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Virtual Environment to Evaluate Multimodal Feedback Strategies for Augmented Navigation of the Visually Impaired

Masayuki Hara, *Member, IEEE,* Solaiman Shokur, *Student Member, IEEE,* Akio Yamamoto, *Member, IEEE,* Toshiro Higuchi, *Member, IEEE,* Roger Gassert, *Member, IEEE,* and Hannes Bleuler *Member, IEEE*

Abstract— **This paper proposes a novel experimental environment to evaluate multimodal feedback strategies for augmented navigation of the visually impaired. The environment consists of virtual obstacles and walls, an optical tracking system and a simple device with audio and vibrotactile feedback that interacts with the virtual environment, and presents many advantages in terms of safety, flexibility, control over experimental parameters and cost. The subject can freely move in an empty room, while the position of head and arm are tracked in real time. A virtual environment (walls, obstacles) is randomly generated, and audio and vibrotactile feedback are given according to the distance from the subjects arm to the virtual walls/objects. We investigate the applicability of our environment using a simple, commercially available feedback device. Experiments with unimpaired subjects show that it is possible to use the setup to "blindly" navigate in an unpredictable virtual environment. This validates the environment as a test platform to investigate navigation and exploration strategies of the visually impaired, and to evaluate novel technologies for augmented navigation.**

Fig. 1. Example of a virtual corridor invisible to the subject. The subject navigates in an empty room and receives vibrotactile and audio feedback in function of the distance to the virtual walls.

I. Introduction

Navigation tools to detect environmental features and avoid obstacles are essential for the visually impaired to safely walk indoor and outdoor. People suffering from total loss of vision mostly rely on conventional methods such as a white cane or a guide dog. There have been attempts with surgically implanted prosthetic devices such as the Dobelle Eye [1] that allow recognition of simple black-and-white characters and pictures [2], [3], but they are still at an experimental stage and of limited use for navigation and guidance. Recently, mechatronics technology has been adapted to obstacle avoidance (guidance) devices. For example, Borenstein et al. developed the NavBelt – a belt-type wearable travel aid with an array of ultrasonic sensors – and GuideCane – an instrumented, wheeled device which is pushed in front of the user via an attached cane – so as to help the user avoid obstacles [4], [5]. Amemiya proposed a novel haptic direction indicator using asymmetric oscillations and evaluated the utility for the visually impaired in a simple maze surrounded by several partitions [6], [7]. Ando et al. have a haptic interface with an integrated circuit tag system for outdoor applications [8]. The UltraCane (SOUND foresight Ltd.), one of the few commercialized systems, can detect obstacles in front of and above the user by ultrasound sensors and alert over tactile vibrating buttons. The I-CANE (I-CANE foundation) indicates the navigation direction over a rotating sphere located below the thumb (Tactile Arrow). As these examples show, various travel aids using mechatronics technology have been proposed for the visually impaired. However, very few studies have investigated the effectiveness of multimodal feedback strategies for the navigation of visually impaired persons. For practical applications, it is necessary to investigate how such systems affect the human behavior.

This paper proposes a virtual environment to evaluate multimodal feedback strategies for augmented navigation of the visually impaired. We investigate the applicability of a commercial feedback device as a navigation and warning tool. For this, we generated random virtual environments consisting of virtual corridors, walls, and obstacles. We asked blindfolded test subjects to navigate in a free space, while a tracking system linked to the computer recorded the position within the virtual world. The feedback device operated as a guidance tool, giving audio and haptic feedback, as if the virtual obstacles were real (Fig. 1). Such a setup has several advantages:

- Reliability and repeatability: navigation and guidance tests can be performed and repeated in various environments under well-controlled and repeatable conditions.

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H. Masayuki, S. Shokur, and H. Bleuler are with the Robotic Systems Laboratory (LSRO), Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland. {masayuki.hara, solaiman.shokur, hannes.bleuler}@epfl.ch

A. Yamamoto and T. Higuchi are with the Advanced Mechatoronics Laboratory (AML), The University of Tokyo, 113-8654 Tokyo, Japan. {akio, higuchi}@aml.t.u-tokyo.ac.jp

R. Gassert is with Rehabilitation Engineering Laboratory, ETH Zurich, CH-8092 Zurich, Switzerland. gassertr@ethz.ch

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Fig. 2. Virtual augmented white cane with Wiimote and a cap with an active marker of accuTrack 500.

