Floor Interaction with Wearable Projection Interface Using Hand and Toe

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Abstract. We conducted a user study to unveil the usability of a wearable input/output interface using hands and toes for operating applications such as telephone calls and e-mails. Specifically, subjects performed tasks in the states "hands-free," "having baggage in their dominant hands," and "having baggage in both hands" using the proposed system and a smartphone. Then, we evaluated the usability according to a questionnaire, an interview, and the task completion time. The results indicate that hand and toe input in the proposed system were accepted when performing simple button operations such as answering the phone. In addition, hand input in the proposed system was accepted when performing scroll operations such as reading an e-mail. However, when performing accurate button operations such as text entry tasks, hand and toe input in the proposed system were seldom accepted.

Keywords: Floor projection · Wearable computer · Augmented reality · Toe input · Wearable projection

1 Introduction

The widespread use of mobile terminals such as smartphones enables us to access information services both indoors and outdoors, even while walking. For example, we use information services to find a route, check e-mails, and update a social network service (SNS). These information services are used frequently and briefly. Furthermore, most of them can be used by a simple operation. However, such mobile terminals have several limitations. First, the mobile terminal cannot indicate information larger than the display size. Second, it is difficult for users to give attention to their surroundings due to watching the display screen in their hands. Third, the mobile terminal needs to be retrieved from a pocket or bag. Fourth, the user has to hold the device itself with at least one hand, even while only viewing. Therefore, it is difficult to use the mobile terminal when both hands are occupied.

Thus, we focus on a type of projection system that can compensate for these limitations and provide a more efficient way of viewing information [1, 2, 23]. We especially focus on a wearable projection system that enables the user to access information via a large screen without retrieving the device [3, 4]. Additionally, Matsuda proposed a wearable projection system composed of a mobile projector, depth sensor, and gyro

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sensor, which are equipped on the user's chest [5, 17]. This system allows the user to conduct "select" and "drag" operations by footing and fingertips controlling in the projected image on the floor (Fig. 1). In this paper, we evaluate the usability of hand and toe input in our system and propose applications for our system based on the results.

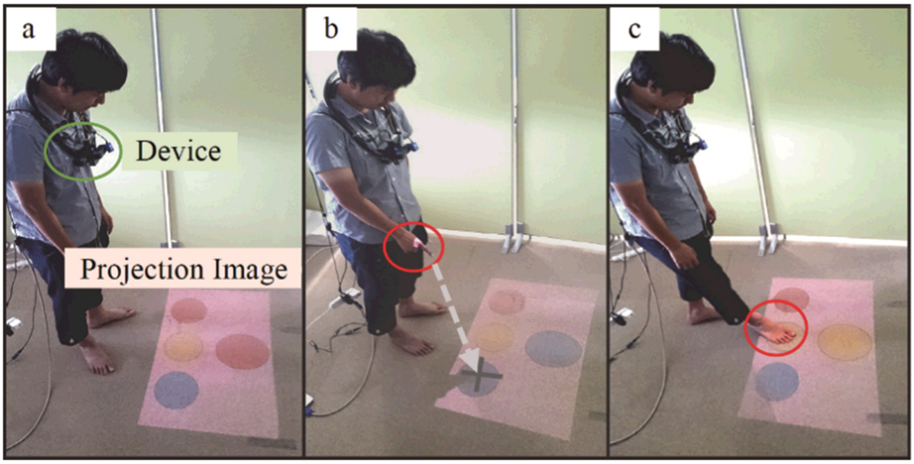

Fig. 1. System overview

2 Related Work

In this section, we discuss related work regarding the input interface to a graphical user interface (GUI) and the input method using the foot.

2.1 Input to GUI

Standard GUIs are operated using a pointer on the screen with pointing devices such as a mouse and trackball. However, the operability has worsened as the devices have been downsized for portability. Mobile terminals also restrict the use of one hand, and these devices need to be taken out of a pocket or bag. Related work has investigated hands-free input with wearable computing devices. For example, there are systems that accept finger-pointing input, such as a hand mouse [6], and input systems based on the line of sight [7]. These systems are accompanied by the burden of attaching and detaching required special devices. They also occupy the hands and eyes, which makes it difficult to conduct other tasks because these are the most frequently used parts of a user's body.

