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Development of a Cane with a Haptic Interface Using IC Tags for the Visually Impaired

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Abstract— **It is often difficult for visually impaired persons to walk outside to his or her destination. In this paper, we develop a cane with a built-in haptic interface for use by visually impaired persons. The cane is paired with IC tags buried underground (e.g., under street pavement). The haptic interface is controlled with a position and velocity control system that accurately indicates four directions (forward, backwards, right and left). After evaluating the vibration in the haptic interface, we determined the optimal vibration frequencies indicating a specific direction were combinations of 5 (Hz) and 1 (Hz). Furthermore, the optimal repetition of vibrations was determined to be two times. By using these conditions, the four directions were recognized more than 95% of the time. It was also confirmed that the visually impaired person recognized the presented direction even when an IC tag was buried underground. In the future, a mechanism will be developed that will allow visually impaired persons to recognize directions more accurately even if they swing the cane in a controlled manner. In addition, we will integrate a route decision system into the cane equipped with the haptic interface.**

I. INTRODUCTION

A. Navigation of the Visually Impaired

THE number of visually impaired people is in Japan 0.3 million (0.3% of the total population). These people often need navigation assistance in the form of a guide when they travel to destinations for the first time because they lack a full understanding of their real-time position and route. The rate at which visually impaired people travel outside the home daily is 30.2%, which is lower than the 40.4% rate for persons with other forms of disability [1].

Currently, the most effective way to introduce a visually impaired person to a previously unknown location is to have that person accompanied a guide. The visually impaired person receives and understands which direction to move by grasping the elbow or shoulder of the guide. However, this navigation method imposes not only a physical burden on the guide, it also imposes a psychological burden on the visually impaired person.

B. Related Studies on Navigation Systems for the Visually Impaired

As stated above, it is difficult for visually impaired persons to freely travel where they want to go. Resolving this problem would encourage greater social participation by visually impaired persons.

There have been numerous related studies on navigation systems for the visually impaired [2], such as guidance by voice [3], ultrasound [4], miniature radio receivers [5] and image recognition systems [6]. Unfortunately, these studies have encountered the following problems: limited usage area, influence of the surrounding environment, influence on sighted persons, and cumbersome system size.

Currently, navigation systems using tactile sensation, which imitates the navigation information provided by a sighted guide, have been researched. In one example, Mori et al. developed a guide dog robot [7]. However, this system is too large to be of use in many daily activities.

Other researchers have studied portable navigation systems [8]. The focus of some of these studies has been the integration of a portable system and the white cane typically used by the visually impaired. Additionally, a direction teaching system using vibrating motors was developed [9]. However, it was difficult for users to recognize the guidance provided by the vibration motor due to its low directivity. As an interface to show direction, there was a separate study on the change of acceleration using the slider crank mechanism. In order to show at least four directions, Nakamura et al. [10] and the authors [11] developed a haptic interface for a cane that is based on the velocity changes of weights. This system becomes portable by integrating it with the position information provided by an IC tags and a GPS system.

C. Purpose

In this paper, we show the conditions under which visually

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impaired persons can most accurately perceive a direction of travel when the developed haptic interface is used. In addition, we evaluate the effectiveness of the navigation system provided by the developed cane with the built-in haptic interface in an environment where IC tags have been buried underground.

Section II explains the "Pedestrian Intelligent Transport System" project in Japan. Section III shows the design of the haptic interface and the white cane with the built-in haptic interface. Section IV presents the performance of the haptic interface with the position and velocity control system. Section V discusses the optimal frequency and vibration to be provided for determining the direction and Section VI evaluates the cane with built-in haptic interface in an actual environment using an IC tag. Finally, Section VII presents a summary and discusses future work.

II. PEDESTRIAN INTELLIGENT TRANSPORT SYSTEM PROJECT

In Japan, the Ministry of Land, Infrastructure, and Transport has been the primary manager of the Pedestrian ITS (Intelligent Transport System) project [12]. The goal of Pedestrian ITS is to develop a system that will allow safe, secure, and smooth travel by all pedestrians, including the elderly, the visually impaired and wheelchair users, as well as bicyclists. Pedestrian ITS is composed of the following three components:

(1) Route navigation – direction and position guidance based on the user's characteristics
(2) Attention reminder – reminders provided in roadways or at crossings
(3) Neighboring information input – providing information on the present location or on the nearest wheelchair-accessible restrooms, etc.