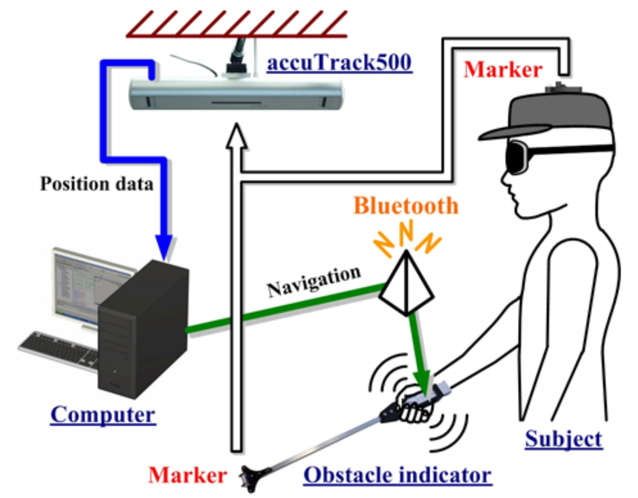
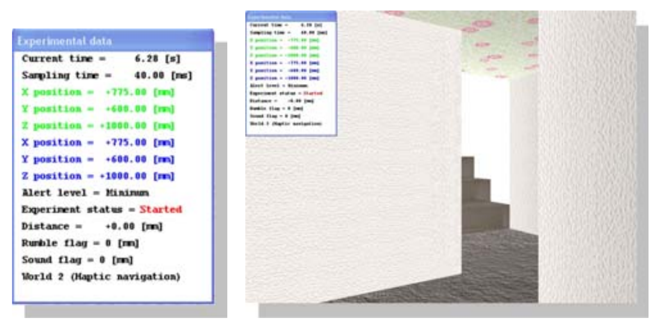


Fig. 3. Schematic diagram of experimental system.



(a) Status window (b) Virtual corridor

Fig. 4. A status window and a visualized virtual world. These information are shown only the experimenter not the subjects.

This could have numerous potential applications in evaluating devices, training, assessing progress, etc.

- Cost: various feedback strategies can be tested in unpredictable and fast changing environments without having to construct the physical environment
- Safety: accidents are prevented. The detection of a pit or obstacle can be trained without endangering the subject.

II. Experimental Setup

A. Hardware and Software

In this study, we selected the Wiimote (Nintendo, Kyoto, Japan) to provide audio and vibrotactile feedback to the user (Fig. 2). The Wiimote is a widely-used game controller with many integrated functions and can be easily obtained at low price. In our device, the Wiimote is attached to the end of an aluminum stick with 0.4 m length to present audio or haptic feedback to the user. The Wiimote holds a speaker and a button-type vibrator, and both the sound and rumble functions can be controlled via Bluetooth wireless communication. In addition, an active marker of a commercially available optical tracking system (accuTrack 500, atracsys, Renens, Switzerland) is attached to the other end of the aluminum stick allowing to calculate interaction with the virtual environment. Fig. 3 presents a schematic diagram of the experimental setup. The alerts with audio and haptic feedback, which are computed based on the tool position, are sent to the Wiimote via wireless communication. Another marker attached to a cap worn by the subject enables to observe and record the navigation behavior. The sampling rate of this system is set at 25 Hz to guarantee the wireless communication.

A GUI-enabled application is programmed based on the Wiiyourself!! library (http://wiiyourself.gl.tter.org/) in Visual C++ (Microsoft, Redmond, USA) in order to assist the experimenter in setting the experimental conditions. In this application, the experimenter can easily and quickly change the experimental conditions via dialog boxes. In addition, an OpenGL program visualizes the virtual environment from the subject's viewpoint as a 3D scene in a main window, and the experimental data such as experimental conditions and the position of subject are displayed in a small window, as shown in Fig. 4.

