Prototype Development of a Low-Cost Vibro-Tactile Navigation Aid for the Visually Impaired

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Abstract. Vibro-tactile support for navigation tasks is helpful, not only for visually impaired people. However many different prototypes exist which are not available for experimental usage or commercial ones are expensive. We developed a low-cost prototype of a wristlet and anklet that can easily be rebuild. We evaluated them in a two step procedure with 11 and 10 participants. Both prototypes are easy to use and comfortable to wear. However, the wristlet had a high error rate so that it was not used in the second test. Comparisons between the anklet and voice guidance during navigation in the second test showed the potential of vibration for navigation tasks, but implied a refinement of the design, which will be tested in further studies.

Keywords: Vibro-tactile wristlet/anklet · Blind · Visual impaired
User study · Prototype · Navigation

1 Introduction

Navigation generally involves providing directional and environmental information to people. This includes visual markers, which play a major role in orientation. People with visual impairment do not have these navigation options, so they need to help themselves with other means, e.g. a guide dog or the classic white cane. In recent years, electronic navigation aids have been increasingly developed to assist visually impaired people. While these were initially independent systems, today the development of new assistive technologies is often focused on extending or supplementing smartphones, as they are now widely used. These systems are often based on acoustic feedback, such as spoken language or sonification. However, the problem of these issues in noisy environments is obvious, which is why haptic systems are increasingly being researched.

We developed a low-cost prototype of a wristlet and anklet to help visual impaired people during navigation tasks in their daily living. We opted for a wristlet because previous studies have shown that perception on the arm is simple and intuitive [1–3]. With directional instructions, however, there is always the

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problem of the arm position, so that right/left instructions can be misinterpreted depending on the position of the arm, e g. when carrying a handbag or the relaxed arm. For this reason, we have developed an additional ankle strap that can be worn around the ankle under the trousers. Both prototypes have been tested in a proof-of-concept study with visually impaired and sighted people for their perception of vibrations.

2 Related Work

In recent years, much research and development has been done in the area of vibro-tactile navigation support. Although many of these developments have taken place in the field of assistive technologies, the benefits of support for almost all people cannot be denied.

A wristlet called GentleGuide [1] was developed at the Dutch University of Technology. It was not only designed to navigate visually impaired people, but to navigate in unknown buildings such as a room in a hospital. The prototype is worn on both the left and right wrist and has one vibration motor per device. The detection of a certain direction therefore only depends which of the two devices vibrates. This easy recognition of the direction offers great advantages in navigation, which could be demonstrated in a practical test by the authors.

VibroTac [3] is another wristlet developed with a focus on ergonomics. It can be flexibly adapted to different arm sizes and consists of six motors, which are mounted in a plastic housing. Although the device can be attached flexibly, a problem arises with thin arm circumference, because the motors are very close to each other and the vibrations cannot be clearly distinguished. This could lead to incorrect behavior during applications. A further disadvantage is the operation via a computer, which leads to problems with a navigation application in particular, if an alternative route has to be calculated due to construction sites or non-passable roads.

With the proliferation of smartphones, some research has also been done to use built-in features, such as vibration, of the devices [4–7]. In the approach of Azenkot et al. either the navigation direction is displayed by actively moving the smartphone or the corner points indicate the direction. Peng et al. use vibration to detect obstacles. If there is an obstacle on the way, the phone vibrates. If you swing the device to the right or left, the vibration stops if the path is clear. In comparison the Cricket system from Spiers and Dollar is an external cubic device that, like the smartphone apps, uses vibrations to indicate direction. The disadvantage of most approaches is the use of the device in the hand, so that the smartphone/system has to be used actively in addition to a white cane or guide dog, which makes it difficult to handle in a real scenario. Especially in bad weather conditions such as rain or extreme cold in winter the permanent holding of a device in the hand makes it uncomfortable to use und therefore not suitable for our use cases.

