Development of the Future Body-Finger

A novel travel aid for the blind

Kiyohide Ito
Department of Media Architecture
Future University Hakodate
Hakodate, Japan
itokiyo@fun.ac.jp

Yoshiharu Fujimoto
Department of Media Architecture
Future University Hakodate
Hakodate, Japan
fujimonia@gmail.com

Junichi Akita
School of Electrical and Computer Engineering
Kanazawa University
Kanazawa, Japan
akita@is.t.kanazawa-u.ac.jp

Ryoko Otsuki
Department of Media Architecture
Future University Hakodate
Hakodate, Japan
g2112008@fun.ac.jp

Akihiro Masatani
Graduate School of Electrical and Computer Engineering
Kanazawa University
Kanazawa, Japan
masatani@ifdl.jp

Takanori Komatsu
Faculty of Textile Science and Technology
Shinshu University
Ueda, Japan
tkomat@shinshu-u.ac.jp

Makoto Okamoto
Department of Media Architecture
Future University Hakodate
Hakodate, Japan
maq@fun.ac.jp

Tetsuo Ono
Graduate School of Information Science and Technology
Hokkaido University
Sapporo, Japan
tono@complex.ist.hokudai.ac.jp

***Abstract*—We have developed a device with a haptic interface that enables blind persons to perceive the environment. The device, which we call the Future Body-Finger (FB-F), measures the distance between a person and an object using an infrared sensor and transmits distance information to the user's haptic sense by the angular motions of a link. In this report on the FB-F, we (1) outline its concept, (2) describe its mechanism, and (3) demonstrate its usability by comparing it to commercially available products.**

Keywords-haptic interface; electric travel aid; perception

I. INTRODUCTION

Human beings are often said to obtain almost all of their information via the visual modality. However, nonvisual modalities can also provide rich information. Therefore, shedding light on the positive use of nonvisual modalities for exploring our surroundings is an important issue. In addition, we assume that a novel subjective experience of the environment (e.g., that of an “extended mind” [1]) could be realized by means of devices that function as parts of our body and endow us with “embodied cognition.” We have been working to develop devices that harness this form of cognition. We refer to a device that enables us to have an “extended mind” experience as a “Future Body.” As a first step, we have developed a device called the “Future Body-Finger” (hereafter, “FB-F”) that enables visually impaired people (hereafter, “the blind”) to perceive their surroundings.

Numerous devices called electric travel aids (ETAs) [2] have been introduced to assist locomotion of the blind. In order to ensure the safety of locomotion, ETAs have incorporated functions that obtain information on orientation. For example, ETA sensors determine a user’s location, the direction in which the user moves, and the distance of nearby objects.

ETAs are categorized into two types based on their output modality: auditory and haptic. Devices of the former type transform spatial information into audible sound [3]. For example, Tri-sensor [4] and Miniguide [5] measure distance via ultrasonic waves, convert the data into sound, and convey information on the distances of objects around a user. These devices emit a low-pitched sound when an object is distant from the user and a higher-pitched sound when the object approaches.

Devices of the latter type, which use haptic output [6], typically convert spatial information into vibration. The intensity and frequency of the vibration are conveyed as information via the user's skin sense. For example, the vibration frequency of such a device increases when a user approaches an object. Users become accommodated to the skin stimulation provided by this type of haptic output because the threshold of vibration sensitivity becomes increasingly high as users are exposed to the same vibration stimulus for increasingly longer times.

Unfortunately, the aforementioned ready-made devices are difficult to handle skillfully. For example, the blind need to develop higher cognitive abilities to comprehend the information conveyed by sound or vibration, i.e., they must interpret the sound and vibration signals by learning to associate a sound of a certain pitch or arbitrary vibration frequency with the distance to an object. Otherwise, they will fail to infer the locations of objects. In this sense, blind children will have difficulty managing these devices because their abilities in higher-order cognitive processing are not fully developed. Furthermore, adventitiously blind persons may have to make greater efforts to use ETAs because they have difficulty in discriminating sound pitch as well as the intensity and frequency of vibration compared with congenitally blind persons.

