# FB-Finger: Development of a Novel Electric Travel Aid with a Unique Haptic Interface

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**Abstract.** We developed a unique haptic interface, the "FB-Finger," which enables users to detect the distance to an object. When a user holds the FB-Finger and places his/her forefinger on a link, the finger bends or extends depending on the link's angular motion (which corresponds to the metric distance between the user and the object). We expected the FB-Finger to provide more accurate distance estimation than similar commercial electric travel aids. To test this hypothesis, we conducted psychological experiments with blindfolded sighted participants who were asked to make distance estimations in conditions using three different devices. Results revealed that the FB-Finger allowed participants to make more accurate judgments compared to the other devices. These findings suggest that using the FB-Finger provides significant potential for ETA application among visually impaired individuals.

**Keywords:** Haptic Interface, Electric Travel Aid, Perception.

## 1 Introduction

Numerous devices, referred to as electric travel aids (ETAs), have been introduced to assist locomotion in individuals with blindness. In order to ensure locomotion safety, ETAs have incorporated functions that obtain information regarding orientation. For example, ETA sensors determine a user's location, the direction in which the user moves, and the distance of nearby objects.

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However, visually impaired individuals have difficulty handling such ETAs skillfully. The main reason is that these individuals need to exert substantial effort learning to use these devices. For instance, associating haptic (vibratory intensity and frequency) or auditory (sound intensity and frequency) output variables with the distance or direction of surrounding objects is challenging. To address this problem, our pervious study proposed a novel and intuitive haptic interface to assist walking among visually impaired individuals. This interface, depicted in Figure 1, was termed the CyARM [1]. The CyARM has been shown to be effective in detecting obstacles during locomotion. [2]

Additionally, our previous study indicated that sighted individuals who were blindfolded could recognize the size and shape of objects by using the CyARM [3]. The CyARM was quite effective in enabling participants to explore obstacles and specify distances to those objects without excessive effort for training.

However, the CyARM is impractical for daily use among the visually impaired for two reasons. For one, the CyARM is too large. Secondly, the CyARM constrains a user's arm and trunk movement due to the device's mechanics. Since the CyARM is not portable, we developed a novel and easy-to-handle device for intuitively exploring an environment. Below, we discuss the outline of this device, which we termed the "FB-Finger," and demonstrate the usefulness of this device based on results from two separate experiments.

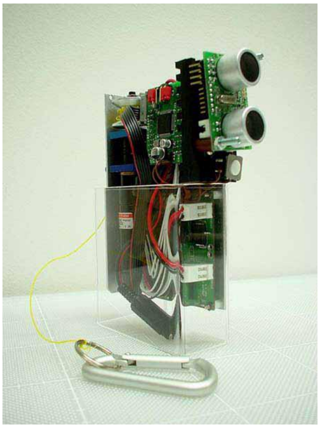

**Fig. 1.** Representation of the CyARM

## 2 Outline of the FB-Finger

We designed the FB-Finger in order to address user interface problems encountered with the CyARM. The FB-Finger is expected to enable users to intuitively obtain spatial information, such as the direction and distance, to an object.

Figure 2 depicts how to operate the FB-Finger. Users hold the FB-Finger 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 degrees in correspondence with the metric distance between a user and an object. The FB-Finger can provide users with distance information since the extent that the user bends his/her forefinger is directly associated with the link's movement. The link's angle increases when the distance between the FB-Finger and an object decreases (e.g., when an object approaches), whereas it decreases when the distance increases.