In addition, there are several studies on vibration belts [8–10] or different haptic devices in combination with additional output variations or camera systems to avoid obstacles [11–13], which shows that the use of vibro-tactile feedback has potential in many areas. However, although many prototypes and studies were carried out on vibration bands, most of them did not lead to a commercially available product or the product is very expensive, so we could not use it in our studies.

3 Vibro-Tactile Wristlet and Anklet

The wireless design of both prototypes is based on a microcontroller with a Bluetooth Low Energy module (BLE) and battery. The main part consists of an Adafruit Feather, which has an integrated Bluetooth and charger module and thus bundles all components in a compact package, resulting in a design that is currently smaller than putting all components together individually. We used three Pololu shaftless vibration motors in each prototype, but integrated ones with more mass for the anklet, which results in a slightly greater vibrational force [14]. The decision to choose two different motors was made deliberately because the threshold of the two-point discrimination at the foot is greater and thus impulses are better recognized by a greater vibration force [15]. In addition, it is known that the perception at the foot decreases due to movement, which is why the higher vibration force is also advantageous here [2].

Fig. 1. Final version of both prototypes

In order to protect the components from external influences and to avoid contact with the user's skin, a 3D printer was used to develop a case that firmly encloses the electronics. The electronics were then attached to a tape, which was also produced by 3D printing. The strap is made of an elastic synthetic material and can be individually adjusted to fit different arm (14–20 cm) and leg (19–30 cm) sizes. In order to ensure an even distribution of the three vibration motors, two pockets have been installed on the sides, in which the motors can be reinserted. This ensures that the vibrations are always perceived on the right and left side, the middle one serves as a calibration point. The final design of the prototypes can be seen in Fig. 1.

Table 1. Correct assignments of vibration motors for wristlet and anklet

Prototype	Correct assignments				∅
	100%	86.67%	80%	66.67%	
Wristlet	5	3	2	1	88.67%
Anklet	11	0	0	0	100%

4 Evaluation of Vibro-Tactile Recognition and Patterns for Navigation

Several studies were conducted to evaluate the usability and usefulness of our prototypes. The focus of the first user study was a proof-of-concept test to ensure that the chosen components work together and that the vibration motors are recognized and can be distinguished. Thus, the perception, pleasing strength and duration of different vibration motors for both prototypes were evaluated. The study was taken by 11 volunteers aged 20 to 65 (7 male, 4 female), two of whom were visually impaired (age 23 and 48, both male). The entire test took an average of 30 min to complete.

The tests for wristlet and anklet were similarly structured. Initially, the participants could get used to the prototypes and adjust the intensity and duration individually for each of the three vibration motors. Comparing the intensity and duration of both prototypes it was found that intensity of the middle motor was always higher than the left and right one, which were equal in both cases. The middle duration of all motors was 0.76 s for the wristlet and 0.96 s for the anklet. The value of the anklet is due to the reduction of the duration of one participant to 0.7 s whereas all other participants chose 1 s as the optimal duration. After the adjustments, the participants had to run a straight track during which they received 15 different vibration signals one after the other. All participants walked independently, e.g. in the case of the visually impaired participants, only the white cane was used as an aid. Only one motor was switched on at once and the participants were asked to tell which motor had vibrated. These statements were later compared with the actual motors being controlled. The summary of the correct assignments of all participants for both prototypes is given in Table 1. A more detailed analysis shows that the major problem with the wristlet was the confusion of either the left or the right motor with the middle one. If the wristlet was worn on the right arm, the participants confused the left and the middle motor, while participants wearing it on the left arm confused the right and middle motor. Such problems could not be found with the anklet. For all tasks and adjustments, no differences between visually impaired and sighted persons could be detected [16]. A second study investigated the use of the anklet during navigation and object detection. The wristlet was not used for the test because of the bad recognizability and confusion of the motors. For the navigation task, 10 participants were asked to run a route of about 300 m with junctions and natural occurring objects like bicycle. During the route, there were two types of signals: Prewarnings that an instruction or object was coming and the concrete instruction at the turn-off point. The prewarning consisted of two short impulses (each 1 s with 0.5 s distance) on the side to which the bend should be made, e.g. if the next instruction was "turn left", the signal was sent to the left vibration motor. For the prewarning of an object, all three motors were activated with the before mentioned pattern. The concrete turning instruction consisted of a long signal of two seconds on the side of the instruction, in the above example on the left. The same signal was used to indicate the location of an object.

