THE WALKING STRAIGHT MOBILE APPLICATION: HELPING THE VISUALLY IMPAIRED AVOID VEERING

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ABSTRACT

The visually impaired community still faces many challenges with safely navigating their environment. They rely heavily on speech-based GPS in addition to their usual guiding help. However, GPS-based systems do not help with veering issues, which affect the ability of the visually impaired to maintain a straight path. Some research systems provide feedback intended to correct veering, but these tend to employ bulky, custom hardware. In response, we implemented our "Walking Straight" application on an existing consumer device, taking advantage of the built-in sensors on smartphones. First, we investigated whether a continuous or discrete form of non-speech audio feedback was more effective in keeping participants on a straight path. The most effective form was then tested with nine blind participants. The promising results demonstrate that Walking Straight significantly reduced the participants' deviation from a straight path as compared to their usual behaviour, e.g., with a guide dog or cane, without affecting their pace.

1. INTRODUCTION

Walking straight when deprived of vision is a known problem [1, 2], hypothesized to be caused by motor error in stepping movement [3, 2]. Without reference to environmental cues such as the sun, humans have a tendency to walk in circles [2]. Blind people have the same problem, so are trained from an early stage to walk straight and, in particular, to cross streets while staying away from cars without exiting the pedestrian markings. The training consists of listening to the environment, especially traffic noise, as well as feeling the borders of pavement and sidewalk. In a related research project, some blind participants complained that despite their training, they still had difficulties walking straight. According to mobility specialists at the Institut Nazareth et Louis Braille (INLB, `http://www.inlb.qc.ca/`), this is a common problem, exacerbated by the rising number of modern open spaces with little or no distinction between the pavement and the road.

For daily navigation, blind people use specific devices, such as the Trekker (HumanWare Trekker Breeze, `http://www.humanware.com`), which plan a route to the selected destination and speak directions in a similar fashion to traditional GPS systems for cars. However, these systems do not offer any assistance to users in maintaining their heading over a distance. For example, at intersections, a traditional GPS would simply state, "go straight" without further details. For safety reasons, however, it is important for the user to stay within the confines of the pedestrian crossing. It is also particularly challenging in open spaces, where one can easily veer off and lose orientation and the lack of any curb or other physical distinction between the road and the sidewalk can be very dangerous.

We envision a system that would ideally initialize automatically upon detection of a sidewalk, and automatically recalibrate itself when the path direction changes. Similarly, the system should be able to detect street crossings, in particular in open spaces, offering feedback to help a blind user safely cross. Although such a system does not currently exist, the necessary technology is already available, often embedded in consumer smartphones, which offers several benefits of widespread availability, a lightweight, small form factor device, and an avoidance of aesthetic concerns [4]. The remaining challenge is to integrate the various software components to take full advantage of the underlying hardware and develop an appropriate user interface that makes the resulting system one that can be used without inordinate effort.

Our initial efforts in this direction resulted in the development and evaluation of a smartphone-based "Walking Straight" application, which aims to help blind people reduce their veering and thus maintain a straight path. The contributions of our work toward this objective include the design of appropriate auditory feedback based on typical mobility training for the blind, and empirical testing on commodity smartphone hardware with blind participants. Before exploring details of our system development, we first review relevant literature in the following section.

2. RELATED WORK

Even though few systems are commercially available, extensive academic research has been conducted to facilitate the mobility of the visually impaired, resulting in the development of navigation and orientation aids relying on GPS, infrared, or Radio Frequency IDentification (RFID) technology. Some of these systems address veering problems as part of their navigation and wayfinding capabilities. However, these require custom hardware and their testing of veering correction has been fairly limited.

2.1. Haptic Feedback Navigation Systems

TouchGraphics Inc. developed the WiiCane (`http://www.touchgraphics.com/research/wiicane.htm`) a haptic cane that helps train blind people to walk straight using an overhead IR lighting track and the Wii hardware to track the user's position and the orientation of the cane. Information about veer-

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ing is provided through speech and non-speech audio cues while vibrations of the Wii remote indicate corrections of the grip to ensure the wrist stays straight. This is the only system that specifically tackles the veering issue, though is limited to indoor training. Other systems have focused on providing general navigation assistance by coupling haptic feedback with directional and GPS sensors. These include for example tactile belts [5, 6],[1] haptic shoes (see "Le Chal" [7]) and a hand-held indicator that can generate a haptic force sensation in at least eight cardinal directions [8]. None of these systems currently provide feedback for maintaining a straight path but rather, only provide turn-by-turn instructions.

