Mobility Support System for Elderly Blind People with a Smart Walker and a Tactile Map

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Abstract— **Elderly blind people with walking disabilities have difficulties in using common navigation aids like the white cane or a guide dog. Therefore, a smart walker was developed to provide walking assistance and transmit the surrounding information of the position of surrounding objects. The handicapped receive the information via haptic feedback to avoid collisions. Obstacles are detected by a laser range finder and information of the obstacle position is transmitted to the user via a group of vibration motors on a belt around the waist. A self-rotating map was involved to display the global setting and help preplanning the route. First experiments show that after a short training period user can safely avoid collisions with obstacles in a test course.**

Keywords— **Visually impaired, navigation aid, haptic feedback, collision avoidance, tactile maps.**

I. Introduction

Since the visually impaired have difficulties in acquiring spatial information, assistive devices are needed to support their independent travel. The mobility problem can be split into two parts: first, collision avoidance including obstacle detection and second, route finding.

White canes are the traditional and widely accepted assistive technology to avoid collisions. The cane is simple, cheap and easy to control but has a low sampling rate and a limited field of "view" due to its length. Besides, it is difficult to detect overhanging objects and to predict oncoming objects with the cane, which is necessary for walking safely [1].

Therefore, numerous electronic devices have been developed to assist the visually impaired people. Information is gathered, processed and outputted to the users in nonvisual form. After decades of study, researchers have built up kinds of different systems, but none of them have been widely accepted. For example, some aids use the auditory system for information transfer so that the primary senses of blind people for spatial orientation, collision detection and path finding, gets disturbed by these additional acoustic signals [2]. On the other hand, 81.7% of all 39 million blind people worldwide are older than 50 years [3]. As most of the people become visually impaired by old age, a high number of them additionally suffer from impaired mobility. But most aids are only designed to compensate the visual impairment and not as an aid against walking disabilities.

Considering the people with impaired mobility and sight, we present a walker as a new aid, which detects obstacles in the users' vicinity [4]. The information of the obstacle position is transmitted to the user via an array of vibration motors on a belt around the waist. The skin is the largest sense organ that contains the biological sensors of touch [5]. Moreover, the great majority of the receptors are not involved in daily tasks. Thus, it's ideal to use skin as information receptor in vision substitution systems, especially for the blind where the visual cortex requires less attention [6]. Research groups have investigated various methods to transfer environmental information to visually impaired people via vibrotactile stimulation [7-14]. Two types of wearable tactile aids, a waist belt and a back array, have been successfully applied in experimental trials for collision avoidance and navigation. Srikulwong and O'Neill compared both approaches and came to the result that, using a tactile belt the test subjects performed significantly faster and more accurately than using a tactile back array [15]. This confirms our intention to use a tactile belt.

Maps are widely used by non-blind people for their travel planning and navigation. Tactile maps are a group of devices showing graphic information using reliefs [16]. Placing a tactile map inside or outside an entrance assists the blind in understanding the layout and finding routes to some specific location. But it is nearly impossible to find the right site just by haptic memory, so handheld tactile maps have been developed. Using these tactile maps, the blind can obtain a general idea of his environment and preplan the routes.

With the advent of 3D printing technology, the speed of generating objects with multiple levels has been raised greatly. Additionally, they are easy to update or edit [17]. In practical applications of handheld tactile maps, the problem often occurs that users get lost after altering the walking direction. Therefore, we propose a static tactile map combined with a magnetic sensor and a step motor to make the map and pedestrians rotate simultaneously like vehicle navigation systems. In the presented paper, the main focus

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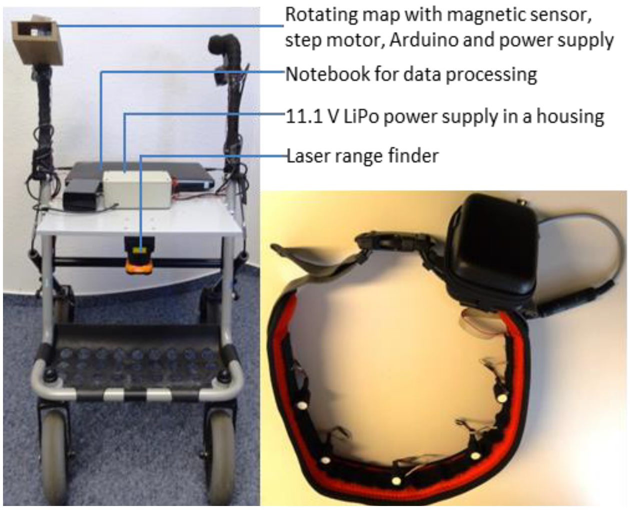

Fig. 1: Standard walker (left) equipped with a laser scanner and a notebook for environmental perception and data processing. A self-rotating tactile map is mounted on the right handle. The belt (right) contains five vibration motors and a Bluetooth receiver.

is directed to evaluate the effectiveness of the walker, tactile maps and a combination of the two in collision avoidance tasks.