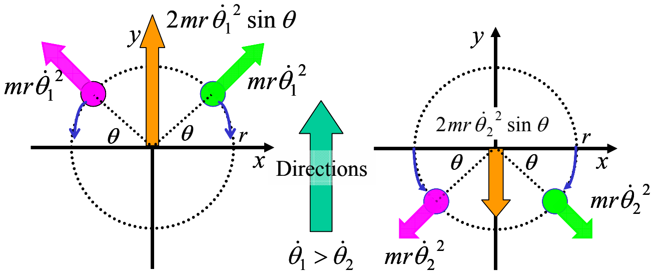
In this study, IC tags are buried under textured paving blocks. The information is read through a reader attached to the tip of a visually impaired person's cane and to the person by means of vibration. This allows the visually impaired person to navigate the route. The frequency used by the IC tag is 125 (kHz), which is resistant to rain and dust.

In this paper, the IC tag buried under the textured paving block is used to provide map information. The cane's haptic interface is called the "Force Blinker". It enables the visually impaired to navigate with the information obtained by the IC tag reader.

III. CONCEPT OF THE HAPTIC INTERFACE "FORCE BLINKER" AND THE PROTOTYPE

In this section, the haptic interface "Force Blinker" is proposed and the mechanism that allows the prototype cane to show directions is introduced.

Two eccentric weights are used in this system. In Fig. 1, the center of gravity of the weights is the pink and green circles.



(a) Direction instruction by resultant force (b) Reduce the resultant force

Fig. 1: Mechanism of direction indicator

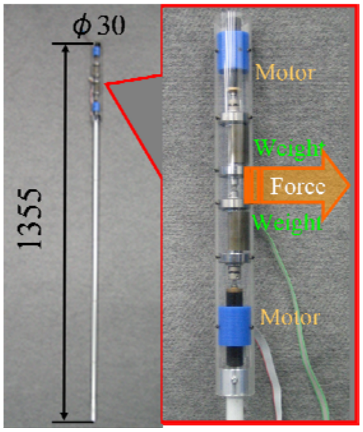


Fig. 2: Haptic interface built-in cane

As shown in Fig. 1, the two weights rotate in opposite directions and the resultant generated centrifugal force (orange) is presented as the direction of travel (Fig. 1(a)). The rotational velocities of the weights are high in the traveling direction, which provides higher centrifugal force. Conversely, the velocities are lower on the opposite side. Based on the velocity and position controls of the two weights, the centrifugal force generated in the cane is transmitted to the hand of the visually impaired person. As a result, the Force Blinker is able to indicate the correct direction to the goal. The prototype of the Force Blinker built-in cane is shown in Fig. 2. In this cane, two types of eccentric weights (120 (deg) sector shape, radius 14 (mm), height 30 (mm), mass 57 (g)), DC motors (Maxon, 3(W), reduction ratio 17) and encoders (Maxon, Resolution 256 (ppr)) have been embedded. The specification of the prototype is as follows: size 1355 × φ30 (mm), weight 560 (g), and maximum force 1.3 (N). The two motors is mounted inside of the handle of the cane.

IV. CONTROL PERFORMANCE EVALUATION

A. Objective

To present direction accurately, the weight in the haptic interface must be controlled accurately. The focus of this section is to explain the development of a control system for the weights. Specifically, we compare the velocity control system with the position control system, which includes the minor loop of the velocity control system.

B. Methodology

The block diagrams of the velocity control system and the position control system with the velocity feedback loop are shown in Figs. 3 and 4.

The weight rotational velocity is expressed using the rotational frequency in this paper as follow.

$$f = \omega / 2\pi \qquad (1)$$

where f is the rotational frequency, ω is the rotational velocity.

