are located at the right edge. On the whole, elapsed time of feet is longer than hand, which is considered to be due to the difficulty of stopping for clicking.

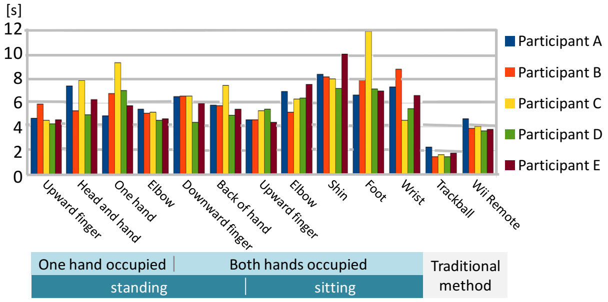
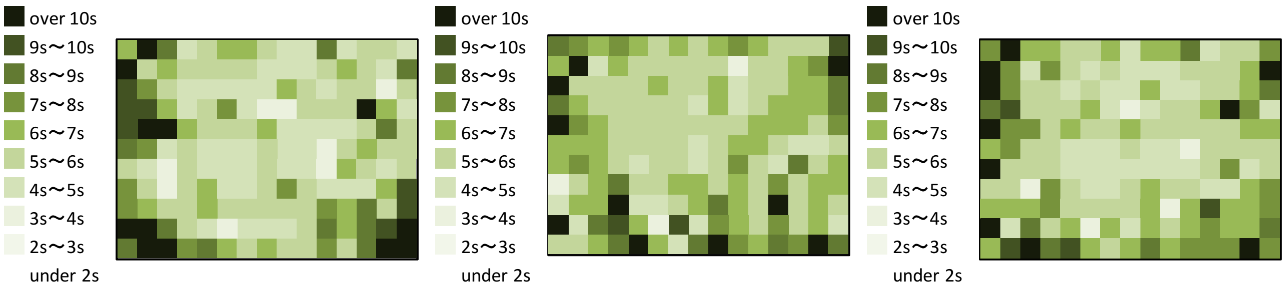


Figure 8: Elapsed time with each fixed points

The elapsed time of the proposed method is longer than that of existing devices. However, users need to have one hand free to be use the trackball. Thus, users cannot use it



(a) Movement distance under 400px (b) Movement distance over 400 px (c) All

Figure 10: Elapsed time for each target position

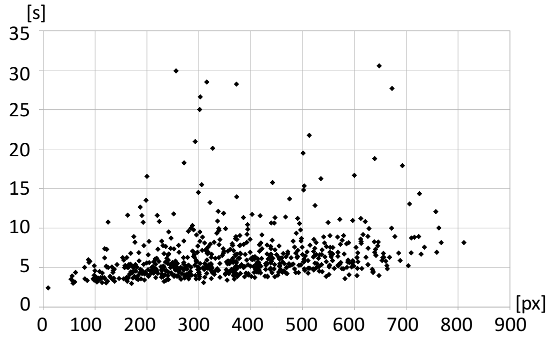


Figure 9: Relationship between elapsed time and movement distance

when both hands are occupied. To use Wii remote, the users needs to move his/her head. This makes it inconvenient because of the lack of eyesight stability, and the situation where users is in crowds is danger. Moreover, moving the head feels strange. Also, this draws undesired attention to the user. On the other hand, the proposed method can be operated in various situations by switching the operating parts.

Relationship between distance and elapsed time

The relationship between movement distance of cursor and elapsed time observed on the last day is shown in Figure 9. The elapsed time of each position of the display is shown in Figure 10. The darker the color, the longer the elapsed time. We confirmed that the most of the elapsed time is not the transferring time but the click time because elapsed time increased very little even if the distance from the icon was farfrom the cursor. When the target located at the screen edge, the elapsed time sometimes becomes very longer if the distance to be moved was short (Figure 10(a)). Thus, we need to simplify pointing at the screen edge. The difficulty of pointing at screen edge affects the total elapsed time.

5. MENU STRUCTURE FOR XANGLE

The arrengement of icon and menu structure in a GUI are based on Cartesian coordinates. This structure is quite good for usage in a traditional environment. However, when using the proposed method, control was achieved by the angles of two lines. We proposed a menu structure suited for Xangle. The menu items lie in both the lines shown in Figure 11, and the items can be selected by moving only one fixed point. The following steps explain how to point at menu items.