Despite the appeal of providing such feedback haptically, thereby leaving the user's audio channel free to attend to critical environmental information, previous studies with blind participants suggest that localized vibratory cues are the least preferred form of feedback [4], whereas speech or tonal sound output was the most acceptable. Moreover, a majority of participants agreed that even if a given navigation assistance device worked well, they would be concerned about its appearance if worn in public.

2.2. Audio feedback Interfaces

2.2.1. *General wayfinding systems*

Golledge et al. [9] introduced the wearable Personal Guidance System (PGS) to help blind people navigate. The PGS uses a differential GPS receiver, a notebook computer in a backpack or shoulder bag, and a fluxgate compass. The system offers waypoint-to-waypoint navigation as well as an audible warning cue, originating from the nearest point on the original path, to prevent the user from veering outside the boundaries of a defined corridor. In later versions [10], the user was notified when the relative bearing to the next waypoint exceeded a threshold of 10 degrees. The initial system [9] was mostly speech-based but later work [10] tested alternative audio output methods, in particular spatialized and non-spatialized speech and tones, plus different compass locations on the user's body. Their evaluation results indicate that spatialized speech or non-speech cues may be the best performing approach to waypoint finding, and the system should not require the user to hold anything in a hand.

Ross and Blasch [11] developed and evaluated three wearable orientation and wayfinding interfaces using a computer in a backpack with three speakers, a digital compass and a cap with ear buds. These interfaces indicated the heading to follow, using a sonic guide with a spatialized bell-like tone, spoken angular directions, and a "shoulder-tapping" interface that used one or a combination of the speakers, whose outputs result in perceived vibration, to give directional cues, with the location of the "tap" corresponding to the amount of deviation from the correct direction with thresholds of 7.5 and 15 degrees. Evaluation with 15 visually impaired participants resulted in an average reduction of veer to 31% of baseline veer, with performance and preferences being highest for the tapping interface with the sonic guide a close second.

These wearable systems described above are similar in terms of auditory cueing to the Walking Straight application described in this paper. However they require many components to be worn, including a portable computer, an audio processor, audio presentation hardware, tactile input devices, and position and orientation tracking technologies, raising the important issues of price and aesthetic. By utilizing equivalent technology already integrated in a consumer mobile phone, Walking Straight aims to provide a more compact and cost-effective solution. The integration of the necessary components into a single, everyday consumer device is an important contribution. Doing so overcomes otherwise significant barriers to wide-scale deployment, not only by reducing the amount of equipment that must be carried, but perhaps more importantly, by increasing accessibility of the technology to the wider community, in particular to the many potential users who already own smartphones.

2.2.2. *Anti-veering systems*

In their survey of systems designed for obstacle avoidance, Dakopoulous and Barboukis [12] mention the "Mini-Radar",[2] which includes a "directional stability" function that employs verbal messages related to deviation from magnetic North to help blind users maintain a direction. However, interpreting deviation from the spoken messages requires some cognitive effort, which may be a dangerous distraction in contexts such as crossing the street. An entirely different approach was taken by the European Sesamonet project [13], which uses an RFID cane reader to sense tags embedded in the ground to guide blind people along a safe path. Such a solution solves the accuracy issues of current GPS-based systems, but would require a large-scale deployment, ongoing maintenance of the embedded tags, and would constrain the visually impaired to specific paths. The closest work to the system described in this paper is the gyroscope-based *Anti-Veering Training Device (AVTD)* [3], which corrects veering via speech cues and also provides the user with feedback about performance. However, it appears that these systems have not been evaluated.

2.2.3. *Applications for pedestrian crossings*

Shen et al. [14] explored computer vision algorithms on cellphone images to detect the crosswalk and its alignment. Ivanchenko et al. [15] developed a more complete solution using the camera and audio output of a Nokia N95 phone to tackle all the challenges a blind user must overcome in order to cross the street safely. These include the detection of a crosswalk, correct alignment to it, and knowing when to cross. The user simply needs to pan the camera from left to right until audio tones are emitted to indicate the detection of a crosswalk. Once this is found, speech prompts provide feedback for alignment, allowing for accurate orientation of the user relative to the corridor. Evaluations with a few blind participants demonstrated their ability to use the system to detect crosswalks and align themselves properly [15]. In order to guide the user towards the crosswalk, Ahmetovic et al. [16] developed the *ZebraRecognizer*, a library to identify zebra crossings and compute the user relative position to the crossing. Building on its output, they further developed the *ZebraLocalizer*, an iPhone application that also uses accelerometers to enable blind users to identify a crosswalk, align to the middle of it and safely cross. For detection, alignment and guidance, short speech messages are emitted. However, it is unclear whether any guidance is provided to the users to prevent veering while crossing. Combining the zebra-crossing-detection capability of this work with our Walking Straight application would be an obvious next step for either project.