The weight velocity in the traveling direction is defined as f_{fast} (Hz), and the weight velocity in the opposite direction is defined as f_{slow} (Hz). The conditions of the weight velocities were f_{fast} = 8 (Hz) and f_{slow} = 1 (Hz) and f_{fast} = 7 (Hz) and f_{slow} = 2 (Hz). These conditions were determined based on the maximum power of the motor used in this study. The target value of the position is calculated as the integration of the weight's velocities, f_{fast} and f_{slow}. The number of the rotation that the centrifugal force was generated was five in each condition.

C. Experimental Equipment

The signal flow is shown in Fig. 5.

The QNX real-time operating system was selected as the software for this system. The control system was composed of a PC/104 bus module (CPU Cyrix NS Gx-1, 300 MHz), 128 MB of system memory, an IO board (Advantech), a D/A board (Micro science, 12 bit), and a counter board (TAC, 12 bit).

D. Experimental Result

We evaluated the following capabilities of each weight's position and velocity relative to the target position and velocity.

For example, Figs. 6 and 7 show the relationship between the rotational frequency and time with velocity control and position control, which includes the velocity control minor loop, on based the condition that f_{fast} = 8 (Hz) and f_{slow} = 1 (Hz). Figures 8 and 9 show the relationship between the rotational number (rotational position) and time with velocity control and position control, which includes the velocity control minor loop, on the condition that f_{fast} = 8 (Hz) and f_{slow} = 1 (Hz).

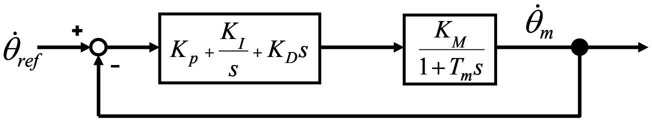


Fig. 3: Velocity feedback loop

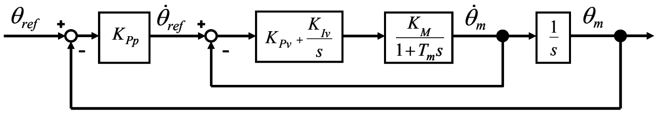


Fig. 4: Position feedback loop (with velocity feedback loop)

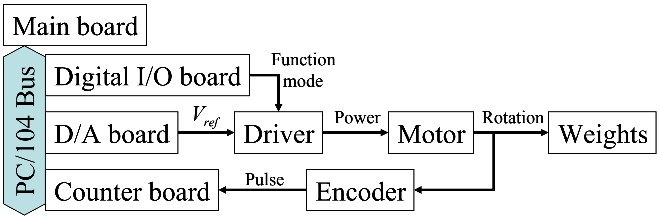


Fig. 5: Signal flow

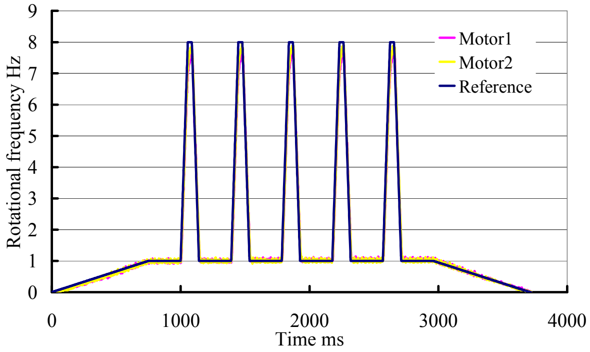


Fig. 6: Rotational velocity (f_{fast}= 8 (Hz),f_{slow}= 1) Velocity feedback)

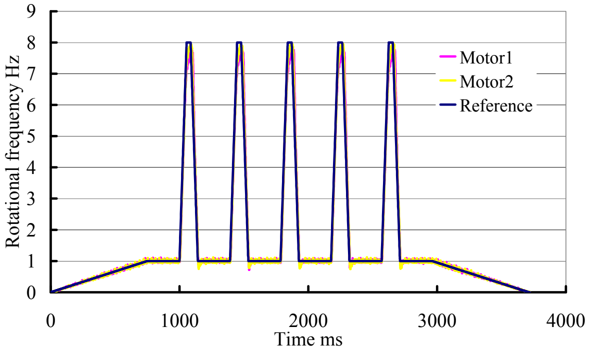


Fig. 7: Rotational velocity (f_{fast} = 8 (Hz), f_{slow} = 1)((Position and Velocity feedback)

E. Experimental Discussion

As shown in Figs. 6 and 7, the following capability of the velocity with velocity and position control was similar to that with only velocity control. The average differences between the target velocity and measured velocity of the weight subject to velocity and position control are shown in Table 1 and compared with the velocities of the weight subject to velocity control only. These results indicate that the error in target velocity with position control, including the velocity control minor loop, was smaller than the error with velocity control alone. Furthermore, the error for the condition f_{fast} = 8 (Hz) and f_{slow} = 1 (Hz) was larger than that for the condition f_{fast} = 7 (Hz) and f_{slow} = 2 (Hz).