2.2 Accessing Information Using Projector

Accessing information via a projector has been studied for many years [8]. Technology that combines reality with wearable computers has been developed. The use of a projector instead of a head-mounted display (HMD) offers advantages such as mobility by accurately displaying images in a certain location. Studies on augmented reality have used projectors such as the tele-direction interface [20]. These studies have demonstrated the effectiveness of displaying annotations in the real world using a projector. T. Karitsuka superimposed a movie and annotated a real-world surface with graphics and characters [9]. However, the system required a marker on the projection surface, which made it difficult to project the image anywhere. Yamamoto projected information on a palm-top using a projector attached to the shoulder, which provided a stable display [10]. However, this system was not hands-free, and the display was not large enough to allow the user to access information. P. Mistry projected information onto a wall and real objects using a head-mounted or neck-strap-mounted projector, where inputs using finger gestures were recognized by an RGB camera [11]. However, this system required image processing because it often failed to recognize fingers with different ambient light and background colors. C. Harrison studied the "OmniTouch," which uses a depth sensor to detect finger input on many surfaces [12]. These studies show that using hands and fingers as input interfaces is an available and efficient approach for wearable projection systems. However, these studies required the users to raise their arms, which led to strain, and the system occupied both of the users' hands.

2.3 Foot-Based Input

There are studies that design input interfaces using the foot. Some deal with attaching sensors to the objects in the environment; others, to the user's body.

An example of a study that involved attaching sensors to the environment is Multitoe [13], designed by T. Augsten, which enables highly accurate user input using the floor. Users invoke menus and operate a keyboard with this system.

Studies involving systems that attach sensors to the user's body include the WARAJI [14] projects conducted by S. Barrera. Those sensors are attached to the user's legs and determine leg acceleration. This system is used to realize movement in virtual reality. However, this system demands the attachment of a device to the leg, and it does not consider the interaction between the foot and display. Another study investigated foot input based on a sensor in the user's pocket [15] to obtain the acceleration of the foot. Also, Daisuke [22] conduct research to detect user's posture based on a sensor in the user's pocket for investigating risk management. This study did not require the attachment of a device to the feet; however, it also failed to consider the information display. Other studies have recognized the toe using a camera on a mobile terminal device. One of these involved the input for a soccer game using the foot. The device was attached to one of the user's hands, and it did not consider the interaction between the toe and the floor. V. Paelke used a mobile device and a toe for inputting information [16], but that study did not consider the interaction between the toe and the floor. Simpson considered the interaction between the toe and the floor, but not with a mobile projector [21].

According to these works, it is effective to input to the floor projection by hands and toes, which is the principal point of our work.

3 System

We implemented the system as shown in Fig. 2. The system consists of a depth sensor, mobile projector, and gyro sensor. All the components are mounted on the user's chest. We used a seeser M1 (ESplus, Inc.) laser micro projector to project visual feedback onto the floor. Furthermore, we used an InertiaCube4 (InterSense, Inc.) to measure the orientation of the system and to fix the projected image on the floor. This prevented the projected image from moving due to the user's motion when stepping on the floor. We used a DS325 (SoftKinetic) as a depth sensor to detect the user's hands and toes. The DS325 is robust against changes in background color and ambient light. This depth sensor estimates the position and the motion of hands and toes. The physical burden is smaller and more socially acceptable than mounting at the user's head—the user wears only one device on the chest.

