The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

Mechanism and Evaluation of a Haptic Interface “Force Blinker 2” for Navigation of the Visually Impaired

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Abstract— **In the navigation of the visually impaired, an external input such as force or sound is required about the direction of travel to reach a particular target position. We develop a new haptic interface called “Force Blinker 2” to navigate the visually impaired. In Force Blinker 2, rotating weights and repulsive magnets are used to reduce the force generated to the direction opposite the traveling direction, which caused false recognition in the previous system, “Force Blinker 1.” In Force Blinker 2, the rotational radius of the weight varies depending on the velocity of the rotational weight. Ten visually impaired subjects evaluated Force Blinker 2 by comparing it with Force Blinker 1, a fixed radius type interface. The directions presented by Force Blinker 2 were correctly recognized at a rate of approximately 85%, which is approximately a 10% improvement over the rate by Force Blinker 1.**

I. INTRODUCTION

THE number of visually impaired people in Japan is 0.3 million (0.3% of the total population). The rate at which visually impaired people travel outside the home daily is 30.2%, which is lower than the 40.4% rate for people with other forms of disabilities [1].

Currently, the most effective way to introduce a visually impaired person to an unfamiliar location is to have a guide accompany that person. 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, but also a psychological burden on the visually impaired person.

As a consequence, it is difficult for visually impaired people to travel freely. Resolving this problem would encourage greater social participation by the visually impaired.

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 people, and cumbersome system size.

Recently, 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 useful 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 a slider crank mechanism [10]. To show at least four directions, Nakamura et al. [11] – [13] and the authors [14] developed a haptic interface that is based on the changes of the rotational velocity of weights. However, according to the evaluation by ten visually impaired subjects, the recognition rate of the direction presented by our haptic interface was approximately 75%.

From our previous results, we established the hypothesis that the navigation force of the haptic interface to the side opposite the traveling direction confused the users. Consequently, we developed a new haptic interface to decrease the force generated to the side opposite to the traveling direction. The interface developed based on this hypothesis was evaluated by the visually impaired by comparing it with the previous interface.

In this paper, Section II explains the concept of the navigation system for the visually impaired. Section III shows the mechanism of Force Blinker 1 and its major problem by using a simulation. Section IV presents the concept and prototype of Force Blinker 2 to decrease the generated force in the side opposite to the traveling direction. Section V describes the evaluations of the developed Force

Manuscript received March 10, 2010.

This work was supported in part by the Global Center of Excellence (GCOE) Program “Global Robot Academia” at Waseda University, and a Grant-in-Aid for Scientific Research (20240058).

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Blinker 2 by ten visually impaired people in comparison with Force Blinker 1. Finally, Section VI presents a summary and discusses future work.

II. CONCEPT OF TOTAL NAVIGATION SYSTEM

In Japan, the Ministry of Land, Infrastructure, and Transport has been the primary manager of the Pedestrian ITS (Intelligent Transport System) project [15]. The purpose of Pedestrian ITS project is to develop a system that allows safe, secure, and smooth travel by all pedestrians, including the elderly, the visually impaired and wheelchair users, as well as bicyclists. The Pedestrian ITS project 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.

As a step to fulfill the above components of this project, Fig. 1 shows our concept of a navigation system for the visually impaired. First, the target destination is set by the user’s voice using a speech recognition technology. Second, the current position of the user is recognized using GPS and IC tags that are buried under textured paving blocks in the Pedestrian ITS project. Then, the route to the target destination is determined by using existing navigation systems such as car navigation. Finally, the user is navigated by the developed portable haptic interface, which is attached to the user or built into the cane.

In this paper, the portable haptic interface was the focused on the technical research topics.

III. HAPTIC INTERFACE OF FORCE BLINKER 1

In this section, the haptic interface called “Force Blinker 1” and its primary problem are explained.

Two eccentric weights are used in the haptic interface. In Fig. 2, the centers of gravity of the weights are the pink and green circles.