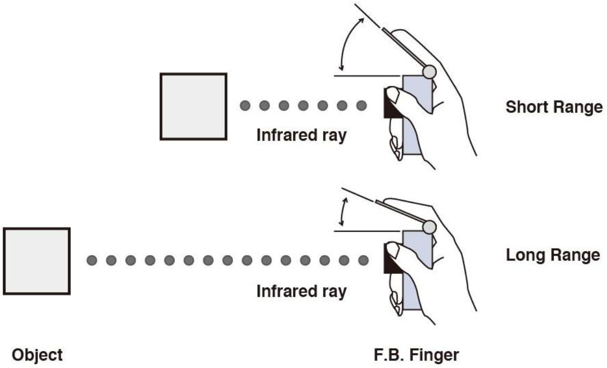

**Fig. 2.** Operation of the FB-Finger

## 3 Hardware Configuration

The hardware specifications of the prototype FB-Finger are as follows: weight, 60 g; height, 7.5 cm; width, 4.5 cm; and depth, 3.5 cm. The hardware architecture of the prototype FB-Finger is shown in Figure 3. The developed FB-Finger consists of three functional blocks—a controller, sensor, and actuator units—that are connected to a common communication channel. Each unit has a microcontroller (MCU, Cypress CY8C21123). The sensor unit has a position-sensitive device, a (PSD)-type distance sensor, that radiates infrared rays toward an object; this device 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-Finger 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 received angular information. The controller unit periodically requests distance information from the sensor unit, converts the measured distance to angular information, and transmits this information to the actuator unit; this chain of operations forms the sensor-actuator system.

The prototype FB-Finger can install two different distance ranges of sensor units: short-range and the long-range sensors. For the short-range sensor, the distance measured varies from 0.3 to 1.4 m, while for the long-range sensor the distance measured varies from 0.1 to 2.8 m. The link angle changes from 70 to 0 degrees for both sensors.

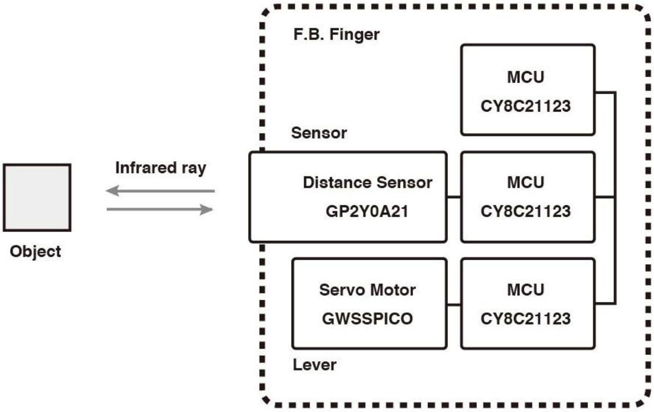

**Fig. 3.** Block diagram of the FB-Finger

# 4 Experiment 1: Relationship between Perceived and Actual Distance

## 4.1 Purpose

The first step in evaluating the effectiveness of the FB-Finger included an experiment conducted to reveal the correlation between the actual and perceived distance to an object in the different distance sensors conditions.

## 4.2 Method

**Participants.** Eight sighted adults served as participants.

**Object for 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 five test stimuli for the trials.

**Experimental Conditions.** The short distance range sensor (hereafter, "short condition") and the long distance range sensor (hereafter, "long condition") were set. In the short condition, the object was presented at a distance of 0.4 m from an FB-Finger device fixed on a table ("standard stimulus") or at one of five positions ranging between 0.4 and 1.2 m from the table ("test stimuli"). The distance between each pair of adjacent test stimuli was 0.2 m. In the long condition, the object was presented at a distance of 1.0 m from an FB-Finger ("standard stimulus") or at one of five positions ranging between 1.0 and 2.6 m from the device ("test stimuli"). The distance between each pair of adjacent test stimuli was 0.4 m.

**Procedure.** Figure 4 shows the experimental setup. All participants put on noise-canceling headphones with blindfolds so that auditory and visual cues could not be used. During each trial, participants were asked to use the FB-Finger to detect the distance to a stimulus that was presented for three seconds. Initially, the standard stimulus was presented, after which one of the five test stimuli was randomly presented. A magnitude estimation method was used to estimate the distance to the presented stimulus. For 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 that reflected the judged magnitudes of his/her experiences. During magnitude estimation, each stimulus was assigned a number that reflected its distance as a proportion to the standard. The standard stimulus was set at “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 each sensor range condition, every participant performed six trials for each of the five stimuli.

