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RESEARCH ARTICLE

White Cane-Type Holdable Device Using Illusory Pulling Cues for Orientation & Mobility Training

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ABSTRACT For visually impaired people, a white cane is an important aid for obtaining information about the surrounding environment. Although the visually impaired should attend this training by orientation & mobility (O&M) specialists to learn proper cane technique, the number of specialists is limited. In our previous study, we developed a training system that enabled the visually impaired to learn white cane techniques using illusory pulling cues. In the previous prototype system, a cane grip-type device was developed with a built-in vibrator to generate asymmetric vibration stimuli, and illusory pulling cues were fed according to the position of the cane tip. Although the prototype system showed positive results, issues related to the lack of user-friendliness of the device associated with the wired drive and the impractical gripping method were observed. This study developed a more practical white-cane-type device for O&M training, envisioning independent training for the visually impaired, which improved the above-mentioned issues. Specifically, the device was wireless and had a vibration mechanism for the gripping method of the general cane technique, and its validity was demonstrated by evaluation experiments. In addition, the paper explains the usefulness of the device as per discussion with an active O&M specialist. The results of the evaluation experiments indicated that the devices were implemented to satisfy the requirements for cane training.

INDEX TERMS Illusory force sensation, touch technique, training system, white cane.

I. INTRODUCTION

White canes are the most widely used aids by visually impaired people for outdoor walks. The primary purpose of the white cane is to obtain information about the surrounding environment of the visually impaired (i.e., preview), to protect themselves from obstacles (i.e., defense), and to let people know that they are visually impaired (i.e., identification) [1]. Among these, preview and defense require training using a white cane, called orientation & mobility (O&M) training. O&M training involves rehabilitation of the visually impaired, and it is advised that the visually impaired attend the training by O&M specialists. However, the number of active specialists (approximately 500) in Japan is extremely small compared to the number of visually impaired people (approximately 300,000) [2].

We attempted to solve this challenge using a rehabilitation-engineering approach. Specifically, to provide the visually impaired with the opportunity to train independently without O&M specialists, a prototype of a training system for

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the white-cane technique was developed [3]. The prototype system targeted the most basic and critical touch technique (the cane technique of swinging the cane from side to side to preview obstacles) and guided the proper swing width of the cane using haptic feedback because novices tend to have a narrower swing width on the non-dominant hand side and miss obstacles. Haptic feedback uses illusory pulling cues induced by asymmetric vibration stimuli [4], [5] because these illusions can provide compelling directional information using only a small vibrator and can guide the motion of the upper limb [6]. In the prototype system, a cane grip-type device was developed with a built-in vibrator to generate asymmetric vibration stimuli. The illusory pulling cues were fed back according to the position of the cane tip, as measured by motion capture. The user test results demonstrated a significant decrease in the error from the target swing width before and after using the training system [3]. Therefore, the prototype system was effective in teaching the swing width of the touch technique.

However, the prototype system was impractical because its purpose was only to verify that the swing width could be guided by illusory pulling cues in the laboratory. In detail, the vibrator in the cane-type device required an AC (alternating current) power supply and a large external amplifier (160 (w)×96 (h)×250 (d) mm). Such a complex device is not user-friendly for the independent training of the visually impaired. In addition, three traditional gripping methods were used for the white canes: thumb grasp, index finger grasp, and pencil grasp [7]. The prototype gripping device was designed to be grasped so that the entire grip was covered by the fingers and palm (thumb grasp), owing to the constraints for inducing illusory pulling cues. However, in the general touch technique, the visually impaired grasped the cane with the index finger extended straight towards the tip of the cane (index finger grasp). In other words, the gripping method of the prototype system was inappropriate for practice. As mentioned above, the lack of user-friendliness of the device associated with the wired drive and the impractical gripping method are critical issues of the prototype system.