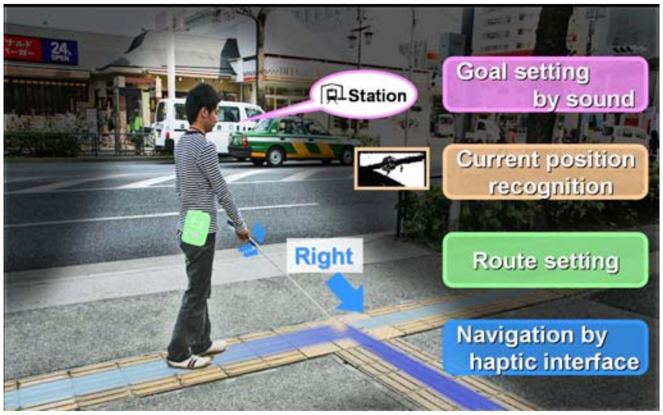


Fig. 1 Concept of total navigation system for the visually impaired

As shown in Fig. 2, the two weights rotate in opposite directions and the resultant generated centrifugal force (orange) is presented as the direction of travel (Fig. 2(a)).
The rotational velocities of the weights are high in the traveling direction to provide higher centrifugal force. Conversely, the velocities are lower on the opposite side. Based on the velocity and position controls of the two weights, the generated centrifugal force is transmitted to the user. As a result, Force Blinker 1 is able to indicate the correct direction to the goal. According to our previous research [13], the required rotational frequency of the weights in the traveling direction was 5 (Hz) and that in the opposite direction was 1 (Hz) to recognize the direction most accurately. However, in this rotational condition, the recognition rate of the traveling direction was low (approximately 75%).

In this previous work, only the maximum presented force at the position of the highest and lowest velocity was considered. This result was based on the system of the uniform angular velocity model of the weight’s rotational movement. Therefore, only the centrifugal force was considered as the presented force of the haptic interface.

In this paper, first, we simulate the centrifugal force in a sequence of rotational movements of the weight. In this model, as shown in Fig. 3, the presented force, F (N), is calculated as the following equation:

$$F = 2mr\dot{\theta}^2 \times \cos\theta \qquad (1)$$

where the x-axis is the traveling direction, m (kg) is the mass of the weight, r (m) is the distance between the weight and rotational axis, and θ (rad) is the angle of the weight.

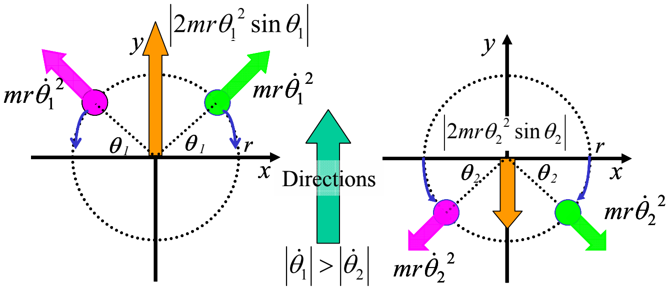
In Force Blinker 1, the mass of the weight was 57 (g) and the distance between the COG (center of gravity) of the weight and the rotational axis was 6.3 (mm). We simulated the presented force, F, under the condition that the rotational frequency of the weight was the combination of 5 (Hz) and 1 (Hz). The presented force became maximum when $\theta = \pi$ (rad) and minimum when $\theta = 0$ (rad). Thus, the presented forces were 0.22 (N) and 0.045 (N), respectively.

However, the actual system is a nonuniform angular velocity model of the rotational movement of the weight. Therefore, the inertia force needs to be considered.

We simulated the presented force using a nonuniform angular velocity model of the weight’s rotational movement. As shown in (2), inertial force is added into the presented force calculated by (1).

$$F = 2m\left[\, r\ddot{\theta}_{(t)} \sin\theta_{(t)} + r\dot{\theta}_{(t)}^2 \cos\theta_{(t)} \,\right] \qquad (2)$$

Figure 4 shows the result of the simulation on the presented force using (2).