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[1] Also see the Tactile Belt™ (`http://www.tactilesight.com/products`).

[2] `http://bestpluton.free.fr/EnglishMiniRadar.htm`

3. THE WALKING STRAIGHT APPLICATION

The literature surveyed above indicates the potential for various forms of feedback to assist a blind user in maintaining a relatively straight path. However, most of these solutions are either very expensive or remain confined to research systems, and are thus not widely available to the community, in particular given their dependency on custom hardware. Finally, the focus of many such systems is generally on navigation assistance, with veering prevention included as a secondary feature. This risks their being perceived simply as a competing design against existing navigation technologies for the blind community, rather than as a useful tool in their own right.

The “Walking Straight” application was developed on a smartphone, the iPhone 4, justified in part by the reasons described above. However, this was equally motivated by our initial choice of the iPhone platform for development of our In-Situ Audio Services (ISAS) software architecture, which provides the blind and visually impaired community with a greater awareness of their environment through spatialized audio rendering [17]. Moreover, the iPhone integrates already accepted accessibility features (VoiceOver) for the blind community, making this a natural choice for the intended user group. Although we are working toward realization of automatic initialization capabilities, the system, in its current implementation, requires the user to specify the desired heading by a simple manual gesture, i.e., tapping the screen with two fingers when it is pointed in the desired direction. The guidance system then begins providing feedback to keep the users aware of their deviation from that direction until a new desired heading is specified.

With regard to the choice of feedback modality for continuous assistance in a walking straight task, Marston et al. [18] found that auditory and tactile (vibration) signals were equally useful, and in terms of the former, that a simple binary signal, indicating on- or off-course, was adequate to support accurate route following. We therefore adopted this approach for our implementation, focusing our efforts on a systematic evaluation of two simple audio feedback strategies. This enabled us to perform a preliminary investigation of the feasibility of using the smartphone sensors for orientation sensing in a manner that would support the application as described here. We provide a summary of the initial results of this investigation in Section 5.

3.1. Sensors

Originally, the application used both the compass and the gyroscope to determine the chosen direction and any deviations from it, using a sensor fusion algorithm to calibrate the gyroscope to north depending on the validity of the compass values. However, initial testing demonstrated that the compass is easily influenced by magnetic interference from the environment, e.g., cars, in particular larger vehicles, which can cause an offset of over 30 degrees. The gyroscope is less jittery in the presence of magnetic interference, although, it suffers from accumulation of error due to drift. Fortunately, such drift tends to be sufficiently small over short periods of usage of a few minutes, so we are able to rely on it exclusively for our needs. Nonetheless, we attempted to measure the gyro drift after each trial in order to determine if it was a significant factor in the system’s overall accuracy. Our first implementation of reading the iPhone sensors worked best with the device held flat, so this orientation was adopted for our experiment.

3.2. Auditory Feedback

Two types of auditory feedback have been developed using the Pure Data library: a continuous tone and an intermittent beeping. Their modes of operation are the same: when the user deviates in either direction from the desired heading, feedback is produced in the opposite ear, indicating the necessary correction, e.g., feedback in the right ear indicates that the user has veered to the left.

In the literature, deviation thresholds of 7.5 all the way to 15 degrees have been considered as “straight” [11, 18]. For our system, we chose a lower threshold of three degrees, so as to maintain the user on the sidewalk, if starting from the middle of the sidewalk, and walking for a stretch of 15 m. Indeed, National guidelines in various countries recommend that crosswalks and sidewalks have a minimum width of between 1.5 m (Canadian recommendation) and 2.4 m (UK recommendation), which should be increased in urban and crowded areas [19, 20, 21]. For a 15 m crossing distance, these widths correspond respectively to maximum angular deviations of 2.87 and 4.59 degrees before a pedestrian might venture beyond the crosswalk boundary. Below the three degrees threshold of deviation, no feedback is provided to the user. This design is supported by findings from Marston et al. [18], indicating that the absence of feedback when walking straight was considered more natural and preferred by blind participants. As deviation increases, the continuous-tone feedback becomes louder whereas the intermittent beeping feedback speeds up. The effectiveness of these two options was compared in a pilot study, described in Section 4.2.