This study developed a more practical white-cane-type device for O&M training, envisioning independent training for the visually impaired. The training system was improved based on the issues of the prototype system. This study is the continuation of the work conducted in [3], and the primary contributions since the previous report are as follows:

- Implementation of a wireless-driven white cane-type device with integrated vibrator control circuitry.
- Design and evaluations of a vibration presentation mechanism for the griping method of the general touch technique.

The remainder of this paper is organized as follows. Section II discusses the related work. Section III proposes the design requirements for the improved white-cane-type device and implements the device. Section IV evaluates the developed device based on the design requirements. Finally, Section V discusses the developed device, and Section VI presents the concluding remarks.

II. RELATED WORK

Many white canes with haptic feedback, called smart canes, have been proposed. Specifically, devices to assist the visually impaired, such as smart canes, provide information on obstacles and direction of travel to the visually impaired using vibration [8], [9], [10], force [11], [12], [13], and thermal cues [14] based on ultrasonic distance sensors, light detection and ranging (LiDAR), and global positioning system (GPS). However, these devices are intended to provide mobility assistance to the visually impaired and do not aim to support training. Even when using smart canes, the visually impaired must learn basic cane techniques; hence, providing sufficient training support and mobility assistance is essential. Therefore, previous studies have used the haptic and auditory feedback method to train in a virtual outdoor environment [15], [16], [17], [18], [19], [20]. Although these systems can help the visually impaired safely familiarize themselves with the outside environment, training in cane technique is also very important to perform preview and defense.

Illusory pulling cues have also been used to assist the visually impaired, even though their purpose is to provide mobility assistance. Amemiya et al. [21] and Choinière et al. [22] guided users along a walking path by inducing an illusory pulling cue with a handheld device. However, in these systems, the white cane and the device generating the asymmetric vibration stimuli were independent, requiring both hands of the visually impaired person to grasp the cane and the device. In contrast, Ando et al. proposed a device in which a mechanism for generating asymmetric vibration stimuli was built into a white cane [23]. However, this was not mentioned in [23]; an overview of this device suggests the requirement of an external controller because the motor cables exit outside the vibration mechanism. Assuming independent training of the visually impaired, the controller and battery must be built into the white cane, in addition to the vibration mechanism.

III. IMPLEMENTATION OF A WHITE CANE-TYPE DEVICE

A. REQUIREMENTS OF THE DEVICE

The requirements for a white cane-type device to achieve independent training for the visually impaired are as follows.

Req. 1 The device must be controlled wirelessly from the information terminal.

Req. 2 Even if the white cane has a built-in vibrator, controller, and battery, it must comfortably swing as a commercially available white cane.

Req. 3 The illusory pulling cue must be induced in the gripping method of the general touch techniques.

Many visually impaired people can operate information terminals, such as personal computers (PC), smartphones, and tablets, using screen readers. Therefore, the finalized training system is aimed to incorporate the white cane-type device, simple sensors like an inertial measurement

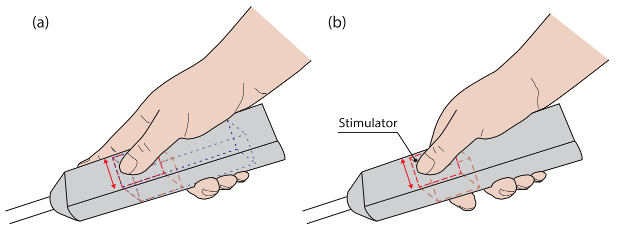

FIGURE 1. **Gripping methods of the white cane. (a) Index finger grasp. (b) Thumb grasp.**

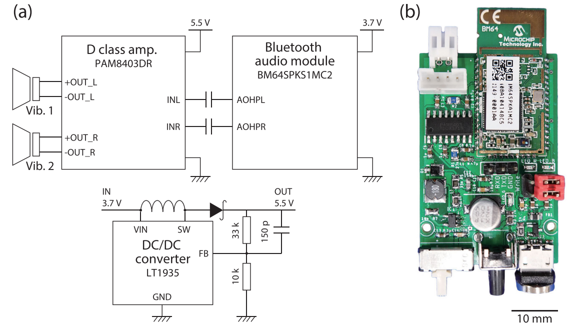

FIGURE 2. **Wireless communication circuit. (a) Block diagrams. (b) Overview of the PCB.**

unit(IMU) to measure the swing of the cane, and the information terminal to control them. To achieve a finalized training system, the device must be controlled wirelessly in response to the commands from the information terminals. Furthermore, for usability, the controller and battery should not be external to the vibration presentation mechanism; instead, they should be built into the cane grip (Req. 1).