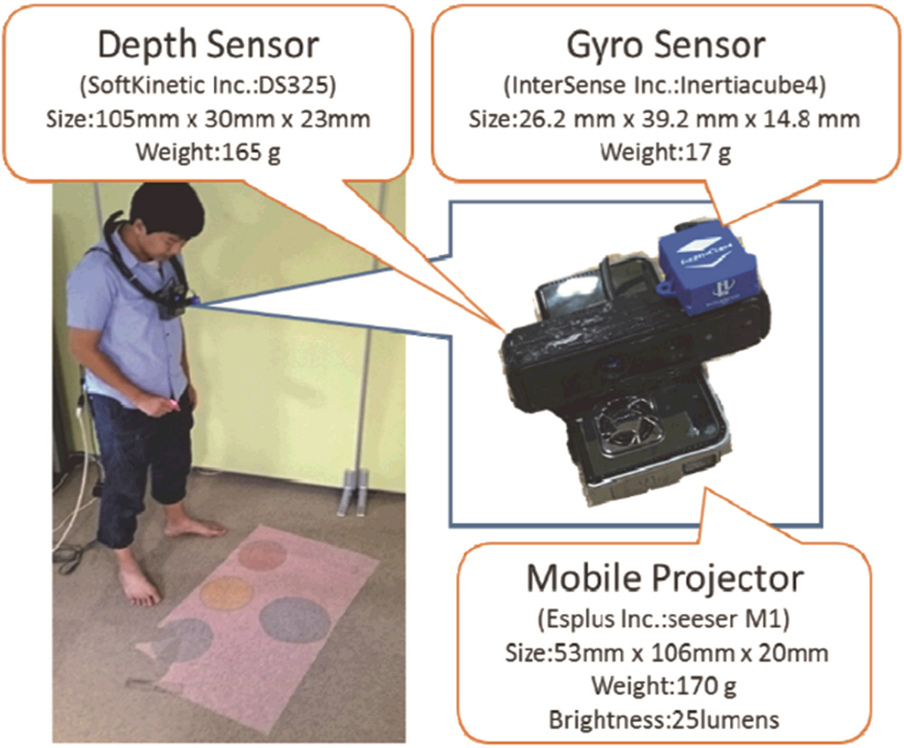

Fig. 2. System configuration

There are input motions to the floor projection by the hands. We focus on the pinch interface [18, 19] as shown in Fig. 3. The user can select contents from the floor projection by means of attaching the forefinger to the thumb. In addition, the hand position synchronizes with the pointing position. The hand position and select motion are detected by the depth sensor. The detection algorithm is similar to the algorithms of related works [21]. However, we do not utilize the direction of the user's hand as input. Figure 4a shows the raw image of the depth sensor. To separate the hands and feet, we set a threshold at the height of the hips empirically. The input position of the floor projection is evaluated by means of the position of the tip of the hand. The select motion is judged by means of a closed area of the hand as shown in Fig. 4b.

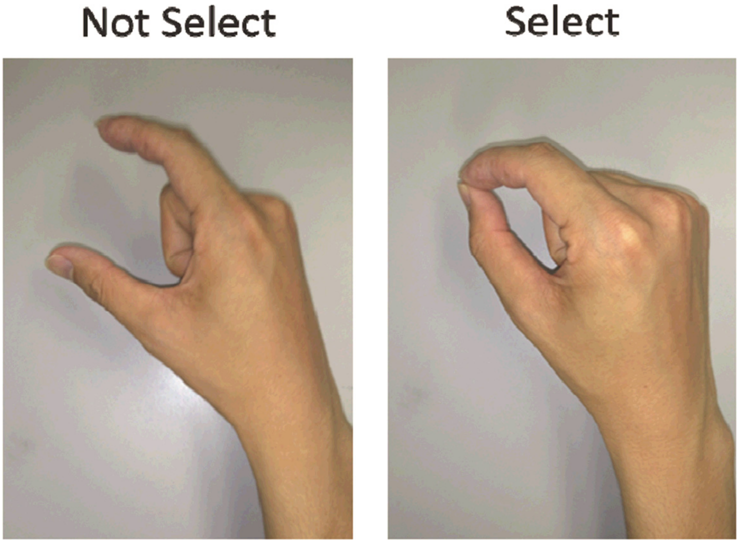

Fig. 3. Select motion of hand input.