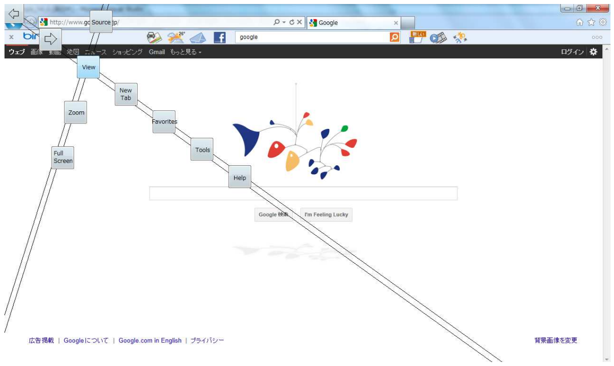


Figure 11: Arranging icons in menu

First, the menu items show after pointing at a particular position. Second, the menu items lie in one of the lines. Third, the sub-menu items lie in another line after one of the menu items is selected. Finally, we can select the sub-menu items.

We evaluated the elapsed time for when the upward finger motion and shin were used. We used two menu structures, the proposed and the traditional are. There were some sub-menu items. There were five menu items and four sub-menu items of each menu. In evaluation, we measured the elapsed time which is for when participants click a sub-menu items 20 times. The target item is selected at random. The method of clicking is equal to the method in Section 4. The participants were the same in Section 4. In the evaluation, participants wore an HMD with an 800 × 600 pixel screen.

The result is shown in Figure 12. It shows that elapsed time with the proposed menu structure is shorter than the elapsed time with a traditional menu structure. Therefore, we confirmed that Xangle can be used to shorten the elapsed time by rearranging menu items. The effect of the proposed menu structure when using the shin is better than with the upward finger. The proposed menu structure simplified the operation because the menu item can be selected by operating only one axis. We consider that this decreases the shaking of feet.

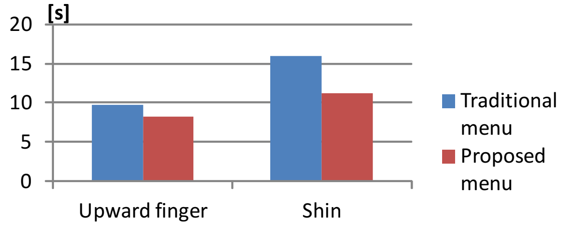


Figure 12: Elapsed time for each arranging icons in menu

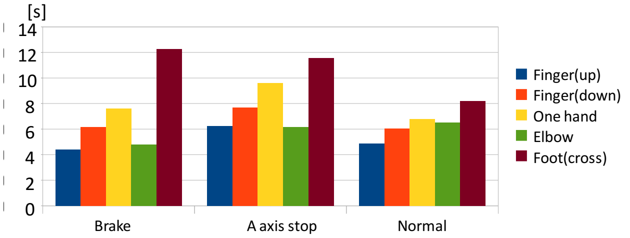


Figure 13: Elapsed time using improvement system for each fixed points

6. ACCESSIBILITY FEATURE

From the result of Section 4, it became apparant that the shake of fixed position was the factor of decline in the pointing speed. Thus, we propose two accessibility features below.

Brake function

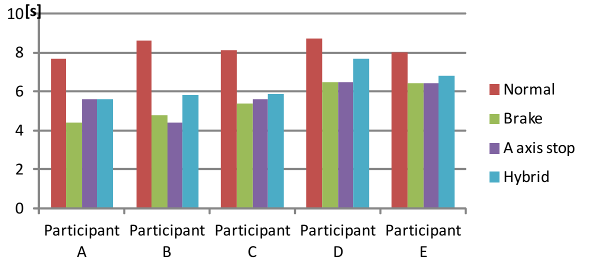
This uses an accelerometer which is not used for pointing, which decreases shake by switching the speed of cursor. The movement speed of cursor is limited by the accelerometer. Specifically, there are 3 types, Normal, Slow, and Stop. When the type is Slow, user can know the type because the lines changes from black to red. When the type is changed to Stop, click is done at a time.