(a) Direction instruction by resultant force (b) Reduction of resultant force

Fig. 2 Mechanism of direction indicator

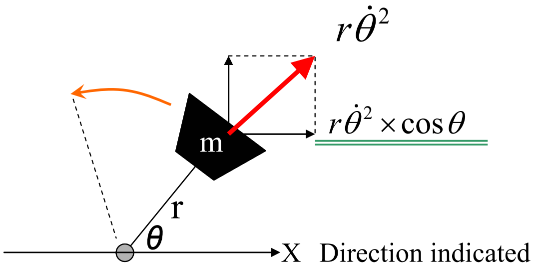


Fig. 3 Model of Force Blinker

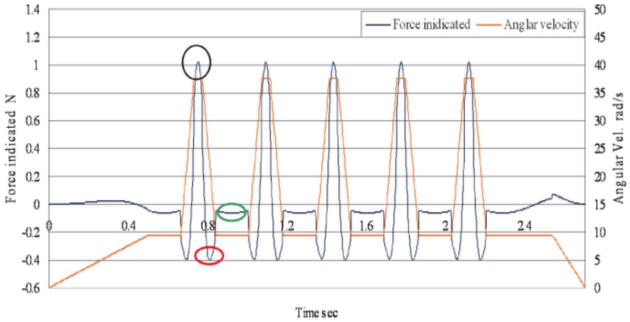


Fig. 4 Simulation of indicated force and angular velocity

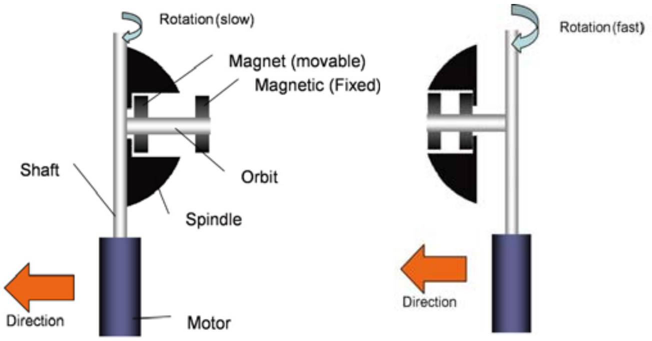
As a result of the simulation, it was found that the generated force to the opposite side to the traveling direction became the maximum value when the rotational weight became the position between the traveling direction and opposite side of the traveling direction. The inertia force in acceleration and deceleration is the main cause of this phenomenon.

Therefore, we established the hypothesis to improve the recognition rate because the navigation force of this haptic interface to the side opposite of the traveling direction (opposite presented force) confused the users.

IV. HAPTIC INTERFACE OF FORCE BLINKER 2

A. *Concept of mechanism of Force Blinker 2*

In Force Blinker 1, to reduce the opposite presented force, the acceleration and deceleration of the weight needed to be reduced. This also means the reduction of the presented force. The relationship between the increase of the presented force and the decrease of the opposite presented force is a trade-off. Therefore, it is difficult to decrease the opposite presented force while keeping the presented force in Force Blinker 1.



(a) Opposite side direction (b) Traveling direction

Fig. 5 Simple model of Force Blinker 2

In this section, we propose a new haptic interface called "Force Blinker 2" to decrease the opposite presented force while keeping the presented force.

The main concept of Force Blinker 2 is to change the distance between the weight and rotational axis to decrease the opposite presented force.

Fig. 5 shows the mechanical model of Force Blinker 2. Force Blinker 2 is composed of a motor, shaft, rail, movable weight and movable magnet along the rail, and a fixed magnet. The movable and fixed magnets are arranged to repel. The weight moves freely with the movable magnet along the rail.

When the rotational velocity is slow, as shown in Fig. 5 (a), the weight exists at the rotational axis side by the effect of the repulsive magnets. Conversely, when the rotational velocity is fast, as shown in Fig. 5 (b), the weight moves to the outer side along the rail, because the centrifugal force of the weight becomes larger than the repulsive force of the magnets.

Therefore, when the rotational velocity is slow (that is, when the weight does not exist at the traveling direction), the weight rotates next to the rotational axis and the centrifugal force is small. On the other hand, when the rotational velocity is fast (that is, when the weight exists at the traveling direction), the weight rotates far from the rotational axis and the centrifugal force is large.

By applying this mechanism to Force Blinker 2, the difference between the presented force and opposite presented force becomes larger than that when the rotational radius of the weight is fixed, as in Force Blinker 1.

B. *Prototype of Force Blinker 2*

A prototype of Force Blinker 2 is shown in Fig. 6. In addition, the extended figure of the mechanical model of the movable weight part is shown in Fig. 7. As mentioned in Section III *A*, Force Blinker 2 is composed of motor, shaft, rail, movable weight and magnet along the rail and fixed magnet.

The specifications of the prototype are as follows: size: 3100 × φ30 (mm), weight: 465 (g), and maximum force: 1.3 (N).

In this prototype, two types of eccentric weights (mass 28 (g)), DC motors (Maxon, 3 (W), reduction ratio 17, RE13-118638) and encoders (Maxon, Resolution 256 (ppr), MR Type S-241062) were embedded.