However, if the vibrator, controller, and battery are built into the cane grip, the device may be heavy. Although it is assumed that the device will be used for training alone and that commercially available canes will be used in daily life, the device must be designed to be as comfortable as commercially available devices. The physical parameter that hinders the swing of the cane is the moment of inertia. The perception of the reaching distance using a rod, such as a cane, is dominated by its moment of inertia rather than its weight itself [24]. The white cane-type device in the prototype system has the same moment of inertia as that of commercially available canes. Moreover, the white cane users felt the device was light [3]. Hence, although the entire device may be heavier, its moment of inertia must be comparable to that of the commercially available canes (Req. 2).

In general, the grasp of the index finger shown in Fig. 1 (a) is used in the touch technique, and the index finger must be extended straight toward the cane tip. By contrast, the illusory pulling cue is induced by pinching an asymmetrically vibrating object, such as a vibrator, with the thumb and index finger [5], [25], [26]. Because the thumb and index finger cannot pinch the vibrating object in the case of index finger grasp, the thumb grasp shown in Fig. 1 (b) was used in the prototype system [3]. However, the gripping method must correspond to the index finger grasp to ensure our training system is more practice-oriented. As we demonstrated that the swing width was guided by inducing the illusory pulling cue in the thumb grasp condition, the same training effects might be achieved if the illusion can be induced in the index finger grasp. Therefore, the vibration mechanism must be designed for index finger grasp in the novel device (Req. 3).

B. CONFIGURATION OF THE WIRELESS COMMUNICATION SYSTEM

Based on Req. 1, the configuration for driving the vibrator wirelessly was designed (Fig. 2). Because voice-coil type vibrators were used to induce an illusory pulling cue [5], [25], [26], similar vibrators (639897, Foster Electric Co., Ltd.) were used in the white-cane device. The asymmetric vibration stimuli can be controlled by audio signals because the principle of voice-coil-type vibrators is similar to that of acoustic speakers. Therefore, a Bluetooth audio module (BM64SPKS1MC2, Microchip Technology Inc.) was used to transmit the control signal from the information terminal to the vibrator. This module allows the white-cane-type device to be connected wirelessly to the information terminals as quickly as a Bluetooth headset. Control signals were generated in advance using MATLAB R2020b (MathWorks Inc.) in WAV format and were transmitted to the audio module by SBC (Sub Band Codec), one of the codecs of Bluetooth. The received signals were output as analog signals from the audio module and input to the vibrator via a class-D amplifier (PAM8403DR, Diodes Incorporated). A lithium-ion polymer battery (DTP502535, Data Power Technology Ltd.) was used as the power source. The power supply to the amplifier was boosted to 5.5 V by a DC-DC converter (LT1935, Analog Devices, Inc.). The circuits were mounted on a printed circuit board (PCB).

C. DESIGN OF A VIBRATION PRESENTATION MECHANISM

A vibration presentation mechanism was designed for the index finger grasp. The primary conditions for the stimulation method of asymmetric vibration to induce illusory pulling cues are as follows:

- The asymmetrical vibrating object is pinched with the thumb and index fingers [5], [25], [26].
- The lateral vibration must be presented to the finger pads [5].
- The pinched object must be vibrated at a relatively large acceleration [27].