One axis stop function

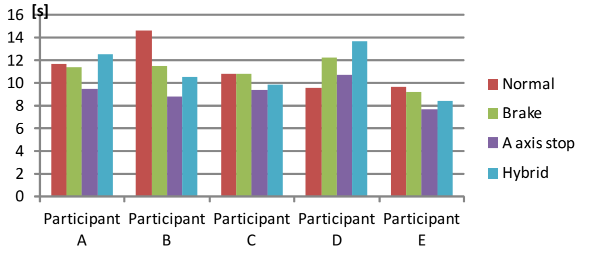
This uses an accelerometer which is not used for pointing, which decreases shake by stopping the axis which achieved the target on the assumption that the factor of shake when it operates with 2 axes. To change the value of the accelerometer and stop an axis, the user moves his heel in an up-down motion if the accelerometer is attached on the instep. When the action is done twice, 2 axes stop and a click is made. To notify user of the axis stopping, the stop line changes color.

We evaluated above 2 functions for the upward finger, downward finger, one hand, elbow, and shin. Participants clicked 5 icons per set for each of fixed points after practicing for about 10 minutes las described in Section 5. Participants perform 3 sets. The upward finger, elbow, and shin are evaluated where participants are sitting with both hands occupied. The downward finger is evaluated where the participants are standing with both hands occupied. In one hand, participants did their evaluation when standing with one hand occupied. For the upward finger and downward finger, one hand, and elbow, accessibility features are used by an accelerometer on the instep of the right foot. For the shin, accessibility features are used by an accelerometer on the elbow. We measure elapsed time per set and calculated the time for one click time. Participants are same as those described in section 4.

The result of the average elapsed time for 5 participants in the evaluation are shown in Figure 13. The y-axis shows elapsed time per pointing, and the same color shows same the fixed point. Judging by the result, elapsed time is not always shortened by the accessibility features. The problem of the both the brake and the axis stop function is that users cannot operate them well at first. In addition, the three accessibility features are hard to use. We considered that these are improved by using the accessibility features on a regular basis. Fast movement of the accelerometer causes errors with the brake function. This can be reduced by using an angular accelerometer. In an axis stop function, participants can operate them stably. However, this requires time to stop the axes. Furthermore, participants need to click again when they made an error or failed to click. Thus, the elapsed time becomes long. However, an axis stop function reduces the need to focus on pointing and can be used easily. The participants said that the using the foot with accessibility features when standing was more difficult than when sitting. For the upward finger and downward finger, pointing with the brake function is easier than when participants do not use Stop.



(a) Upward finger



(b) Shin

Figure 14: Elapsed time using improved system in proposal menu

We surveyed the effect an accessibility of using the proposed menu structure. We evaluated in the same way as described in Section 5. The participants were the same as those in Section 4. Accessibility features has brake function, an axis stop function, and hybrid function which combined them, and which were used in evaluation. Participants had sufficient practice using accessibility features.

Elapsed time per a sub-menu item in all data items are shown Figure 14 by accessibility features. We found that the elapsed time of the upward finger improved. For the shin, elapsed time of participant A and D are longer than others when participants used the brake and the hybrid function. When the shin is used, shaking often occurs. Therefore, participants limit how quickly they use the cursor. Furthermore, as previously explained, moving it quickly causes mistakes and errors in clicking because of switching the cursor speed. A problem of an axis stop function is that, pointing is difficult if lines are misaligned from the center of icon. Thus, we expect that elapsed time to short if the icon form changes and cursor is an absorbed icon.

7. CONCLUSIONS

We implemented 9 fixed points by using Xangle. Our method can be used to operate a computer in various situations in wearable computing environments. Furthermore, we propose a specialized menu structure for Xangle. The result of an evaluation showed that it was useful. In addition, to solve the problems which we found during the evaluation, we proposed a brake and an axis stop function, and we expect both pointing time and accuracy improve.

In the future, the brake function and the axis stop function need to be improved. Moreover, on method need an icon form which is best and absorbed cursor function. If we improve these, proposed method can be intuitively and quickly used in wearable computing environments.

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