Haptic Direction Indicator for Visually Impaired People Based on Pseudo-Attraction Force

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Abstract Wayfinding is of vital importance if visually impaired pedestrians are to walk by themselves from one place to another, since they must calculate both their orientation and position. Here, a new haptic direction indicator is proposed, which will help blind pedestrians to avoid hazardous areas intuitively and safely by means of haptic navigation. A novel translational force perception method, called the “pseudo-attraction force” technique, is applied to a haptic direction indicator, which exploits the non-linear relationship between perceived acceleration and physical acceleration to generate a force sensation. An experiment was performed to clarify the perceptual characteristics when a visually impaired person held the haptic direction indicator. The results indicate that the angular resolution of directional force under 8-direction (compass) conditions was better than that under 12-direction (clock position) conditions with the haptic direction indicator. The finding constitutes a criterion for designing smaller haptic direction indicators.

1 Introduction

Wayfinding is of vital importance if visually impaired pedestrians are to walk by themselves from one place to another. There are two main factors that relate to this walking ability, namely orientation and mobility [1]. Physical mobility and the ability to recognize both the current and target locations and the required direction are essential. Location and direction recognition is achieved by interacting with the environment by means of sounds, and smells, and thermal and haptic clues. However, these abilities are sometimes disrupted. Many people with visual impairment have reported that they become disoriented if they fall and then cannot find anyone to help them. Such problems may also occur during
emergencies such as fires or earthquakes. This is because service animals, such as guide dogs, may become frightened, confused, and panicky during and after a disaster in the same way as humans do, or because the environment may change. Therefore, support devices that can provide orientation information are very useful in assisting autonomic walking.

There are certain devices that can provide our exact orientation. These include a compass whose needle can be felt by people with visual impairment. However, as with a conventional compass, the users have to keep it horizontal and wait until the needle stops moving. Even though an electric compass can overcome this problem, its information display is limited to, for example, sound feedback or vibrating pattern stimuli. Some visually impaired people neither want to wear headphones nor to have other sounds superimposed on the audio information from the environment since sound is their primary information channel. Instead of auditory information, vibrotactile stimulation using several vibrators has been proposed as a navigational aid [2, 3]. However, this approach requires that users learn how to convert stimuli to information, which means that it is not intuitive and requires training. A haptic (or kinesthetic) approach has the potential to be more intuitive and expressive than cutaneous stimulation in conveying direction information since haptic devices can indicate a one-dimension direction directly. The intuitive comprehension of orientation information through haptic modality is thought to be important in the situations outlined above.

This paper describes the feasibility of a system based on an ungrounded kinesthetic force display for providing visually impaired people with orientation information. First, a mobile haptic direction indicator is proposed based on a pseudo-attraction force method. Then, the potential requirements of such a system are investigated and a number of visually impaired people are asked to try the proposed haptic device. Finally, the requirements are used as the basis for designing a haptic direction indicator that guides blind users to a particular destination by generating asymmetric oscillations in the right direction (Fig.1).

2 Methods

Mobility assistance for people with visual impairment is divided into two categories. One is a sensory substitution system that extends a person’s sensing range and that is customized to the individual, such as a white cane. Another is a position display system, the purpose of which is to provide directions or ambient information, such as acoustic signals and footpath route indicators.

A significant number of haptic interfaces have been developed and commercialized to guide visually impaired people including Optacon and the tactile vision substitution system (TVSS)[4, 5]. And my colleague and I developed a haptic verbal interface as a mobility aid for the visually impaired.
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Figure 1: Concept of a haptic direction indicator for visually impaired people in emergency situations.

It has also been reported that a combined shoulder-tapping and speech interface can be used by people with severe visual impairment to find their way or their orientation [6]. These reports show the possibility of employing a haptic interface for wayfinding tasks.

Many force feedback devices, which provide a richer experience than vibration, have been developed [7, 8, 9]. However, most of them use a mechanical linkage to establish a fulcrum relative to the ground, or huge air compressors, or require the user to wear a heavy device. None of the above can be used easily outside the laboratory. Although some wearable and mobile force displays have been proposed, they can produce neither a constant force nor a translational force, without also producing a reaction force. Examples include GyroDisplay [10], which utilizes the gyro effect, and GyroCube [11], which presents torque using the change in angular momentum of a motor. These devices can generate only a rotational force for a short time since they employ a change in angular momentum. Kinesthetic, or force, stimulation in mobile devices has the potential to be more intuitive and expressive than cutaneous stimulation as mentioned above. However, most kinesthetic systems are unsuitable for mobile devices. The generation of low-frequency force requires a fixed mechanical ground, which mobile haptic devices lack [12]. The challenge is to realize kinesthetic interaction in hand-held devices.