The movable magnet is a ring type neodymium magnet (Size: Φ8 x Φ5 x 3, magnetic flux density: 3,130 (Gauss)) and the fixed one is also a ring type neodymium magnet (Size: Φ11 x Φ9 x 5, magnetic flux density: 2,840 (Gauss)). The magnetic flux density of both magnets is determined by trial and error.

The weight and rail are made of nonmagnetic stainless steel (SUS304) to avoid any effect of the magnetic force. In addition, brass is used in the region of contact between the weight and rail to minimize the effect of friction.

Moreover, to minimize the rotational radius when the rotational velocity is slow, the shaft is not a cylinder shape at the contact region of the weight.

A micro-computer (H8/3052F, CPU: 25 (MHz), Memory: 512 (kB)) was selected for use as the haptic interface of Force Blinker 2 in the outdoor environment. The signal flow of Force Blinker 2 is shown in Fig. 8. In addition, the power source was supplied by a battery (Kung Long, 12 (V)), and it was confirmed that the developed system continued to actuate the motor for one hour.

The block diagram of the position control system with the velocity feedback loop is shown in Fig. 9.

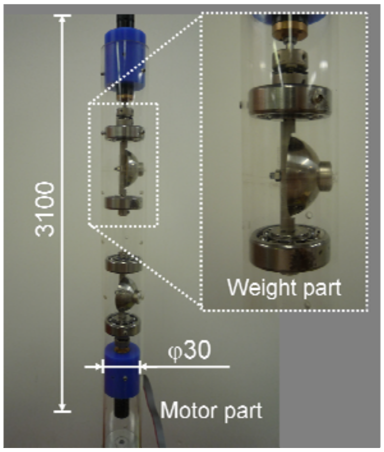
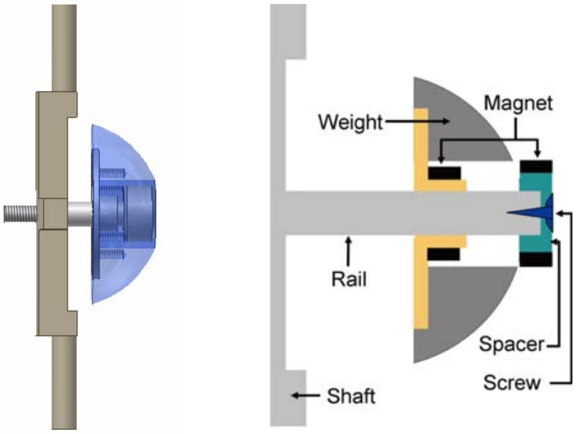


Fig. 6 Prototype of Force Blinker 2



(a) 3D Design (b) Part of rotational system

Fig. 7 Mechanical system to change the rotational radius

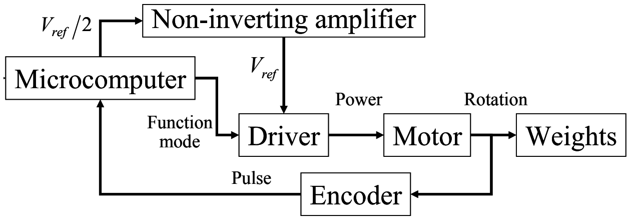


Fig. 8 Signal flow

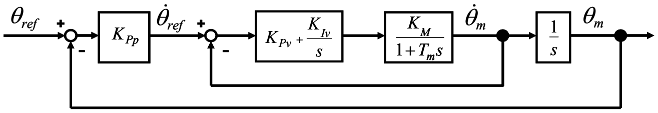


Fig. 9 Position feedback loop (with velocity feedback loop)

C. *Simulation of generated force*

We simulated the displacement and presented force when the rotational axis was fixed and variable to confirm the effectiveness of the mechanism of Force Blinker 2, which relies on passive control of the rotational axis by using the magnet to reduce the opposite presented force.

Fig. 10 shows the rotational velocity of the weight and rotational radius. It is confirmed that the rotational axis became longer by increasing the rotational velocity.