It is impossible to ensure large acceleration if the entire grip of the white cane vibrates. Therefore, in the prototype system, the part where the thumb and index fingers touch the white cane when the user grips it was used as a stimulator (the area indicated by the red dotted line in Fig. 1 (b)), and a large acceleration was ensured by vibrating only that part [3]. However, in the case of the index finger grasp, the stimulator cannot be placed in contact with the index finger, and the condition

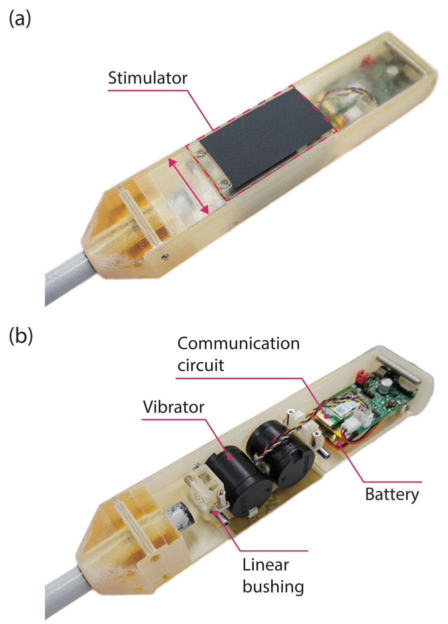

FIGURE 3. White cane-type grip device (grip size: 46 (w)×37.5 (h)×200 (d) mm). (a) Overview. (b) Internal configuration.

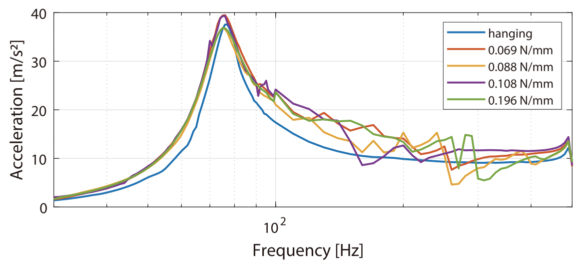

FIGURE 4. Frequency characteristics when the stimulator is hanging and when it is fixed by each spring.

under which the illusion is induced cannot be achieved. This issue cannot be solved when developing a prototype system. Through repeated trial and error in prototyping the stimulator, we obtained the design concept of a novel white cane-type device for the index finger grasp. Specifically, the middle or ring finger was used to pinch the stimulator instead of the index finger by extending the depth of the stimulator (area indicated by the blue dotted line in Fig. 1 (a)). The conditions under which the illusion is induced can be generally achieved using this design concept.

A novel stimulator was developed based on the proposed design concept. By extending the depth of the stimulator, one or two vibrators could be built into it (vibrator size: ϕ 25 $\times$ 27 mm). A preliminary comparison between stimulators with one and two vibrators showed that the illusion was clearer when two vibrators were used. Through a trial-and-error process of prototyping the stimulators, we found a length that could accommodate two vibrators and allow the thumb, middle, and ring fingers to contact the stimulators when the device was held by the authors. Consequently, the depth of the stimulator was 64 mm, which is the minimum length at which the three fingers can touch and the two vibrators can be built in.

Fig. 3 shows the developed white cane-type device. The grip enclosure was made of acrylic and fabricated using a 3D printer. To vibrate only the stimulator, the grip must be grounded to the palm or another surface, and the stimulator must float. The direction of the stimulator was limited to one degree of freedom by linear bushings (LM4MUU, THK Co., Ltd.) and shafts (PSSFUW4-34-M2-N2, MISUMI Inc.), and the position of the stimulator was neutralized by the springs inserted into the shafts. A floating stimulator was developed using this mechanism. To confirm the influence of the resonance characteristics of the stimulator owing to the spring, the frequency characteristics were compared with four different types of springs (spring constants: 0.069, 0.088, 0.108, and 0.196 N/mm) in a hanging condition (Fig. 4). The influence of the difference in spring constants was small in the range of several tens of hertz, where the illusions generally occur [5], [25], [26]. The strongest springs were used to stabilize the neutral position of the stimulator. Through the development of a prototype system, we found that the moment of inertia of the white cane can be reduced by making the end of the white cane heavier and moving the center of gravity closer to the grip [3]. Therefore, the battery and communication circuits are placed at the end of the grip. The grips were attached to the shaft of a commercial carbon white cane (Segawa Cane, SEGAWA., LTD). The entire length of the white cane was adjusted to 1200 mm, well within the range of general cane lengths [28], and its weight was 318 g. To reduce the slippage when the stimulator was pinched, a piece of sandpaper (#1000) was pasted on its surface, as described in previous study [25].