3.3. Filtering Body Sway

During initial tests, users noticed that the feedback kept alternating between left and right. This was due to the natural side-to-side sway of the body during walking, as seen in the blue curve of Figure 1. This caused annoyance and confusion as the users attempted continuously to correct their deviation. Simply increasing the deviation threshold before any feedback is provided would potentially allow enough veering without any corresponding feedback that a user might exit the safe boundaries of a pedestrian walkway. Thus, we developed an algorithm to filter out the effects of swaying while maintaining reliable feedback by adapting dynamically to the walking period of each user. The algorithm detects the walking period by observing changes in peak amplitudes exceeding one degree and calculates the average heading in each period from the appropriate set of values, sampled at 10 Hz (see the green line in Figure 1). This results in a slight delay in feedback since the computation of average heading can only be performed at the end of each period, but this is relatively inconsequential compared to the benefits of eliminating the spurious alternating feedback associated with sway.

As reported in the initial work of Guth [3], we assume that rotation is a dominant factor in veering behaviour and consequently, we do not attempt to detect or compensate for more complex motion patterns such as sidestepping (i.e. a parallel step on the side). However, since we observed sidestepping in reaction to the audio feedback during pilot testing, we asked each participant to avoid this behaviour and to walk normally during the formal experiment.

3.4. Implementation

The application consists of components for user input, e.g., for choosing a desired heading, collection of sensor data, measure-

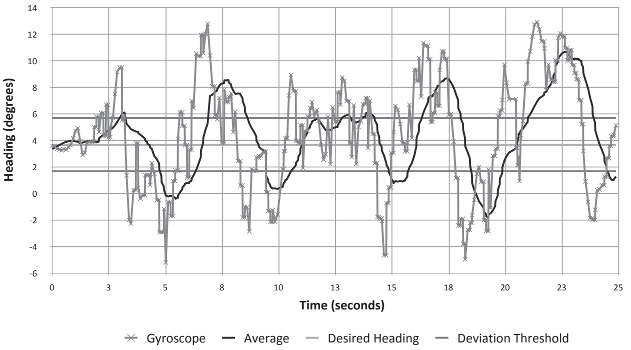

Figure 1: Gyrosope values over time, showing the periodic natural body sway during walking (blue crosses) and the results of the averaging algorithm (dark red). These plots can be seen as different interpretations of the user's trajectory over time.

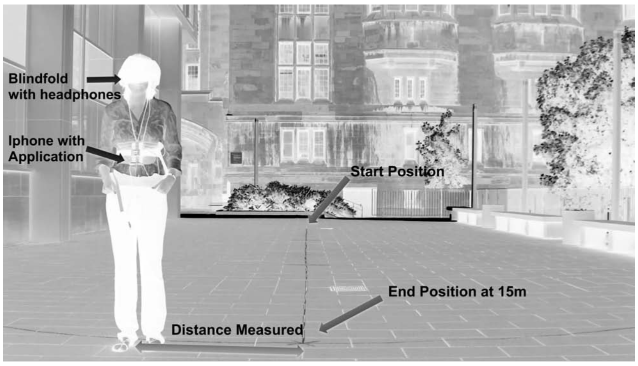

Figure 2: Setup used for evaluation: participants walk until they reach a semicircle drawn 15 meters from their starting position, at which point, they are stopped by the experimenter. The deviation is then measured in a straight line between the ideal target and the participants' actual final position.

ment of deviation, and finally, production of the corresponding audio feedback, as appropriate. The application receives updated gyroscope values every 100 ms. These values are filtered to remove the effects of body sway, as described in Section 3.3, and used to compute an average heading for each walking period, which is then compared to the desired heading. Any deviation is communicated to the component responsible for audio production, based on a sound rendering class that uses functions from the Pure Data (Pd) library. Rendering parameters, such as volume (continuous mode) or frequency (beeping mode), are computed according to the amount of deviation. The output is rendered to the user's left or right side, as appropriate, and played until the deviation is corrected. The output volume is capped to avoid harming the user's hearing.

4. EVALUATION

The evaluation proceeded in three steps. First, a pilot was run with blindfolded sighted participants in order to compare two auditory feedback designs and select the most appropriate option for the following study. Second, these results were confirmed with two pilot blind participants. Third, after modifying the application based on these results, a full experiment was run with exclusively blind participants in order to evaluate the system's performance in helping the visually impaired to walk straight.