II. Materials and Methods

A. System overview

Our system consists of a commercially available walker (Fig. 1) equipped with a planar laser range finder (Hokuyo UTM-30LX), a notebook for data processing capabilities, Arduino microcontrollers and a power supply. Furthermore the system includes a vibration belt with an array of five wirelessly controlled vibration motors, which enable a haptic feedback to the user. Small tubes were designed and created with a 3D printer to encapsulate the vibration motors to assure smooth revolutions.

The software has been developed under ROS [18], an open source robotics framework. The environmental information is transmitted to the user by vibration patterns created from the vibration motors on the belt around the waist. The scan field (-112.5° to 112.5°) used by the laser range finder is split into five equal zones of 45° and corresponding to that splitting, the vibration motors are allocated on the belt around the users' waist. If obstacles are detected within these zones, the system activates the corresponding vibrating motors attached to the belt.

The vibration signals are encoded with pulse-frequency modulation to transmit the distance between the laser range finder and obstacles. The shorter the distance to an object, the higher is the repetition rate of the vibrations. Once the distance is shorter than a predefined value, the corresponding motor vibrates continuously to warn the users about the danger of collisions. This is pretty similar to the signals of the parking aid system in cars.

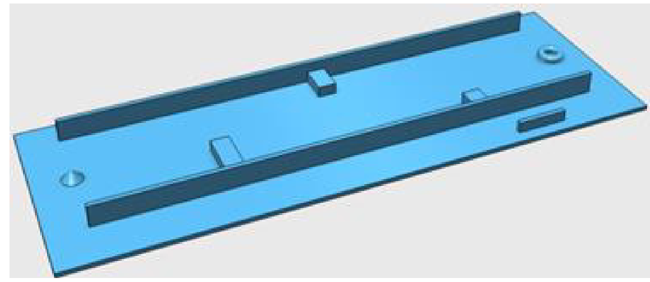

Fig. 2: 3D graphic of a tactile map for a test course.

For our experiments we designed five courses and created tactile maps of them to a scale of 1:100 with a 3D printer. A cone represents the starting point and an annulus represents the end point. Fig. 2 is an example of such a tactile map. To build a self-rotating system, an Arduino microcontroller acquires the orientation information from a magnetic sensor (Honeywell HMC5883L) and calculates the change in horizontal magnetic angle. The tactile map, which is driven by a step motor (Neuftech 28BYJ-48), rotates in the same angle as the change so that its orientation is always consistent with the real environment.

B. Experiments

A test course of 10 m length in a corridor with boxes as obstacles (Fig. 3) was set up for a first evaluation of the system. Twelve healthy-sighted subjects (6 female, age range: 14-30 and 6 male, age range: 22-46) were asked to traverse five different courses blindfolded with the walker and different assistive aids. After each run, the boxes were shifted to avoid the user to remember the position. By using the walker and moving boxes as obstacles, the subjects were very safe during the experiments, because just slight collisions between the walker and the boxes or walls occurred.

Different assistive aids were offered in each trial. In the first run, there was no additional assistance except the walker and subjects travelled through course 1 only according to their intuition. In the second trial, subjects could feel the route setting from a static tactile map. The vibration belt was involved to indicate obstacles' direction in course 3. In the fourth run, besides the vibration belt, a static tactile map of course 4 was offered. The difference between run 4 and run 5 was that the tactile map rotated simultaneously with the subjects. In the training procedure, subjects traversed course 5 for five times under the same setting as the fifth run. After that, course 5 had to be traversed again with the same assistive aids as during the training. For a better overview of the experimental setup, the test settings with the assistive methods during the individual cycles in the test courses are listed in Table 1.