D. ASYMMETRIC VIBRATION STIMULI

The following acceleration waveform, $\ddot{x}_{ref}$, which was confirmed in our previous studies to induce the illusion [29], was used as the stimulus.

$$\ddot{x}_{ref}(t) = A_1 \sin(2\pi ft) + A_2 \sin(4\pi ft + \phi_0) \quad (1)$$

Here ϕ_0 is the phase difference between each frequency component, which is the illusion induced at 0°, and the direction of the pulling cue is inverted at -180° [29]. Therefore, the direction of the illusory pulling cue was controlled by the phase difference. A_1 and A_2 are the amplitudes of the accelerations of the two components, and these parameters were set at 70 m/s^2, which is well above the threshold at which the illusion is induced [27]. f is the fundamental wave set to 75 Hz, where the illusion was reported to occur [5], [29]. The calibrated input signals were generated using the asymmetric vibration control method [29] to output these vibrations.

We confirmed that these stimuli could be outputted from the device. Fig. 5 shows the typical examples of asymmetric

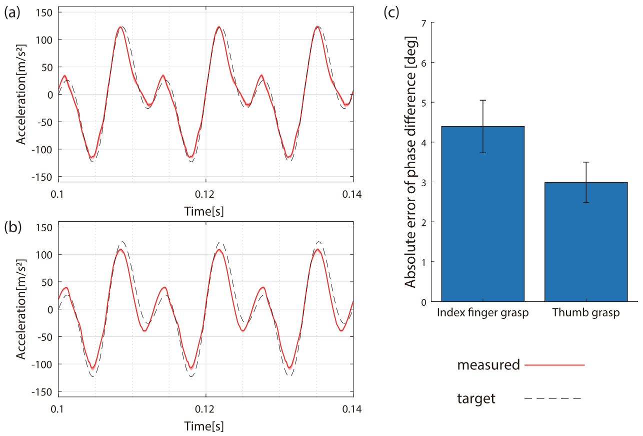

FIGURE 5. **Typical examples of asymmetric vibration stimuli. (a) Index finger grasp. (b) Thumb grasp. (c) Error of the phase differences.**

vibration stimuli measured in each of the conditions of index finger grasp and thumb grasp using an accelerometer (pickup: Type-4517, amplifier: Type-2693-0S1, Brüel & Kjær), and a multifunctional data acquisition (DAQ) device (USB-6343, National Instruments Co.). The target and measured profiles were in general agreement (Fig 5 (a)–(b)), and the phase difference error was small (Fig 5 (c)).

IV. EVALUATIONS OF THE DEVICE

A. OVERVIEW OF EVALUATIONS

The developed white-cane-type device was evaluated based on the requirements described in Section III-A. Based on Req. 1, although the device was wireless, its performance was unknown. Because these devices are used in training, the time between the command of the information terminal and the actual driving of the device is critical. In Section IV-B, the wireless communication delays were measured. Next, in Section IV-C, to verify the device's comfort of swing, the moment of inertia that contributes to it was compared to commercial canes based on Req. 2. However, for Req. 3, the characteristics cannot be clarified without user testing. Therefore, a user test was conducted on participants who simulated acquired blinds and were the future target users for the training system (Section IV-D). In addition to the above quantitative evaluation based on these requirements, a qualitative evaluation based on hearing with an O&M specialist was conducted to clarify the usefulness of the developed device (Section IV-E).