B. Optical Tracking System

Real time position tracking was performed with the accuTrack 500, which has 3 linear cameras and wireless active markers with 4 LED each, with a sampling rate of 4 kHz LED. The resulting tracking frequency for arm and subject position was thus 500 Hz.

We evaluated the tracking precision for sideways movements measured with the accuTrack 500 when an active marker was moved 20, 40, 60, 80, and 100 cm, while facing the sensor bar. Table I lists the travel distances averaged over 5 trials and their standard deviations.

It can be seen that the accuTrack 500 has both high temporal and spatial resolution, allowing precise collision detection within the virtual environment and real-time feedback to the subject. Further, the navigation strategy employed by the subject can be precisely recorded.

C. Wall Detection in Virtual Environment

1) Experimental Conditions: In this study, we simulated walking blindfolded from an entrance to the exit in a small room. To prevent the user from guessing the path, a virtual environment consisting of several corridors and walls was mapped onto a free space of 2.5×2.5 m^2. Fig. 5 shows the

TABLE I

CHARACTERIZATION OF SIDEWAY TRAVEL DISTANCE

		Sideways travel distance [cm]				
		20	40	60	80	100
accuTrack 500	AVG	19.9	40.1	60.1	79.9	100.0
	(SD)	(0.11)	(0.11)	(0.08)	(0.11)	(0.19)

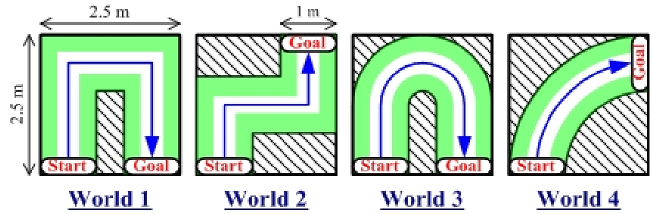


Fig. 5. Schematic of the virtual corridors that were simulated in the experiments.

4 virtual worlds that were simulated. Each world consists of a corridor of 1 m width created by virtual walls and is divided into three areas. The shaded area indicates a virtual wall, the green area is the area up to 0.25 m away from the virtual wall, and the white area indicates the "free" space. In our experiment, these three areas were defined as "Alert level 0" (white area), "Alert level 1" (green area), and "Alert level 2" (shaded area), respectively. They were employed to inform the subject about how far from the virtual walls they were located. In each level, different profiles of audio and haptic alerts were presented on the Wiimote, as shown in Fig. 6. These profiles were provided to the subjects in three different modalities – audio, haptic, and combined audio and haptic feedback. In the experiments, a 3130 Hz sound was used for the audio feedback [9], [10].

2) Experimental Procedure: Fig. 7 shows a picture of the experimental setup. In this experiment, six visually unimpaired subjects with no preliminary experience of navigating with a withe cane were asked to navigate through the virtual corridor with the help of audio and/or haptic feedback from the Wiimote. The virtual environment was not visible to the subjects; in addition the subjects were blindfolded so that they could not estimate the path from information in the real environment. Subjects first started with a training session in a virtual world consisting of a straight corridor to familiarize with the audio and haptic alerts. For the main experiment, subjects walked blindfolded through a randomly selected virtual world with a randomly selected feedback type. In total, 24 trials (4 worlds $\times$ 3 types of feedback $\times$ 2 trials) were conducted, and behavioral data (position of head and arm) were recorded. Subjects were given a break for more than 5 minutes after 12 trials. Further, we asked the subjects to answer to a simple questionnaire just after the experiment.

III. RESULTS

A. Applicability of the Virtual Environment

Fig. 8 shows a top view of the trajectories of a subject when walking blindfolded in "World 2". Figs. 8 (a) and (b) show the navigation path for an audio alert and haptic alert condition, respectively. It should be noted that the subject could pass the corridor from the entrance to the exit. Over all the trials, the subjects always reached the exit in the virtual environment. This fact implies that the audio and haptic alerts from the Wiimote can be useful for obstacle indication to blindfolded subjects, and also validates the use of a virtual environment to evaluate multimodal feedback strategies.