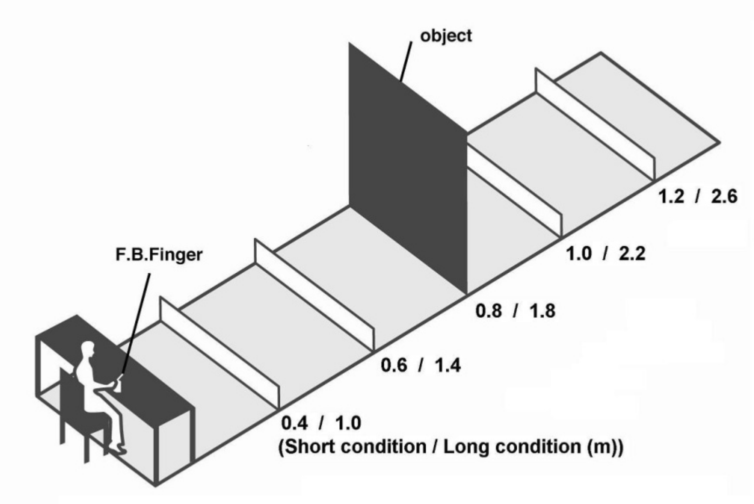

**Fig. 4.** Experimental setup

### 4.3 Results and Discussion

For each condition, a Pearson’s product-moment correlation coefficient ($r$) between the presented distance (i.e., the stimulus actually presented) and the estimated distance was computed. The correlation values were 0.94 for the short condition and 0.95 for the long condition. There was no significant difference between these values. Thus, regardless of sensor distance range (short condition or long condition), distance estimation of the object was strongly correlated with the actual distance. This result suggests that users can detect both near and far distances using both sensors.

We also conducted a linear regression analysis on estimated magnitude against the actual distance and computed a coefficient of determination ($r^2$). Figure 5 depicts regression lines for each sensor range condition ($r^2 = 0.88$ for the short condition and $r^2 = 0.90$ for the long condition, respectively). Results revealed rather high $r^2$ values for both conditions. This suggests that estimated distance was linearly predicted from actual distance, further indicating that users could perceive distance with high accuracy.

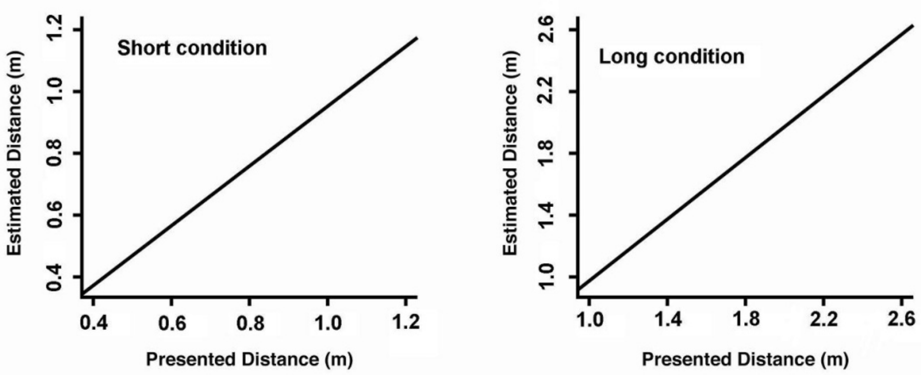

**Fig. 5.** Regression lines of estimated distance predicted from presented distance for the two conditions (n = 240)

# 5 Experiment 2: Comparison of Distance Perception Accuracy with Different Devices

## 5.1 Purpose

For Experiment 2, we compared the accuracy of perceived (estimated) distance using the FB-Finger, CyARM, and a commercially available product.