B. MEASURING WIRELESS COMMUNICATION DELAYS

The delay between the time the PC sends the command and the vibrator is driven was measured. The specific methods are as follows: A video file was created in which the audio signals (sine wave 150 Hz) were repeatedly turned on and off in sync with the video, which reverses black and white in one-second cycles. The vibrators were driven by transmitting audio signals to the device. The distance between the PC and the device was 1 m. The black-and-white reversal of the video

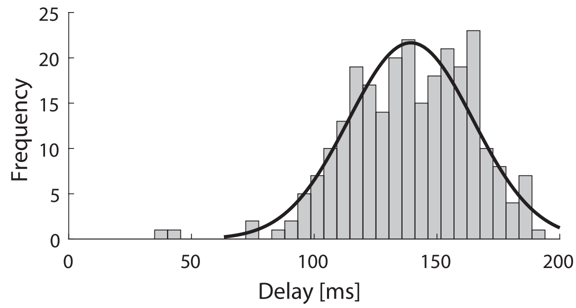

FIGURE 6. **Histogram of communication delays.**

was measured by a photodiode (ST-1KL3A, KODENSHI Co.), the vibration was measured using the accelerometer, and their signals were collected by the same DAQ device in Section III-D (sampling rate: 20 kHz). The video was output from a liquid crystal display (VA32AQ, ASUSTeK Computer Inc.) at 60 fps. This measurement was performed 260 times.

Fig. 6 shows a histogram of communication delays. The average delay was 139±25(SD) ms. No connection defects were observed during these measurements.

C. EVALUATION OF MOMENT OF INERTIA IN THE DEVICE

The moment of inertia of the developed device was compared with that of commercially available white canes. In our previous study [3], we measured the moment of inertia of the canes using the rigid pendulum principle proposed by Bahill [30]. Specifically, the moment of inertia I was calculated from the mass of the white cane m, position of its center of gravity l, and period T at which the end of the white cane was fixed to a bearing and allowed to oscillate freely.

$$I = mgl\left(\frac{T}{2\pi}\right)^2 \tag{2}$$

where g denotes gravitational acceleration. Because the measurement setup is the same as that in the previous study [3], kindly refer to it for details. Commercial canes were made of carbon, aluminum, or graphite; they were 1200 mm long, the same length as our device.

TABLE 1 lists the inertia characteristics of the device and the commercially available canes. The inertial characteristics of the commercial canes were obtained from our previous studies [3]. In terms of mass, our device was the heaviest and more than twice as heavy as the lightest carbon cane. However, the moment of inertia of our device was smaller than that of aluminum or graphite canes and almost the same as that of a carbon cane.

D. CHARACTERISTICS OF ILLUSORY PULLING CUES

1) METHODS

We verified that the device could be used to induce illusory pulling cues. The target users of the training system are acquired blind people who would use canes in the future, rather than visually impaired people currently using white canes. Therefore, ten sighted people (aged 22–30 years, three

TABLE 1. Inertia characteristics of the device and commercially available canes.

Cane type	Weight m [g]	Center of gravity l [mm]	Moment of inertia I [kg·m^2]
Developed device	318	235	0.053
Carbon	138	417	0.047
Aluminum	224	458	0.082
Graphite	203	424	0.070

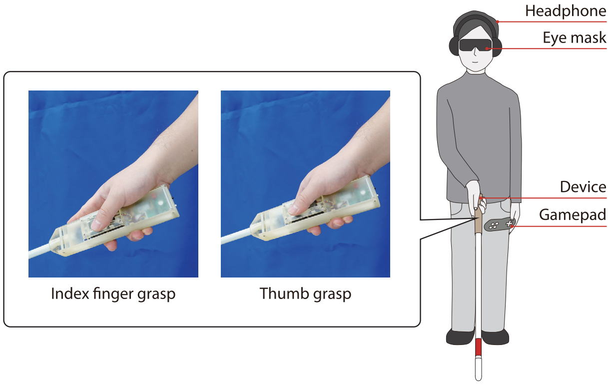

FIGURE 7. Experimental setup.