II. CONCEPT OF FB-F: A "SMART" MECHANISM

As suggested by Runeson [7], we define a "smart" mechanism as a mechanism that directly registers complex variables. We adopted this concept to develop the FB-F. To provide an example of a "smart" mechanism, we begin by explaining how a polar planimeter works (Figure 1). A polar planimeter is a tool to measure the area of irregular shapes, which requires the calculation of complex variables. When a user moves the tracer arm, an attached measuring wheel carefully traces the outline with an index to calculate the area (a complex variable) automatically. The length and angle measured by the polar planimeter are directly proportional to the area. The device is so simple to use that those who have no knowledge of the calculations (e.g., summing up small pieces of a figure) can easily determine the area. Therefore, the advantage of this "smart" mechanism is that it does not require any calculating ability.

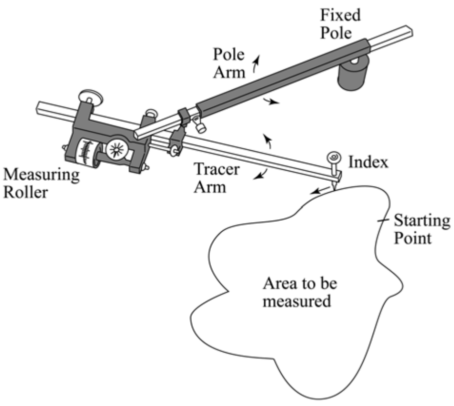

Figure 1. Polar planimeter

III. HARDWARE CONFIGURATION

We designed the FB-F in order to solve the problems of usability mentioned in the previous section. FB-F is expected to enable users to obtain spatial information such as the direction and distance to an object intuitively according to the user's exploratory actions without the use of cognitive inference.

The FB-F is characterized by its haptic "smart" user interface. Users do not need mathematical calculations, mental inference, or higher-order cognitive processing to recognize the distance to an object, whether moving or not.

The hardware architecture of the prototype FB-F is shown in Figure 2. The developed FB-F consists of three functional blocks—a controller, sensor, and actuator units—which are connected to a common communication channel. Each unit has microcontroller (MCU, Cypress CY8C21123). The sensor unit has a position-sensitive device (PSD)-type distance sensor that radiates infrared rays toward an object; it detects the reflection position of the received rays by using a PSD that implements a trigonometric distance measurement technique. The microcontroller on the sensor unit calculates the distance from the FB-F to the object. The actuator unit has a servo motor equipped with a 55-mm-long lever to form a 1-DOF (one degree-of-freedom) link. The microcontroller on the actuator unit controls the servo motor according to the received angular information. The controller unit periodically requests distance information from the sensor unit, converts the measured distance to angular information, and transmits it to the actuator unit; this chain of operations forms the sensor-actuator system. The angle of the link increases when the distance between the FB-F and an object decreases (e.g., when an object approaches), whereas it decreases when the distance increases. Users hold the FB-F (Figure 3) and place their forefinger on the link. The finger bends or extends depending on the link's angular motion. The angle changes from 0 to 70° in correspondence with the metric distances between a user and an object. The FB-F can provide users with distance information because the extent that the user bends his/her forefinger is directly associated with the link movements.

The hardware specifications of the prototype FB-F are as follows: weight, 60 g; height, 7.5 cm; width, 4.5 cm; and depth, 3.5 cm. The distance measured varies from 1,000 to 2,800 mm as the link angle changes from 70 to 0°. The distance-angle coefficient is –7°/180 mm.

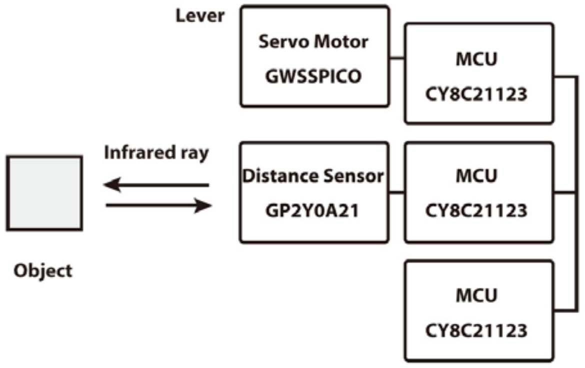

Figure 2. Block diagram of Future Body-Finger

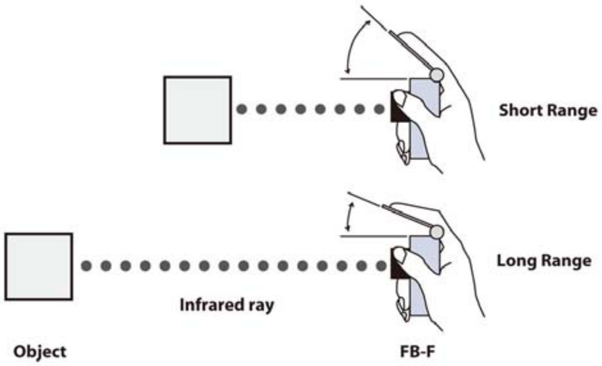

Figure 3. Operation of Future Body-Finger

IV. PSYCHOLOGICAL STUDY ON ACCURACY OF ESTIMATED DISTANCE BY FUTURE BODY-FINGER

A. *Purpose*

We conducted a psychological experiment to demonstrate that the FB-F enables users to perceive distance to an object more accurately than commercially available products.