This study was carried out in the context of the TERRAIN project[1]. The aim of Terrain is to develop a portable assistance system to support the mobility of blind and visually impaired people in the inner city environment. The system combines navigation based on digital map data with camera-based image processing for object detection like obstacles, traffic lights, road crossings as well as interesting landmarks, buildings. For this purpose, a barrier-free, acoustic and haptic user interface is being developed, which can be adapted to the needs and preferences of the users. At the time of the study, navigation instructions were integrated into the self-developed app using natural language and vibration patterns. However, in order to send the signals to each user at the same time, a wizard-of-oz experiment was carried out, so that the user did not have to operate the app himself, but could concentrate entirely on the recognition of instructions. The leader of the experiment used markings on the ground (chalk marks) to trigger the prewarnings or turn directions manually using the app. As the camera-based image processing for object detection is not yet integrated, the obstacles were also triggered by the instructor.

We measured the time needed to complete the navigation task and how often participants missed a signal, did a false turn or had a collision with an obstacle, see Table 2. Comparing the results to a speech navigation on four different routes it can be seen, that there was no significant difference for the time needed. For two routes, the speech was faster, for one the anklet and for the fourth the mean time was equal for all participants. Analysing the misinterpretation, collisions or hesitations, the anklet had worse results compared to speech output. Post-experiment questions indicate, that the participants find it hard to distinguish between the prewarning of a routing instruction and obstacle warning. On the other hand, they liked the intuitive navigation instructions, since they exactly felt in which direction they need to turn, in comparison to the speech approach which troubled three participants, because two have hearing aids and one a right-left weakness. These findings can also be seen in a NASA-TLX rating for both modi which was performed afterwards. For the anklet, the values for *Mental Demand, Performance and Effort* were higher, but not significantly higher, whereas the other three were very similar.

[1] https://www.terrain-projekt.de/.

Table 2. Comparing performance of speech and anklet during navigation and obstacle avoidance

Parameters/modus	Speech	Anklet
Mean time [min]	04:14	04:36
Missing prewarning	1	0
Missinterpr. routing	0	5
Collision obstacle	2	4
Hesitation on signal	0	4

5 Conclusion and Future Work

The design and development of both prototypes is based on ergonomic parameters and is easy to rebuild with low-cost materials. Due to the wireless and minimalist design, both devices can be worn underneath the garment without any problems, which prevents stigmatisation on the one hand and on the other hand allows comfortable wearing. The prototypes were tested with regard to software functionality, usability and accessibility of the app and detection rate of the vibration motors. The app and prototypes were easy to use and operable by visual impaired persons. The user study of the detection rate of vibration motors showed that three motors are not suitable for the wristlet, since the middle one was often confused with either the right or left motor, depending on which arm it was worn. We consider a redesign of the wristlet with either only two motors or only one single motor, but with two wristlet for both arms. The vibrations on the anklet on the other hand were easier and no participant confused any of the motors. Nevertheless, the main problem was the difference between the prewarnings for routing instructions and object detection, so a clearer classification could lead to better performance.

In the future, we assume that user will not use the same mode for routing instructions and object detection, so that the distinction between them will no longer cause confusion. For example, it is more likely that natural language will be used for routing instructions and object recognition is indicated by vibration or vice versa. Nevertheless, it will still be possible for the user to use the same mode for both instructions in the final version of the app, if desired. Further studies, carried out this year, will still address this problem, so we expect better results for the anklet, if it is only used for one instruction mode. In addition, we will compare sonification and vibration on the abdomen with the current modes.

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