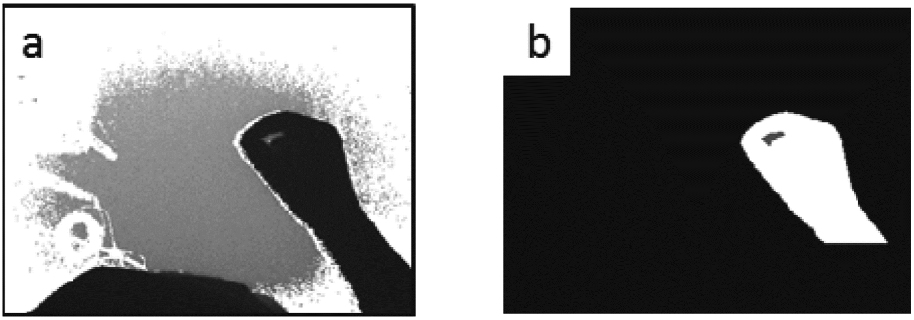

Fig. 4. Hand detection

In the preliminary experiment, we evaluated the accuracy of hand and toe input. Subjects (4 male) selected to the target 50 times. As a result, the average error of hand input was 4.5 cm, and the average error of toe input was 13.4 cm. The negative and positive false detection rate of hand input was 3.5 %, and that of toe input was 16.5 %. Considering this result and [17], we designed the icon size for this user study.

4 User Study

We evaluated the usability of hand and toe input of the proposed system by means of operating existing smartphone GUIs. We also evaluated the usability of input by a smartphone for comparison. The subjects performed tasks such as answering telephone calls and processing e-mail while wearing the proposed system and carrying the smartphone (Sony Ericsson Xperia arc). There are various places to contain the smartphone, such as clothing pockets and bags. In this study, the smartphone was contained in the subject's front trouser pocket for easy retrieval. In addition, we assumed that the user could not immediately access the smartphone because of hand restraints such as holding baggage, putting a hand in a pocket, and putting on gloves. Therefore, we also conducted a study in which the subject performed tasks in three situations: "hands-free" (Fig. 5a), "baggage in dominant hand" (Fig. 5b), and "baggage in both hands" (Fig. 5c). We set the baggage weight to 1.0 kg under the assumption that the user purchased food and a 500 ml bottle of water, which is often the case in daily lives.

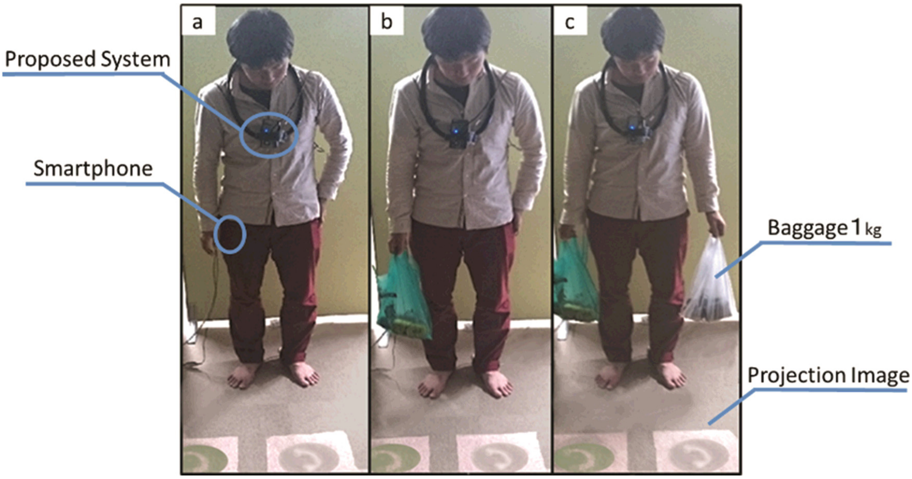

Fig. 5. Experimental apparatus

Before the tasks started, the subject was explained how to provide input and also the situation being addressed. The tasks started with attaching the proposed system to the subject and placing the smartphone in the subject's pocket for the Fig. 5 situations. A sound on the PC signaled the start of the task. Then, the task was displayed on the floor in the case of input by the proposed system, or on the smartphone's screen in the case of input by the smartphone. When the subject was performing the task, he/she was allowed to put down the baggage or to hold the baggage in the other hand. After input for task, the subject has to be the initial situation as the end condition.