We have already proposed a new force perception method that can generate a sustained translational force sensation [13, 14, 15]. The method uses an asymmetric oscillation, where brief intense pulses of acceleration alternate with longer periods of low-amplitude recovery. Although the net acceleration is zero, users perceive a net force sensation in the direction of the pulses. This “pseudo-attraction force” is attributed to the nonlinear relationship between perceived acceleration and physical acceleration. I built a hand-held prototype to generate periodic motion with asymmet-
Figure 2: Asymmetric oscillation generation mechanism based on a swinging slider-crank mechanism.

My previous findings show that the kinesthetic sensation of being pulled was effectively generated with the method [13, 14]. Here, I applied the pseudo-attraction force technique to a haptic direction indicator for visually impaired people.

3 Evaluation

3.1 Overview

I investigated the feasibility of a haptic direction indicator for visually impaired people and its potential requirements with the help of the students and staff of the Kyoto Prefectural School for the Visually Impaired.

3.2 Method

3.2.1 Participants

Seven blind right-handed subjects (24–50 years of age) participated in the study. All the subjects were ignorant of the objectives of the experiment. None of the subjects reported any known tactual impairments of their hands. Auditory effects were not suppressed. Table 1 is a list of the characteristics of the subjects’ disabilities.

3.2.2 Apparatus

The experimental system consisted of a tray-shaped haptic device (haptic direction indicator) containing a force display module, a turntable, and a stepper motor (approximately 750 g), and a small bag containing a battery and a control device (approximately 300 g) as shown in Fig. 3. The haptic device is nongrounded and based on the pseudo-attraction force technique as introduced in Section 2. The size is 55 mm × 216 mm × 87 mm. The weight of the reciprocating mass in the force display module is 40 g.
Table 1: Characteristics of the subjects’ disabilities

<table>
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The motor in the force display module was controlled so that it rotated at a constant speed (5 cycles per second) by a motor amplifier with an electronic governor function since my previous experiment showed that 5 cycles per second is one of the most effective rotational frequencies for clearly perceiving the force sensation [13]. A DC motor (2232R006S; Faulhaber) was used with a power supply voltage of 6.0 V.

The force display module was placed on the turntable. The direction of the force display module was controlled with a stepper motor (KH42HM2-851; Japanese Servo Ltd.). The stepper motor was engaged by a belt with a belt pulley installed in the turntable. Therefore, the perceived force direction was determined by the direction of the force display module. The number of pulses input into the stepping motor was controlled with a microcomputer (PIC18F2525). The reduction gear ratio was 1/6.

3.2.3 Stimuli and Conditions

The haptic stimuli were generated by the haptic device (haptic direction indicator). The equation for the motion of the weight in the swinging slider-crank mechanism (Fig. 2) is as follows:

\[ x = l_1 \cos \omega t + \mu (d - l_1 \cos \omega t) + \sqrt{l_3^2 - \{l_1(\mu - 1) \sin \omega t\}^2} \]  

where

\[ \mu = \frac{l_2}{\sqrt{l_1^2 + d^2 - 2l_1d \cos \omega t}}, \]

and \( x = OD, d = OA, l_1 = OB, l_2 = BC, l_3 = CD, \) and \( \omega t = AOB \) in Fig. 2. \( \omega \) is the constant angular velocity, and \( t \) is time. In the device, \( d = 28 \text{ mm}, l_1 = 15 \text{ mm}, l_2 = 60 \text{ mm}, \) and \( l_3 = 70 \text{ mm}. \) The acceleration is given by the second derivative of \( x \) with respect to time. The measured and calculated acceleration are shown in Fig. 4.

To measure the directional resolution of the pseudo-attraction force for visually impaired people, I compared two ways of describing the presented direction: a 12-direction clock and an 8-direction compass.
Figure 3: Appearance of experimental apparatus.

Figure 4: Actual asymmetric acceleration value with the LPF (seventh-order Butterworth, cutoff frequency 50 Hz for 5 cycles per second, sampling 1 kHz) (blue solid line) vs. the calculated value (black dotted line).
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The 12-direction clock is widely used among visually impaired people to explain the direction of a target location by using the position of the numbers on a clock. Usually, a position directly in front of someone is described as 12 o’clock. For example, “There is a rice bowl at 2 o’clock.” means the rice bowl is located in front and slightly to the right of the visually impaired person. The clock-position method is used to express the relative direction.

In contrast, the 8-direction compass is used to express the absolute direction in terms of north, south, east, and west.