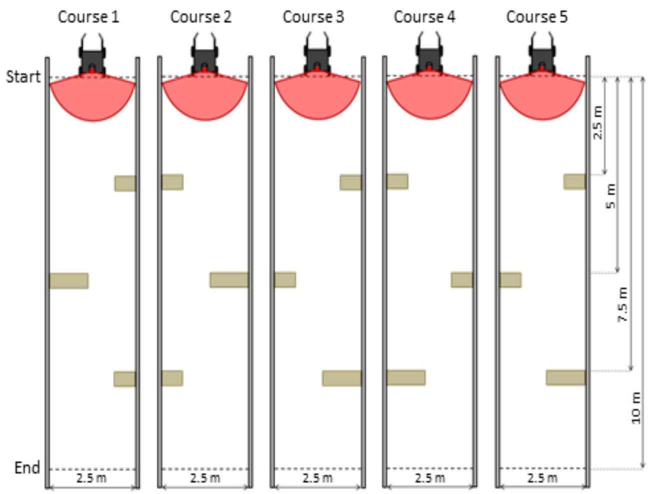

Fig. 3: Sketch of the test courses set up for the experiments. The courses had a total length of 10 m and 2.5 m width. The moving boxes used as obstacles had a size of (0.6 x 0.36 x 0.83) m and (1.1 x 0.36 x 0.83) m.

Table 1: Overview of the assistive methods in each trial.

Test	Course	Assistive method
1	1	No assistance
2	2	Tactile map of course 2
3	3	Vibrating belt
4	4	Tactile map of course 4 + vibrating belt
5	5	Self-rotating tactile map of course 5 + vibrating belt
Training	5	Self-rotating tactile map of course 5 + vibrating belt
6	5	Self-rotating tactile map of course 5 + vibrating belt

III. Results

To compare and evaluate the prototype and the different assistances, a test course as shown in Fig. 3 was set up. The blindfolded subjects were asked to traverse the five courses with the smart walker, different feedback modes and test settings as described in Section II *B*.

To measure the performance of the subjects, the system and the assistive methods, the time required to traverse the courses was measured and the number of collisions with obstacles counted. A collision was defined as a contact of the walker with an obstacle (box) or the walls of the corridor. An effect of training in the users' performance with the system was investigated by comparing the subjects' performance under the same settings before and after the training procedure (experiment settings are shown in Table 1).

After the experiments the subjects were interviewed about the system and the different assistive methods. The results from the questionnaire are demonstrated in Fig.4 and Fig. 6. An overview of the results, the average time for traversing the test courses and the average number of collisions with obstacles is illustrated in Fig. 5 for the individual test courses and settings.

We used a paired two-sided Wilcoxon signed rank test to check whether the differences are significant. Table 2 indicates the p-values. The test also showed a significant difference in the subjects' performance after the training cycles. P-value = 0.0044 for the comparison of the required time for traversing the test course before and after training and p-value = 0.0430 for the comparison of the number of collisions in both cycles.

Table 2: Comparison of different assistive methods on the basis of the time required for traversing the test courses and the number of collisions. Values marked in bold were significantly different ($p < 0.05$).

Test settings	P-value of time comparisons	P-value of collision comparisons
No assistance vs. tactile map	0.5332	0.8477
No assistance vs. vibrating belt	0.0811	**0.0098**
No assistance vs. vibrating belt + tactile map	0.4097	**0.0156**
No assistance vs. vibrating belt + rot. map	**0.0098**	**0.0391**
Tactile map vs. vibrating belt	**0.0459**	**0.0059**
Tactile map vs. vibrating belt + tactile map	0.6338	**0.0117**
Tactile map vs. vibrating belt + rot. map	**0.0356**	**0.0020**
Vibrating belt vs. vibrating belt + tactile map	0.1045	0.6172
Vibrating belt vs. vibrating belt + rot. map	0.2744	0.4629
Vibrating belt + tactile map vs. vibrating belt + rot. map	**0.0127**	1

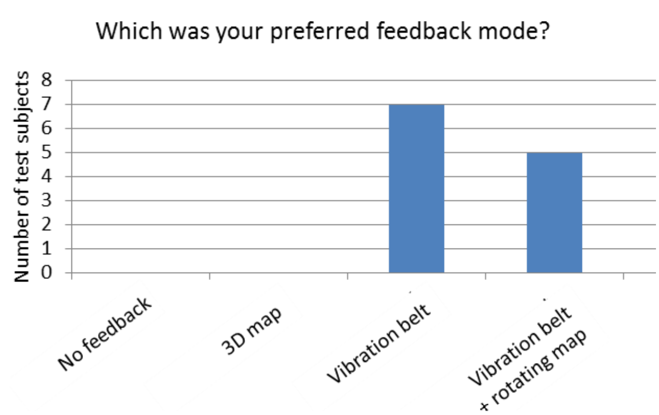

Fig. 4: Result of the questionnaire. The test subjects were asked which feedback of the system they preferred during the experiments.