We next discuss rotational position. As shown in Figs. 8 and 9, the following capability of the system with velocity and position control was better than that with velocity control only. As the number of rotations increases, the error of the rotational position also increases, even if velocity is controlled (Fig. 8). This is because the error of velocity

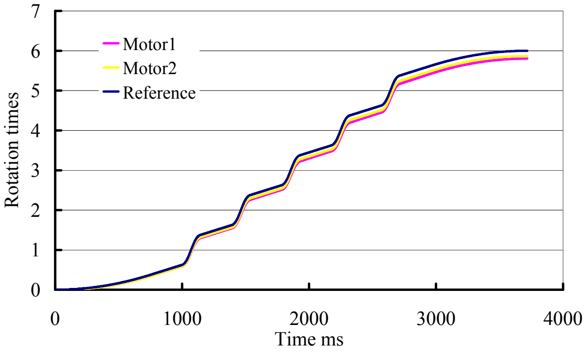


Fig. 8: Rotational angle (f_{fast} = 8 (Hz), f_{slow} = 1) (Velocity feedback)

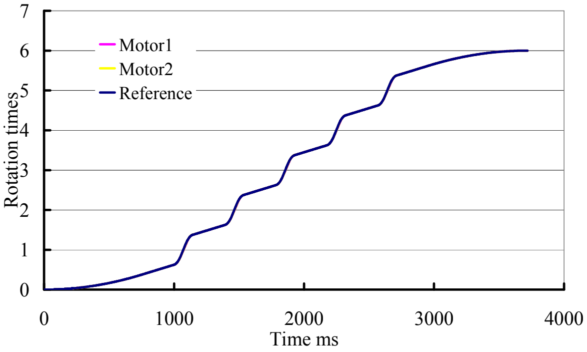


Fig. 9: Rotational angle (f_{fast} = 8 (Hz), f_{slow} = 1)(Position and velocity feedback)

Table 1: Average of velocity error

		Experimental condition Hz	
		$f_{Fast}=8$, $f_{Slow}=1$	$f_{Fast}=7$, $f_{Slow}=2$
Error of velocity %	Without control	43	20
	Velocity control	8.9	6.5
	Position control	6.2	4.8

Table 2: Maximum position error

		Experimental condition Hz	
		$f_{Fast}=8$, $f_{Slow}=1$	$f_{Fast}=7$, $f_{Slow}=2$
Error of rotational position deg	Without control	100	48
	Velocity control	65	47
	Position control	7.8	2.0

accumulated as the rotation of the weight continued. The average error difference between the target velocity and the measured velocity of the weight with velocity and position control is shown in Table 1, and is compared with the error difference when velocity control alone was used. The error for the condition f_{fast} = 8 (Hz) and f_{slow} = 1 (Hz) is larger than that for the condition f_{fast} = 7 (Hz) and f_{slow} = 2 (Hz). As shown in Table 2, the maximum error of the position is 7.8 (deg) with position control, which has the minor velocity control loop. However, the average error of the position is 0.64 (deg). This value is sufficiently accurate for the user to recognize the four presented directions (forward, backwards, right and left).

V. FREQUENCY DETERMINATION EXPERIMENT

A. *Objective*

In this section, we confirmed that a visually impaired person was able to understand the direction information indicated by the haptic interface. We measured the vibration frequency, number of directional presentation and force, which together enabled the subject to identify the correct direction

B. *Experimental Methodology and Condition*

In this experiment, four directions (forward, backward, left and right) were presented to a subject crossing a textured paving block at a right angle.