Alert level	Profile	Type	ON	OFF
0	OFF	No	—	∞
1	ON OFF ON OFF	Discrete	0.2 s	0.2 s
2	ON	Continuous	∞	—

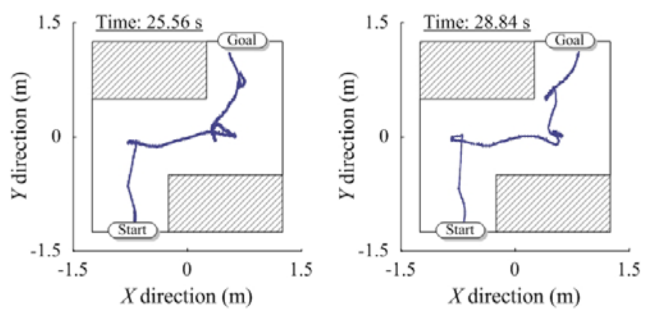
Fig. 6. Profiles of audio and haptic alerts in the three areas. In "Alert level 0," the indication by audio/haptic feedback is always off, whereas on/off is changed every 0.2 s in "Alert level 1". In "Alert level 2," the indication is always on.

Fig. 7. Experimental environment: 2.5×2.5 m free space.

No significant difference between the three types of feedback was found in terms of navigation accuracy or walking velocity. All three types seemed equally efficient in allowing the subject to through the virtual corridors without any collision. Subjects reported that they felt as if they were navigating in a dark room, and that they used the following strategy: move forward until they find a wall, then follow this wall until facing a new wall. The average walking speed in the simulated environment was found to be 0.7 km/h. Similarly we asked subjects to navigate in an unknown, dark (real) corridor and found a similar average speed of 0.85 km/h.

B. Subjective Evaluation

Subjects were asked to answer simple questions about their impressions for three types of feedback. We asked the subjects to rate the following questions on a score from 0 to



(a) Audio feedback (b) Haptic feedback

Fig. 8. Trajectories of a subject when guided by audio or haptic alerts in "World 2".

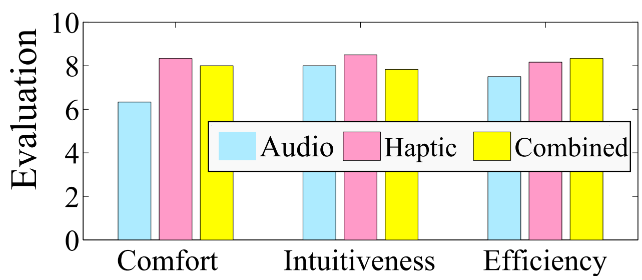


Fig. 9. Averaged subject evaluation for each feedback type in terme of comfort, intuitiveness and efficiency (min score 0, max score 10.

10:

1) How comfortable was each of the three types of feedback?
2) How well/easily could you distinguish each type of feedback?
3) How effective was each type of feedback to indicate the walls?

The average score for all types of feedback was high in terms of intuitiveness and efficiency ($> 8/10$). There was no significant difference between the three types of feedback. Subjects reported that determining the location of walls was straightforward. In terms of comfort the score for all three types of feedback was also high ($> 7.5/10$). However, subjects reported that audio only feedback was less comfortable than when combined with vibrotactile feedback. We expect that this effect will be even higher in a more realistic environment with ambient noise.

IV. Conclusions

In this study, a virtual environment consisting of walls and corridors was proposed as an experimental environment to evaluate multimodal feedback strategies for the navigation of visually impaired persons in a safe and well-controlled manner.

Blindfolded subjects carried a guidance and alert device consisting of a Wiimote and active optical marker, and were guided by audio and/or haptic feedback through a free space onto which virtual walls and obstacles were mapped. Subjects reported that navigation in the simulated environment was intuitive and comfortable. All subjects were able to successfully navigate through the unpredictable simulated environments without crossing the virtual walls.

The proposed experimental setup will be used to study the navigation strategies employed by visually impaired persons when navigating in unknown environments, and to evaluate the efficiency of multimodal feedback strategies for augmented navigation using novel instrumented navigation aids.

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