Fig. 11 shows the presented force when the radius is not fixed as the maximum in Force Blinker 2. The presented force, F, is calculated using the following equation.

$$F = 2m\ddot{x} = 2m \cdot \frac{d^2}{dt^2}\left[r_{(t)} \cdot \cos\theta_{(t)}\right] \tag{3}$$

From the viewpoint of rotation of the weight, the force applied to the weight to the radial direction, F_r, and that to the tangential direction, F_θ, are defined as follows:

$$\begin{cases} F_r = m\left(\ddot{r}_{(t)} - r_{(t)}\dot{\theta}^2{}_{(t)}\right) & (4) \\ F_\theta = m\left(2\dot{r}_{(t)}\dot{\theta}_{(t)} + r_{(t)}\ddot{\theta}_{(t)}\right) & (5) \end{cases}$$

In addition, the force applied to the weight by the magnet to the rotational center direction is as follows;

$$F_r = -\frac{A}{r^2{}_{(t)}} \tag{6}$$

where $A = 16.9$ (N/m^2) was calculated in the pre-experiment, which included an analysis of the relation between the magnetic force and magnetic distance.

Based on (3) – (6), the nonlinear differential equation was solved using the fourth order Runge-Kutta method (sampling time: 2 (msec)). The constraint condition of the radius, $r(t)$, was from 3 (mm) to 10 (mm).

Fig. 12 shows the presented force simulated by using (2) when the radius is fixed in Force Blinker 2.

By comparing the result of Fig. 11 with that of Fig. 12, the ratio of the opposite presented force and the presented force decreases from approximately a third (0.40) to approximately a fourth (0.23). Therefore, approximately 25% of the presented force to the opposite side is eliminated.

As a result, the timing when the rotational radius became the largest was 82 (msec) later than the timing when the rotational velocity became the fastest. This time delay was compensated in the input signal to control the weight.

V. EVALUATION BY THE VISUALLY IMPAIRED

A. *Objective*

The objective of this experiment was to evaluate the recognition rate of the traveling direction by Force Blinker 2 which decreases the opposite presented force by changing the rotational radius. The evaluation is a comparison of the recognition rates by Force Blinker 2 and by Force Blinker 1 by the target users, that is, the visually impaired.

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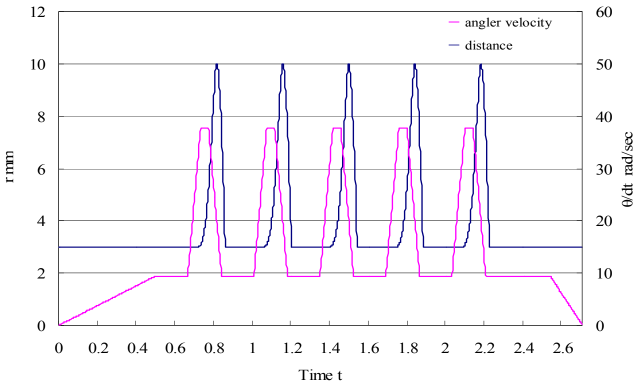

Fig. 10 Position of spindle

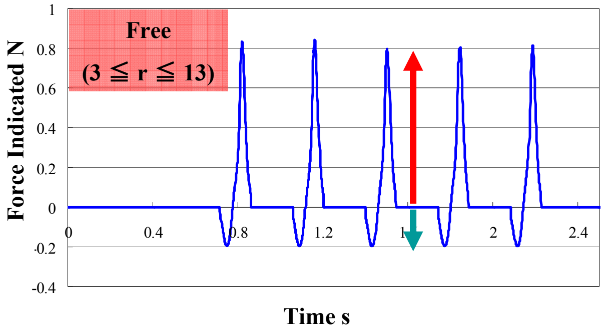

Fig. 11 Force to direction indicated (variable radius)

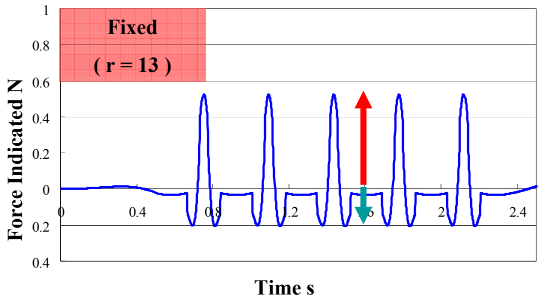

Fig. 12 Force to direction indicated (constant radius)

B. *Methodology*

As shown in Fig. 13, a subject, in a sitting posture, grasped the haptic interface "Force Blinker." In this experiment, four directions (forward, backward, left and right) were presented 80 times (20 trials were conducted for each direction). The traveling directions were randomly selected.