The frequencies (Hz) that generate the centrifugal force are as follows:

(1) $f_{Slow}=1$, $f_{Fast}=2, 3, \cdots, 7$
(2) $f_{Slow}=2$, $f_{Fast}=3, 4, \cdots, 7$
(3) $f_{Slow}=3$, $f_{Fast}=7$
(4) $f_{Slow}=4$, $f_{Fast}=7$

The condition of $f_{Fast}=8$ was eliminated in advance, because the subject stated the vibration was too strong.

Twenty trials were conducted. The presented direction was randomly selected.

The subject (male, 29 years old, vision loss for 16 years) was listed as Class 1st (fully disabled) on his physical disability certificate.

The subject received a detailed explanation of the experimental objectives. In addition, we explained that he was could stop the experiment whenever he desired and obtained his consent to the experimental conditions. The subject was tested in a sitting position because the experiment took a long time (Fig. 10).

C. *Experimental Equipment*

The haptic interface mentioned in Section 3 and the control PC mentioned in Section 4.C was used.

D. *Experimental Result*

The recognition rate of the presented direction was evaluated. The relation between the recognition rate and the frequency, and the relation between the recognition rate and the vibration force are shown in Table 3 and Fig. 11, respectively. The vibration force was calculated as the centrifugal force using the rotational frequency.

Table 3: Recognition rate % (N=20)

		f_{Fast} Hz					
		2	3	4	5	6	7
f_{Slow} Hz	1	55	75	90	100	90	85
	2		60	65	45	70	70
	3						35
	4						50

Fig. 10: Sensory evaluation

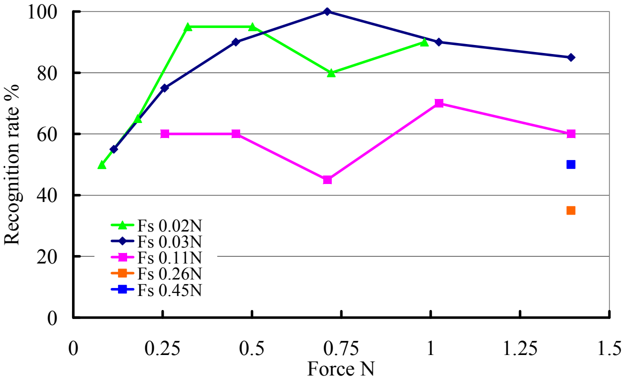


Fig. 11: Recognition rate – force (in f_{Fast}) diagram. Note that F_s is the force in f_{slow}.

Table 4: Recognition rate – number of vibration diagram (N = 20)

Number of vibration	1	2	3	4	5
Recognition rate%	70	95	100	95	100

The relation between the recognition rate and the number of presentations of centrifugal force, that is, the number of the rotation of the weights for $f_{Slow}=1$, $f_{Fast}=5$ is shown in Table 4. The recognition rate was more than 95% when the number of vibrations is at least two.

E. *Experimental Discussion*

(1) Recognition rate

As shown in Fig. 11, the condition of the highest recognition rate (more than 95%), is for $f_{slow}=1$, $f_{fast}=5$.

The recognition rate for $f_{fast}=7$ is lower than that for $f_{fast}=5$, even though the centrifugal force is $f_{fast}=7$. This is because the presentation time of the direction $f_{fast}=7$ (Hz) was shorter than that for $f_{fast}=5$. As a result, it was more difficult for the user to identify the direction.

As shown in Table 4, the recognition rate is more than 95% when the number of direction presentations was at least two. Accordingly, the number of direction presentations in the haptic interface was determined to be two presentations.

Table 5: Recognition rate % (direction N=100, $f_{slow}=1$, $f_{fast}=5$)

	Forward	Back	Right	Left	Ave.	$p(\chi^2)$
%	90	82	97	85	89	0.11

(2) False recognition

The recognition rate differences among the four presentational directions are discussed using the chi-square test. Table 5 shows the recognition rate in each direction with the condition of $f_{slow}=1$, $f_{fast}=5$. There was no significant difference among the directions with $p<0.01$ and it was determined that all four directions could be recognized.

Threfore, the four directions were recognized about 90% of the time when the rotation of the weights in the haptic interface “Force Blinker” was generated two times with $f_{slow}=1$, $f_{fast}=5$.