## 5.2 Method

**Device Conditions.** The three types of ETA devices were used. These included the FB-Finger, CyARM, and a Vibratory device. The FB-Finger and CyARM were our original developed devices. The Vibratory device was a commercial product, the size of which was similar to the FB-Finger. This device had a haptic interface that transformed measured distances into vibratory signals.

**Participants.** 24 sighted individuals wearing blindfolds and noise-canceling headphones participated. Eight participants were randomly assigned to each device condition.

**Object for Stimuli.** We used the same object as Experiment 1.

**Procedure.** Most procedures (experimental setup, magnitude estimation method, and total trials for each participant) were the same as in Experiment 1 except that the standard stimulus was set as 1.0 m, and the five test stimuli varied from 1.0 to 2.6 m.

### 5.3 Results and Discussion

As in Experiment 1, Pearson's product moment correlation coefficients (*r*s) were computed for all three device conditions. Correlation values for the FB-Finger, CyARM, and Vibratory device were 0.95, 0.84, and 0.85, respectively. Thus, the association between estimated and actual distance appeared to be higher for the FB-Finger relative to the other two devices.

Regression analyses for each device condition resulted in mean $r^2$ values of 0.90 for the FB-Finger, 0.72 for the CyARM, and 0.72 for the Vibratory device (Figure 6). A one-way analysis of variance was conducted with device condition (FB-Finger, CyARM, and Vibratory device) as a between-subjects factor. The main effect of device condition was significant ($f\,(2, 21) = 3.73$, $p < 0.05$). Multiple comparison tests between the three device conditions showed significant differences between FB-Finger and the CyARM ($p < 0.05$) and between the FB-Finger and the Vibratory device ($p < 0.05$). There was no significant difference between CyARM and Vibratory device.

These results suggest that FB-Finger gives users two advantages not found in the other devices. First, estimated distance better corresponds with actual distance. Second, FB-Finger allows users to more accurately detect distance to an object.

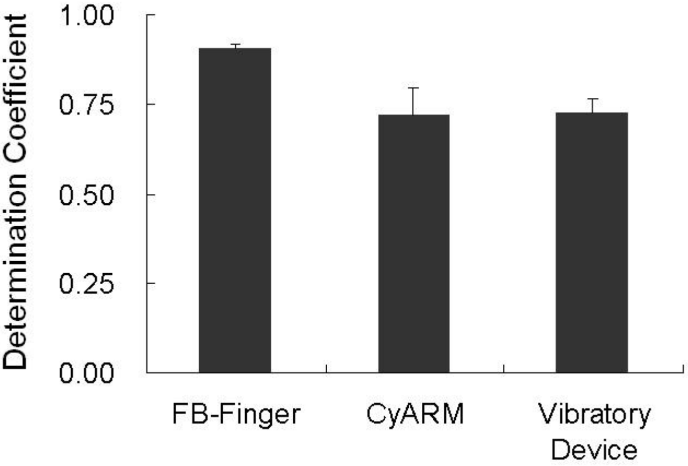

**Fig. 5.** Mean Determination Coefficients for the three device conditions

## 6 Conclusion

We originally developed CyARM as an ETA device assuming that visually impaired individuals could use it intuitively. However, given the cumbersome nature of CyARM, we developed a new type of ETA: FB-Finger. Two experiments were conducted to evaluate the usefulness of this new device. Results showed that highest distance accuracy was obtained with FB-Finger as compared to a commercial product and CyARM. These findings suggest that FB-Finger has the potential for being a useful travel aid while also serving to enhance the quality of daily life among visually impaired individuals.

It is remarkable that FB-Finger enabled blindfolded, sighted participants to judge accurately the distance to an object even though these individuals had little experience with haptic exploration. Taking into account that visually impaired individuals have keen haptic perception skills, it is conceivable that results from the present study provide promising applications of FB-Finger among this population.

FB-Finger is a novel alternative device that should be rather useful as a travel/exploration aid. However, future studies will need to include visually impaired participants to more fully determine the efficacy of this device.

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