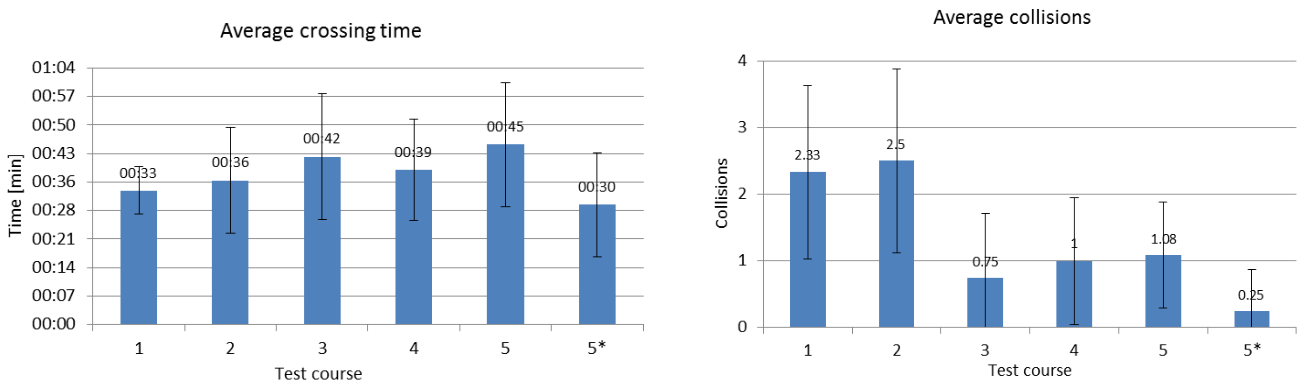

Fig. 5: Average time (left) required to traverse the courses and number of collisions (right) of the test subjects for the test courses. Course 1 was traversed without feedback, course 2 with a static map of course 2, course 3 with a vibrating belt, course 4 with a vibrating belt plus a static map, course 5 with the vibrating belt plus a rotating map and course 5* again with the vibrating belt plus the rotating map but after training.