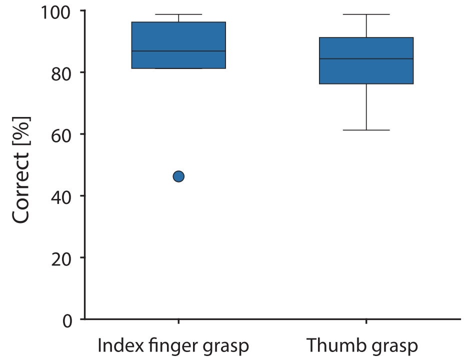

FIGURE 8. Correct answer rates in each gripping method.

females) wearing an eye mask to simulate the acquired blind people, who are novice white cane users, participated in the user test. This study was approved by the Osaka University Academic Research Ethics Review Committee (approval number: 4-3-1). This study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants.

The experimental procedure is as follows. The participants were randomly presented with cues in the left and right directions, and the correct answer rates in the direction perceived by the participant were determined. A two-alternative forced choice (2AFC) was used to determine the correct answer rate. Participants responded to the direction of the perceived cue based on the terms "to the right" or "to the left." The grip condition was set to the index finger grasp, which was newly enabled for this device. In addition, the gripping method of the prototype system, thumb grasp, was also a condition. The participants held the device using the gripping method described above, and the experiment was conducted in a standing position, assuming training (Fig. 7). Participants wore headphones with white noise to suppress their hearing and held a gamepad in the non-dominant hand to indicate the direction of the perceived cue with its cross-key. The tip of the white cane was placed on the floor. Each gripping method was performed randomly for each participant. After the asymmetric vibration stimuli were calibrated for each gripping method before the experiment (refer to our previous study [29]), the main experiment was conducted. The participants practiced directional discrimination in advance to familiarize themselves with illusory pulling cues. The asymmetric vibration stimuli were presented for 1 s, and after a 2-s interval after the response, the next stimulus was presented. Eighty trials (40 trials each in the left and right directions) were conducted for each gripping method. Considering the fatigue that arose during the experiment and the adaptation to the stimulus, all trials were divided into two blocks of 40 trials each, and the participants were allowed one-minute breaks between successive blocks. The above procedures were performed by changing the gripping method conditions.

The correct answer rates were calculated for each gripping method. To demonstrate that the participants could discriminate cue directions, the correct answer rates and chance levels (50%) were compared. Because the data were not normally distributed and had a limited sample size, the Wilcoxon signed-rank test was used for comparisons.

2) RESULTS

Fig. 8 shows the result of the correct answer rates in each gripping method. The top and bottom parts of the box indicate the lower and upper quartiles of the ratio, the whiskers indicate the minimum and maximum values of the ratio, and the horizontal bar indicates the median ratio. The dots indicate the ratios from the lower quartile -1.5×IQR (interquartile range). As a result of the Wilcoxon signed-rank test, significant differences were found between the correct answer rates in the gripping method and chance level (index finger grasp: $p < 0.01, r = 0.85$ and thumb grasp: $p < 0.01, r = 0.89$). The results suggest that participants did not correct the directional discrimination by chance; instead, they could generally determine it correctly. Therefore, our device can present illusory pulling cues in the index finger grasp in addition to the thumb grasp, which is a gripping method in the prototype system.

E. HEARING FOR O&M SPECIALIST

To clarify the usefulness of the developed device, it was used by an active O&M specialist. The specialist was free to comment on this device. The significant comments were as follows:

- As novices tend to shift the white cane from the midline, this device might be used to compensate for this motion.

- Sometimes, I cannot give strong verbal instructions during training; hence, it would be helpful if the device could provide instructions instead.
- For visually impaired people who do not attend training, I taught the hold and swing methods of a white cane at least when selling it.
- When the specialist visits the visually impaired person for training, the time is limited, so the swing of touch technique is not taught in detail. However, training at a facility for the visually impaired at a school for the blind teaches the swing in detail; hence, this device suits such training sites.