B. *Method*

Participants: 16 persons, blind or sighted, participated in the experiment. Eight blind adults, four congenitally and four adventitiously, participated in the blind group. Their ages were between 28 and 57 (mean = 43; SD = 9.50). Eight sighted adults (range, 20–22; mean = 20.75; SD = 0.89) participated in the sighted group.

Stimuli: A piece of cardboard adhered to a whiteboard (1.6 m × 1.0 m × 0.02 m) was used as the object. We used a standard stimulus and 5 test stimuli for the trials. The object was presented at a distance of 1.0 m from an FB-F device fixed on the table ("standard stimulus") or at one of 5 positions ranging between 1.0 and 2.6 m from the table ("test stimuli"). The distance between each pair of adjacent test stimuli was 0.4 m.

Device Conditions: The type of ETA (the FB-F, a Vibratory device, and a Sonar device) was varied as a within-subject factor. Participants were asked to estimate the distance to stimuli under different device conditions (i.e., three types of ETAs). The Vibratory and Sonar devices were commercial products. The Vibratory device (7.0 cm × 4.0 cm × 2.5 cm) had a haptic interface that transformed measured distances into vibratory signals. The Sonar device (6 cm × 3.5 cm × 1.5 cm) transformed measured distances into audible sounds (i.e., sounds with a specific pitch). Both devices used ultrasonic waves to detect the distance to an object.

Procedure: Figure 4 shows the experimental setup. In each trial, participants were asked to use an ETA device to detect the distance to a stimulus that was presented for 3 s. Initially, the standard stimulus was presented, after which one of the five test stimuli was randomly presented. The magnitude estimation method was used to estimate the distance to the presented stimulus. In this method, a participant was asked to report the magnitude of a stimulus that corresponded to some proportion of the standard. The participant estimated his/her subjective experience by assigning numbers to the stimuli so that they reflected the judged magnitudes of his/her experiences. In magnitude estimation, each stimulus was assigned a number that reflected its distance as a proportion of that to the standard. The standard stimulus was set as "100." If a test stimulus was subjectively twice as far as the standard, a participant was required to assign it a magnitude of "200." Under the three device conditions, each participant performed five trials for each of the five stimuli.

Analyses: For each ETA device, the product-moment correlation coefficient (r) between the presented distance (i.e., the stimulus actually presented) and the estimated distance was computed. Additionally, the determination coefficient was computed based on linear regression analysis.

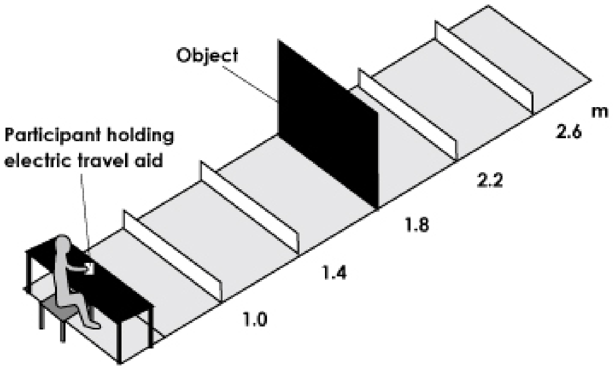

Figure 4. Experimental setup

C. Result

Figure 5 shows the correlations between the presented and estimated distances measured by each device. As the lines can be seen in Figure 5, the product-moment correlation coefficients of the FB-F, Vibratory device, and Sonar device were 0.917, 0.498, and 0.396, respectively. This indicates that the FB-F provided participants with the most accurate estimation of distance to the presented stimuli.

Figure 6 shows the mean determination coefficients of each group in the three device conditions. A two-way analysis of variance was conducted with group (blind and sighted) and device condition (FB-F, Vibratory device, Sonar device) as the between- and within-subject factors, respectively. The main effect of device condition was significant ($F(2, 28) = 66.68$, $p < 0.01$). Multiple comparison tests between the three device conditions showed significant differences between the devices. By contrast, there was no significant difference between the blind and the sighted groups.