In this experiment, the two conditions were tested since they are usually used in visually impaired people’s daily lives. A stimulus of 0 degrees was defined as being directly in front of the subject, that is 12 o’clock and in a northerly direction. The orientation of the force vector was varied between 0 and 360° on the horizontal plane in 30° steps (12 vectors) or 45° steps (8 vectors). The stimuli between 150° and 210° were eliminated in the experiment because of hardware limitations. The orientation was controlled by the stepper motor. The stimulation was presented for five seconds and the stimuli were supplied twelve times for each condition. Adjacent stimuli were not presented consecutively.

3.2.4 Procedure

Seated subjects held the force display with both hands. The subjects were asked not to squeeze the display, but to grasp it with just enough strength to keep it from slipping from their hands. The subjects were required to respond with one of 360 degrees; answers such as “I’m not sure” were not accepted. The sequence of parameters was randomized for all subjects to reduce the order effect. Correct-answer feedback was not provided during the experiment. The subjects held the circular disk with both hands at a tape-marked place. The method of grasping the device was constant throughout the experiment. The arms and hands were not restrained. In order to remove the influence of adaptation to long-term vibration, the subjects were given a thirty-second break after every trial. Pauses were allowed to avoid fatigue.

3.3 Results

I calculated the angular error between the stimulus and the response to evaluate and compare the two conditions. The angular error is the angular difference between the orientation of the stimulus and that of the response. For each subject, the root mean square (RMS) of the angular errors was computed to evaluate the deviation for the all responses. Forward is 0°, backward is ±180°, left is 90°, and right is 270°.

Figure 6 shows the scatter pattern of the responses as a function of the stimuli from all the subjects. The size of the radius shows the frequency of the response. In the graph, data on an identical line mean that the
subjects responded to the direction correctly.

The graphs indicate that a force sensation can be generated in almost all directions on the horizontal plane under each condition. However, in some trials the differences between the responses and stimuli were around $180^\circ$.

These were caused by polarity judgment errors as reported in [13], namely a $180^\circ$-angular error. To compare the direction error without the polarity judgment error, a modified angular error was defined, and the RMS was calculated based on the isotropic force-direction sensitivity from a report stating that systematic distortions are not present in the perception of force direction in a horizontal plane [10].

The RMS of the modified angular errors in the above case is shown in Fig. 8. For all subjects, the RMS values of the modified angular errors under the compass condition were smaller than those under the clock-position condition. I performed a two-tailed pair-wise $t$-test for the RMS of modified angular errors under the compass and clock-position conditions. The results revealed that the RMS of the the modified angular errors for the compass was marginally but significantly smaller than those for the clock-position ($t(6)=3.47, p<.05$), indicating that the force sensation was more precisely perceived using the compass than the clock-position.

Theoretically, the average angular errors decrease as the number of divisions increase. The average angular errors for the compass condition is $\pm 11.25^\circ$, and that for the clock-position condition is $\pm 7.5^\circ$. However, the results show that the ability of visually impaired people to determine direction is not very great, which means that a simple increase in the number of divisions will not provide higher directional resolution. This is consistent with previous results obtained for people with normal vision [13].

In addition, responses were received after the experiment. The requirements as relayed to us by blind people are as follows: The navigation function should be more than just a compass; the device should be
Figure 6: Scatter pattern of the responses as a function of the stimuli for seven subjects. A stimulus and response of 0 degrees was defined as the forward direction, namely 12 o’clock and north.

Figure 7: RMS of angular errors.
small enough to hold in one hand; and the operability should be the almost same as that of smart phones for blind people. Most blind people have expressed the need for a wayfinding tool, even if it means wearing a backpack-type device.

4 Design criteria and future work

The experimental results described above show the angular resolution of the pseudo-attraction force by visually impaired people. This section discusses the design criteria for developing a haptic direction indicator based on the results.

When the force display module is rotated to generate a two-dimensional force vector, the rotation takes considerable time, thus losing immediacy. A two-dimensional force can be generated not only by rotating one force display module, but also by the summation of linearly independent force vectors.

Based on the results showing that the 8-direction compass provides a high level of performance, a prototype for generating an eight-direction force was designed and developed by combining four force display modules (Fig. 9). Furthermore, the motor was attached to a flywheel to stabilize the output torque.

The proposed prototype, complemented with a location- and orientation-aware mobile device (e.g., a global positioning system (GPS) function and a geomagnetic sensor) can be used in systems that guide blind users to their destinations by drawing them in the right direction. I plan to develop a haptic direction indicator with these positioning functions.
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Figure 9: Design and development of a prototype generating eight directional forces by combining four force display modules.

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References