Each subject tested the conditions of Force Blinker 2, whose distance between the weight and rotational axis is variable, and those of the conventional method, Force Blinker 1, whose distance between the weight and rotational axis is fixed at the maximum rotational radius of Force Blinker 2. To avoid the habituation of feeling the direction by the haptic interface, the first condition was randomly selected.

Ten visually impaired subjects (Class 1 (the sum of visual acuity is less than 0.01): eight people, and Class 2 (the sum of visual acuity is from 0.02 to 0.04): two people) evaluated the developed system. Table I shows the subjects' characteristics. A subject evaluating the fixed radius interface before the variable radius interface is defined as "Fix," and a subject evaluating the variable radius interface before the fixed radius interface is defined as "Vari." in Table I.

Fig. 13 Experimental scene

Table I Characteristics of subjects

#	Age yrs	Sex	Dextra-lity	Time elapsed yrs	Grade	1st trial
1	60	F	R	20	1	Vari
2	62	M	L	6	1	Fix
3	57	F	R	18	2	Vari
4	39	F	R	39	1	Fix
5	39	F	R	37	1	Vari
6	27	M	R	27	1	Fix
7	38	F	R	38	1	Vari
8	68	M	R	2	1	Vari
9	39	F	R	6	1	Fix
10	40	F	R	40	2	Fix
avg.	46.9			23.3		

Note that F: Female, M: Male, L: Left, R: Right, Vari: Variable radius type (Force Blinker 2) and Fix: Fixed radius type (Force Blinker 1).

This experiment was approved by Waseda University IRB (#2009-142). The subjects received a detailed explanation of the experimental objectives and were told that they could stop the experiment at any time. We obtained each subject's consent to the experimental conditions.

C. Result and discussion

Fig. 14 shows the recognition rate when the rotational radius is either fixed in a conventional interface, Force Blinker 1, or variable to reduce the opposite presented force in the developed interface, Force Blinker 2. The data of subject #8 was eliminated, because he could not finish the experiment.

The recognition rate of Force Blinker 1 was 74.9±20.1% and that of Force Blinker 2 was 83.0±16.2%. The significant difference between the recognition rate of Force Blinker 1 and that of Force Blinker 2 was statically confirmed (p<0.02). The statistical analysis was Wilcoxson's sign rank sum test, which is a nonparametric method. We used this test because the number of acquired data was less than fifty, the two groups were corresponding, and the distribution of the parent population was not estimated as a Gaussian distribution.

The recognition rate was improved by applying the variable radius mechanism in Force Blinker 2 instead of the fixed radius mechanism in Force Blinker 1.

VI. CONCLUSIONS

In this paper, we developed a new haptic interface called "Force Blinker 2" to navigate the visually impaired. In Force Blinker 2, a rotating weight and repulsive magnets are used to reduce the generated force from the opposite direction to the traveling direction by making the rotational radius variable depending on the velocity of the rotational weight. By changing from Force Blinker 1 to Force Blinker 2, the generated force to the opposite direction decreases by approximately 25%.

Ten visually impaired subjects evaluated Force Blinker 2 by comparing it with Force Blinker 1, which is a fixed radius interface. As a result, the recognition rate of the traveling directions by Force Blinker 2 was approximately 85%, which is approximately a 10% improvement over that of Force Blinker 1.

In the future, we intend to integrate a route decision system with a cane containing the built-in haptic interface.

ACKNOWLEDGMENTS

We sincerely thank the subjects for participating in our experiments. We also thank Dr. Hiroshi Fujimoto (Waseda University) and Mr. Tsutomu Wada (Japan Braille Library) for their kind help and advice for designing the experiment.

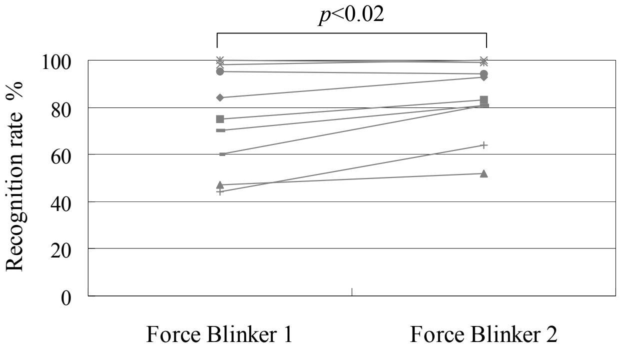

Fig. 14 Recognition rates

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