The subjects performed three tasks. The first task was a one-button operation that did not require high accuracy. This operation is commonly used when answering a call and checking a short message. Specifically, the subject had to select the button once as shown in Fig. 6a. The second task was a scroll operation, which requires two-dimensional motion. This operation is commonly used when reading an e-mail and Web browsing. Specifically, the subject had to scroll to read text as shown in Fig. 6b. Then, the subject had to select the button to clear the end time. The text consisted of 150–200 Japanese characters, which can be read wholly by means of about five drag scrolls. The third task was an accurate button operation that required a lot of two-dimensional motion and high accuracy. This operation is commonly used during text entry such as replying to an e-mail and uploading articles to SNS. The preliminary experiment indicated that input using a QWERTY keyboard layout is quicker and more comfortable than the flick input in the proposed system. Moreover, the flick input is not used daily by all subjects. Therefore, we adopted input by QWERTY keyboard layout to perform the text entry task. Additionally, the toe input is considerably uncomfortable for this task and was therefore not conducted. The text entry task is shown in Fig. 6c. The subject inputs an English word of four characters.

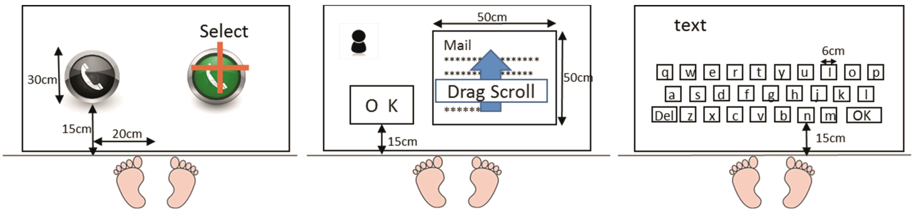

Fig. 6. Experimental task

There were 14 subjects (13 male, 1 female) aged 21 to 25 years, all of which were right-hand dominant. All tasks are conducted indoor situation. In addition, they performed each task five times to practice, and we take care of order of tasks to compensate order effects. We evaluated the usability according to a questionnaire, an interview, and the task completion time.

5 Result and Discussion

The task completion times are shown in Fig. 7. Whisker of box-and-whisker plot in Fig. 7 means standard variation. Also small "o" represent outlier. Input by the proposed system was quicker than input by the smartphone in the one-button operation task. Moreover, the toe input was the quickest when subjects had in both hands. In the scroll task, hand input by the proposed system and input by a smartphone were quicker than toe input. In the text-entry task, hand input by the proposed system was as quick as input by the smartphone when subjects had either no baggage, or baggage in both hands. However, hand input by the proposed system often took more time than input by the smartphone when subjects had baggage in their dominant hands because subjects frequently made mistakes due to input by their non-dominant hands.