VI. EVALUATION OF CANE WITH BUILT-IN HAPTIC INTERFACE IN AN ENVIRONMENT WITH BURIED IC TAGS

A. *Objective*

The objective of this experiment was to evaluate the guidance provided to the visually impaired person by the cane with a built-in haptic interface in an actual location where IC tags have been buried.

B. *Experimental Methodology and Condition*

The same subject that participated in the above mentioned experiment also agreed to participate in this procedure. Using the cane equipped with the haptic interface, the subject walked across the textured paving blocks numerous times. The IC tag was buried under one of the blocks and the subject was able to obtain information regarding the direction of travel from the IC tag. As determined in Section V, the rotation of the weights in the haptic interface was generated two times with $f_{slow}=1$, $f_{fast}=5$. The subject chose his walking velocity arbitrarily.

C. *Experimental Equipment*

In this experiment, the haptic interface developed in Section V was used. However, a micro-computer (H8/3052F) instead of the PC/104 module was selected for use as the haptic interface in the outdoor environment. The signal flow is shown in Fig. 12. The frequency of the IC tag was 125 (kHz). Figures 13 and 14 show photographs of the IC tag and reader. In addition, the power source was supplied by the battery (KUNG LONG, 12 (V)), and it was confirmed that developed system continued to sense the IC tag and actuate the motor during an hour.

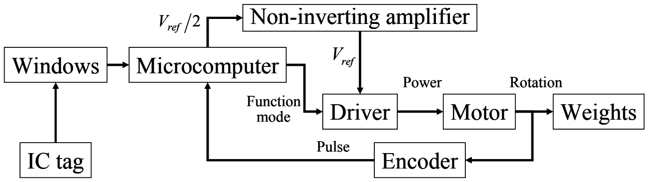


Fig. 12: Signal flow of the navigation system

Fig. 13: IC Tag on guidance block

Fig. 14: IC Tag reader/writer

D. *Experimental Result*

The experimental scenes in Figs. 15 and 16 show that the subject turned to the left and then preceded straight. It was confirmed that the subject recognized the direction presented by the haptic interface and turned in the presented direction.

E. *Experimental Discussion*

The weights rotated over the IC tag and the presented direction was recognized accurately when the subject stopped swinging the cane and used it to identify the information presented. When the subject swung the cane normally while walking, the vibration generated by the haptic interface could be felt, but the presented direction was not immediately recognized.

Based on an interview with the subject, it was determined to be better to present traveling direction information when the subject arrived at the corner. This is because visually impaired persons normally search for textured paving blocks at corners.

VII. CONCLUSIONS

In this paper, we developed a cane with a built-in haptic interface designed to assist visually impaired persons wishing to navigate outside the home. We evaluated the vibration conditions of the haptic interface. As a result, it was determined that the optimal vibration frequencies for presenting the direction of travel were the combination of 5 (Hz) and 1 (Hz). Furthermore, the optimum number of vibrations was two. Utilizing these conditions, four directions (forward, backwards, right and left) were recognized more than 95% of the time. Finally, it was confirmed that the visually impaired person recognized the presented direction of travel provided an IC tag buried in an actual outdoor environment.

In the future, a mechanism that will assist users on recognizing the direction more accurately will be developed so that the visually impaired can more easily determine directions by manipulating the cane. Furthermore, we intend to integrate a route decision system with the cane containing the built-in haptic interface.

ACKNOWLEDGMENTS

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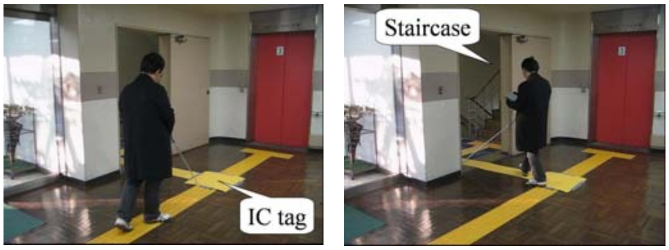

left direction after direction

Fig. 15: Direction experiment (left)

straight direction after direction

Fig. 16: Direction experiment (straight)

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