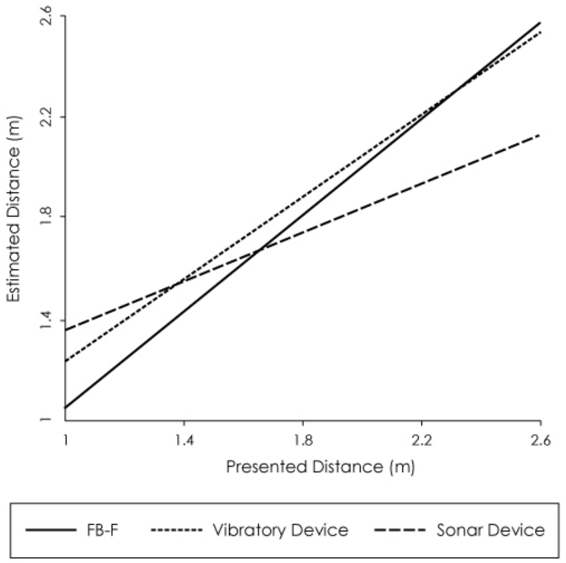

Figure 5. Correlation between estimated and presented distance (n = 400)

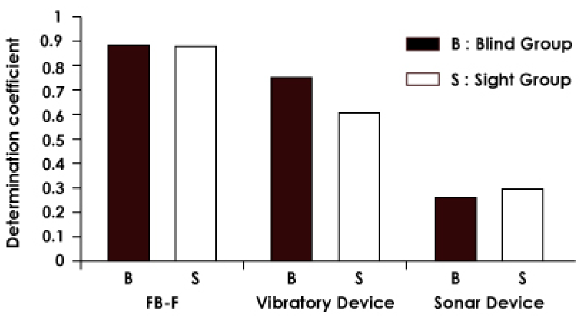

Figure 6. Mean determination coefficients in three devices for the blind and sighted groups

V. CONCLUSION AND FUTURE WORK

ETAs have three requirements. First, they should be portable and one-handed so that users can carry them easily while locomoting. Second, ETAs should be able to detect the distance and direction to surrounding objects accurately. Such spatial information will allow users to make decisions such as avoiding collisions with obstacles and approaching objects. Third, they should be manageable by anyone regardless of age or cognitive ability so as to provide users with information on the direction of or distance to objects intuitively or directly. In this study, we ascertain that the FB-F satisfies these three requirements from the results of a psychological experiment. To enhance the usability of the FB-F, we will continue experimental studies to evaluate its efficiency in traveling. Specifically, we are conducting a psychological experiment in which the FB-F allows blind persons to reach a destination by using an experimental maze. We will make necessary improvements by evaluating the results collected in experimental settings. We hope that our device, which realizes the idea of a "Future Body," will allow both visually impaired and healthy persons to extend their capabilities for exploring surroundings.

ACKNOWLEDGMENT

We wish to extend our special thanks to those who volunteered to participate in our experiment. Our research on the development of the Future Body-Finger was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports and Technology, Japan.

REFERENCES

[1] A. Clark and D. Chalmers, "The extended mind," in Analysis, vol. 58, pp. 7-19, 1998.

[2] B. B. Blasch, W. R. Wiener, and R. L. Welsh, Foundations of Orientation and Mobility, 2nd ed. New York: AFB Press, 1997.

[3] C. Carter and K. A. Ferrell, The Implementation of Sonicguide with Visually Impaired Infants and School Children, Sensory Aids Corporation, D. W. Campbell, Ed. Ill: Bensenville, 1980.

[4] L. Kay, "A sonar aid to enhance spatial perception of the blind: engineering design and evaluation," in Radio and Electronic Engineer, vol. 44, no. 11, pp. 605-627, 1974.

[5] L. Kay, "Acoustic coupling to the ears in binaural sensory aids," Journal of Visual Impairment & Blindness, pp. 12-16, 1984.

[6] L. A. Johnson and C. M. Higgins, "A navigation aid for the blind using tactile-visual sensory substitution," in Proc. EMBS '06, IEEE 2006, vol. 6, pp. 6289-6292.

[7] S. Runeson, "On the possibility of 'smart' perceptual mechanisms," in Scandinavian Journal of Psychology, vol. 18, pp. 172-179, 1977