V. DISCUSSION

A. GENERAL DISCUSSION

A novel white-cane-type device was developed to address the issues of the prototype systems, which are the lack of user-friendliness of the device associated with the wired drive and its impractical gripping method. Although devices can be battery-operated and controlled wirelessly, the communication delay of approximately 139 ms was found. Communication delays may interfere with accurate feedback in the training system. However, the swing time of the white cane is approximately 1.3 seconds [31], and the trajectory of the tip is ballistic [3]. Predicting the reaching position of the tip from the ballistic trajectory may solve the issue of communication delays. Furthermore, the machine learning-based swing prediction proposed by Nakamura et al. [32] may be able to predict more accurate reaching positions.

In addition, although the device became heavier with the wireless version, its moment of inertia was almost the same as that of carbon cane. The position of the center of gravity is critical to decreasing the moment of inertia, and heavy components, such as the communication circuit and battery, should be placed at the end of the white cane as much as possible.

The prototype system developed a stimulator corresponding to a thumb grasp based on the conditions under which illusory pulling cues occur [3]. In the proposed device, the depth of the stimulator was extended, and the mechanism was implemented to pinch it using the middle or ring finger instead of the index finger. It was confirmed that the illusion occurred between the index and thumb finger grasps with almost the same correct answer rates. Therefore, a practical gripping method that could not be achieved in the prototype system assignment is addressed. As described above, we could develop a white-cane-type device in which the requirements listed in Section III-A were achieved.

However, only one participant had an answer rate of approximately 50%. This participant reported introspectively after the experiment that he did not respond to the direction of the cue but rather to the side of the grip on which the vibration was strongly felt. We confirmed that illusory pulling cues were induced more clearly by the learning effect [33]. Therefore, to reduce individual differences in illusion, it is necessary to conduct sufficient procedures to familiarize users with the illusion in advance.

The first comment from our hearing with the specialist suggests that the device can be used in the targeted manner. The second and third comments suggested uses that were not previously assumed. Regarding the second comment, our device was aimed at training the visually impaired to be independent, even though it could be a tool to assist them in smoothly communicating the specialist's instructions. Some trainees were offended by the strong verbal instructions. Instead of verbal instructions, the specialist could use our device to intervene appropriately in real time to ensure smooth training. In the fourth comment, the specialist presented cases for careful training in touch techniques at the facility for the visually impaired and the school for the blind. Our device may be helpful in these cases. However, we consider this device useful when specialists cannot handle it. Therefore, our device may also be used for limited-time training.

B. LIMITATIONS

Although the novel device induced as much illusion as the gripping method of the prototype system, we could not show that this device is effective for training. In addition to the issues addressed in this paper, in the prototype system, the visually impaired person cannot set up only the camera because optical motion capture is used to measure the swing of the cane. A simple sensing system using an IMU must be developed to solve the above issue; the effects of our novel device on training can then be verified.

In addition to the training touch techniques, our device can be used to guide walking paths, as in previous studies [21], [22], [23]. However, our current devices may cause serious accidents if the walking paths are guided by the device because the device cannot present cues with 100% correct answer rates. Therefore, our current device can only be used in a guaranteed safe environment for indoor training. To induce the illusion more clearly, the method of placing pin arrays on a stimulator proposed by Teshima et al. [34] may be effective.

VI. CONCLUSION

In the touch technique training system developed in this study, the lack of user-friendliness of the device associated with the wired drive and the impractical gripping method, which are issues associated with the prototype system, have been addressed. Specifically, the device has been designed wireless and has a vibration mechanism for the index finger grasp. The results of the evaluation experiments indicate that the devices were implemented to satisfy the design requirements. In the future, the sensing system will be improved, and the effectiveness of the training system will be verified at actual training sites.

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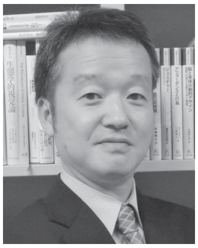

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