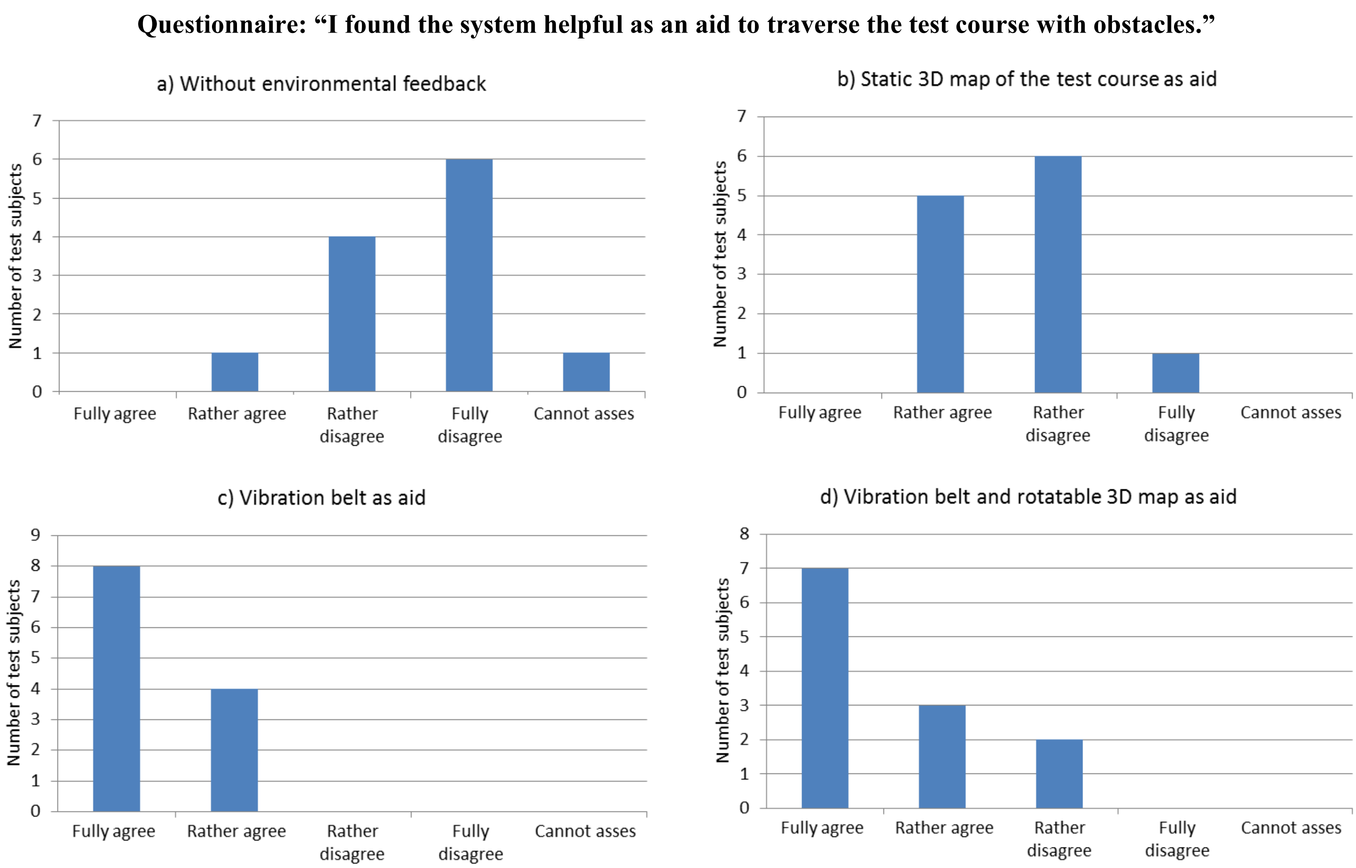

Fig. 6: Results of the questionnaire. The test subjects were asked after the experiments to rate if they found the individual feedback modes, a) no environmental feedback, b) static 3D map of the test course, c) vibration belt and d) vibration belt plus rotatable 3D map, helpful for traversing the test courses with obstacles.

IV. Discussion

In the presented work we evaluated the walker, tactile maps and a combination of the two in collision avoidance tasks of traversing 5 courses with movable boxes as obstacles (Fig. 3.).

Comparing the time required to traverse the courses with different assistive methods presented in Fig. 5, on the average, the subjects used less time to finish the task without aid than with other methods. The main reason is that the subjects had no environmental information which had to be processed and interpreted, what takes some time. The performance in collision avoidance without environmental information is of course worse compared to the other modes.

Table 2 demonstrates the comparison of the different assistive aids with the p-values of a paired two-sided Wilcoxon signed rank test. No significant difference could be revealed between no assistance and a tactile map of the test course as assistive method. The combination of the vibrating belt and a tactile map or a self-rotating tactile map of the courses exposed also no significant difference against the use of the vibrating belt as single assistive aid. In contrast to that, a significant difference between no assistance or a tactile map and a vibrating belt as aid or a combination of the vibrating belt and a static or self-rotating map could be found.

Before the first five experiments (see test 1-5 in Table 1), no training with the system and the assistive methods took place. To evaluate the effect of training, 5 cycles of test 5 in course 5 were executed and afterwards, in a last experiment, the time and the number of collisions measured again. The average time needed to traverse course 5 has been significantly reduced from 45 s to 30 s after training and also the average number of collisions has been significantly reduced from 1.08 to 0.25 (see Fig. 5). This shows that an introduction to the receiving signals of the system and a training program is indispensable to reach a good performance with the system.

The conducted interview after the experiments revealed that seven out of twelve subjects preferred the vibrating belt as assistive method and five preferred the combination self-rotating tactile map with the vibrating belt (see Fig. 4). The subjects which preferred the vibrating belt stated that the additional information via the self-rotating tactile map lead to confusion and in worst case to misinterpretation of signals due to the higher number of information which had to be understood and interpreted. To avoid misinterpretation and confusion by using both assistive aids at the same time, more training needs be executed by the users.

Fig. 6 provides an overview of the subjects rating of the assistive methods. All the users “fully agreed” (8 out of 12) or “rather agreed” (4 subjects) that they found the vibration belt helpful as an assisting aid to traverse the test course. Seven test persons also “fully agreed” that the combination of the vibrating belt with the self-rotating tactile map is a helpful aid and four subjects ”rather agreed” but one test person “rather disagreed”.

Generally we can state that some people don’t want too much information, because of the simpler and faster interpretation and other prefer having more information provided. Our system meets different needs of both kinds of people, persons who prefer less information just can avoid touching the tactile map and only rely to the receiving information from the vibrations of the belt.

V. Conclusion

We outlined an obstacle avoidance system for visually and mobility impaired people based on laser scanning technology, vibrating feedback via a waist belt and self-rotating tactile maps. After a short training period, most of the users could avoid collisions with obstacles in a test course. The vibrating belt as assistive aid seems to be sufficient for obstacle collision avoidance. Some users appreciated the combination of the assisting methods vibrating belt and self-rotating tactile maps, cause of the possibility of additional information about the surrounding. Besides collision avoidance, further studies will focus on how to accomplish route-finding tasks based on the existing system.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Statement of Informed Consent and Human Rights

Informed consent was obtained from all subjects prior to the study. The study was performed in compliance with the Helsinki Declaration.

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