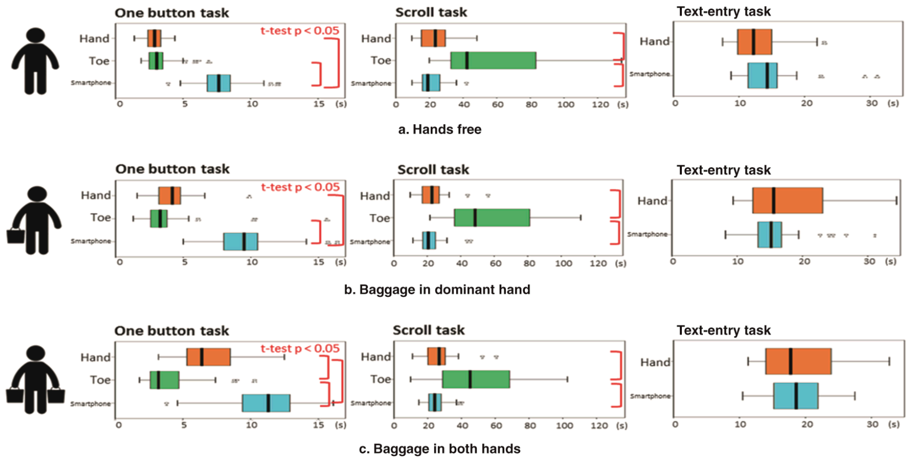

Fig. 7. Task Completion times

The results of the questionnaire are shown in Figs. 8, 9 and 10. In the one-button task, when subjects had either no baggage, or baggage in their dominant hands, the hand input by the proposed system was accepted, while the toe input was not accepted, whereas, when subjects had baggage in both hands, the toe input was the most accepted.

Most subjects cared for easy input, but a few subjects cared for certain input by the smartphone. In the scroll task, regardless of the situations of the subjects, they preferred hand input and input by smartphone, rather than toe input, because of the accuracy. Some subjects preferred the smartphone because it is more private than the projection image, which may be seen by people around them. In the accurate button task, regardless of the

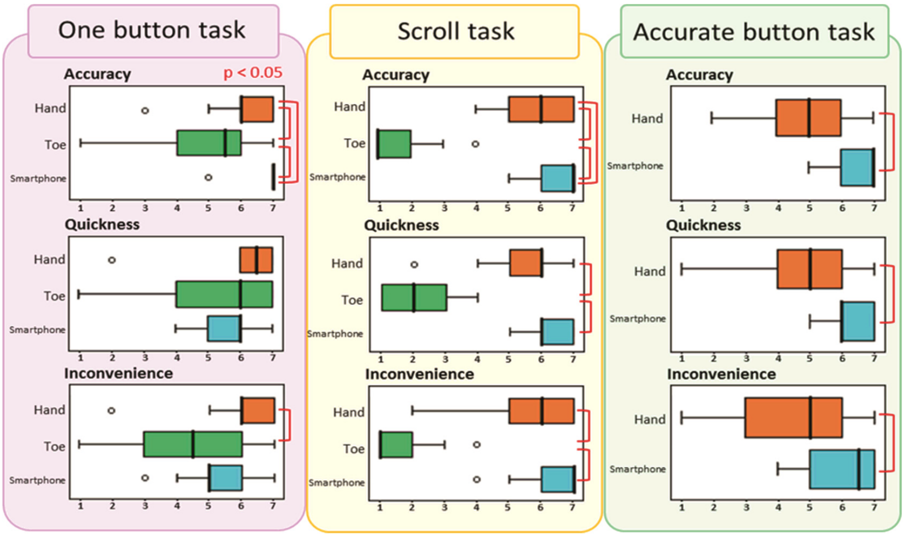

Fig. 8. Results of questionnaires in hands-free situation

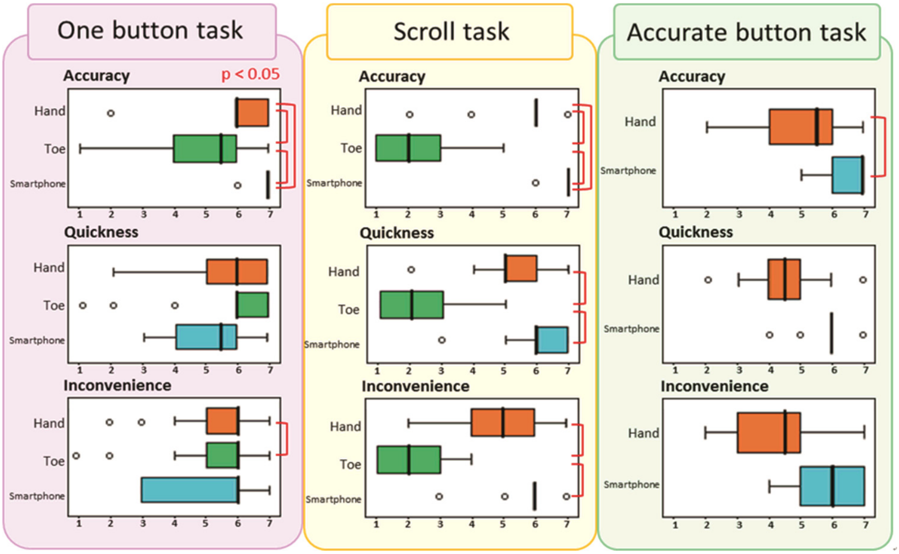

Fig. 9. Results of questionnaires with dominant hand occupied

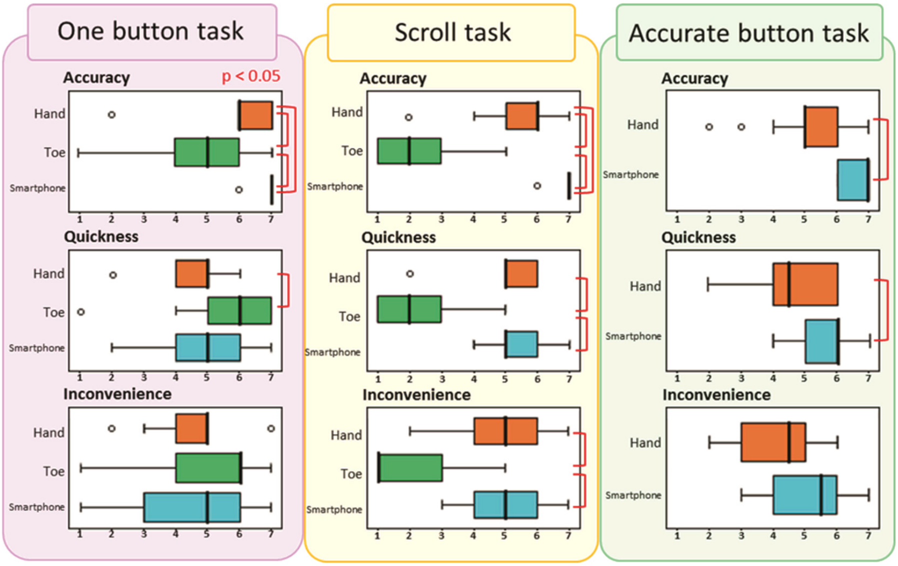

Fig. 10. Results of questionnaires with both hands occupied

situations of the subjects, they preferred to input by smartphone rather than the proposed system because of the input accuracy.

From these results, it was determined that toe input is accepted only for simple operations when both hands are occupied and that hand input is accepted for simple operations when both hands are free. Namely, the proposed system is fitting for applications that request simple operations such as answering a call, checking messages, reading e-mail, and scrolling Web pages and maps. In contrast, input by the proposed system is not accepted when users input only four characters, regardless of their hand situation. Thus, the proposed system is not suited for applications that request more operations, such as replying to e-mail and uploading articles to SNS. However, the task completion time of hand input by the proposed system was as quick as by smartphone, even though subjects use smartphones on a daily basis. Therefore, if they use the proposed system on a daily basis, they can become more comfortable and perform as well as with a smartphone.

Our future work will investigate applications and utilization of the proposed system. For example, the proposed system allows input not only from one person wearing the device but also from people around the user simultaneously. This system can also provide multi-user interaction using multiple devices, allowing the user to share information and communicate with other users.

Furthermore, the projection area can be utilized as an extended display for mobile devices as shown in Fig. 11. For example, in cases in which users should keep watching an application, they can drop the application from the smartphone display to the

Fig. 11. Extended display for mobile devices

projection area. The projection area allows users to improve the usability of a multitask application and to check notifications without the inconvenience of using mobile devices. In addition, in cases of simple operations, users can process information without retrieving their mobile devices.

6 Conclusion

In this work, we studied the usability of our proposed system when performing tasks such as answering phone calls and processing e-mails. From this study, we suggest that the proposed system is fit to be used for most information services that are used outdoors. The proposed system is convenient in a variety of situations, even when the user's hands are occupied. We believe that our system will be innovative in mobile computing.

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