4.1. Methodology

The main task was consistent throughout all of the experiments. This consisted of a series of trials under two conditions in which participants were asked to walk straight. Each condition was tested in blocks, presented in ABBA counterbalanced order, in which each block, A or B, consisted of 5 trials, for 20 trials in total per participant. To accustomize participants to the audio feedback and reduce the impact of learning effects, prior to each set of trials, participants were presented with the audio feedback (either beeping or continuous tone) that they would be hearing.

The experiment was carried out as follows: participants were placed at the start position, pointed towards a target at a fixed distance of 15 meters, and asked to walk straight in that direction until they were told to stop (see Figure 2). A straight line was drawn on the ground between the two endpoints for the benefit of the experimenters. This line was used to align the participants and the device at the start of each trial. For safety, one of the experimenters was by the participant's side at all times.

For idealized testing conditions noise-cancelling over-the-ear closed headphones were used. In real-life situations, "open ear" headphones that do not prevent users from hearing the sounds of traffic, people around them, or other important environmental cues would be used for safety reasons. Examples of such headphones include AirDrives,[3] whose speakers are placed in front of the ears rather than over them, or Audio Bone headphones,[4] which rest on the bone in front of the ear.

For each trial, the output of the device sensors was recorded into a log file for later analysis and the participant's behaviour was recorded with a video camera. The deviation from a straight path was calculated as the linear distance between the desired position and the position reached (see Figure 2) and then converting this measure to an error angle. The experimenters also noted relevant participant behaviour, comments and any external factors that might affect the results, such as weather or ambient sounds.

At the end of the experiment, participants were asked to complete a Likert-scale questionnaire evaluating their comfort with the auditory feedback, annoyance, ease of use, confidence and fatigue.

4.2. Pilot: Choosing Between Two Auditory Feedbacks

Two different forms of auditory feedback were tested as described in Section 3: a continuous audio tone and an intermittent beeping. The pilot study aimed to determine which of these forms of feedback was preferred and which provided the lower deviation from the straight-line path. For this pilot experiment, six sighted volunteers were recruited from our research laboratory at McGill University and blindfolded with a black cloth. All volunteers were male, ranging in age from 20 to 33 years. The pilot took place on our campus in a flat, safe area with no obstacles apart from two benches off to the side (see Figure 2). To validate the results of the pilot for its intended user population, the study was also conducted

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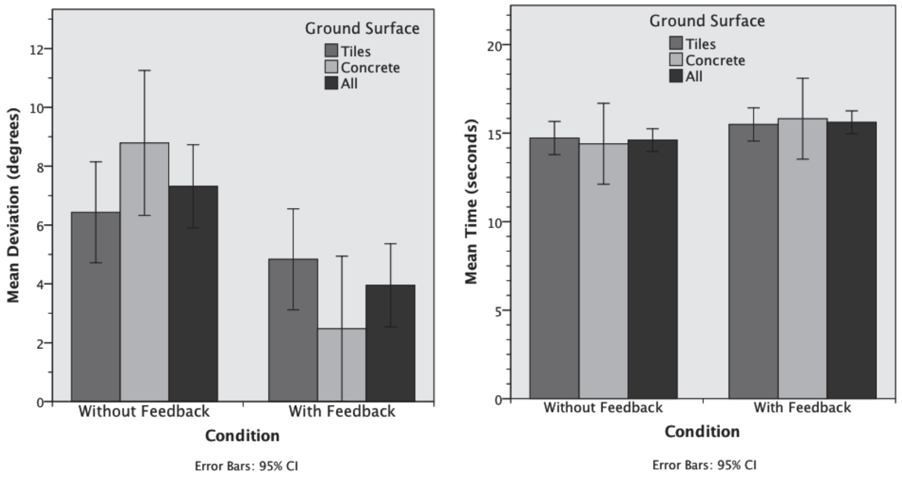
[3] `http://www.airdrives.com`

[4] `http://www.audioboneheadphones.com`



(a) Comparison of mean deviations

(b) Comparison of walking time to travel 15 m

Figure 3: Results of the quantitative analysis, comparing deviations (in degrees) and walking time (in seconds) on tiled and concrete ground surfaces, based on feedback condition (without and with feedback)

with two blind participants. One of them completed the whole pilot experiment while the other one did only half of the trials. They were not blindfolded and they used their canes.

The results from the pilot study demonstrated that the continuous feedback was the most appropriate both quantitatively and qualitatively. Quantitatively, analysis with an outlier removed yielded smaller deviation with the continuous feedback (*M* = 2.85, *SE* = 0.17) compared to the beeping feedback (*M* = 3.05, *SE* = 0.27), but this was not significant ($t(4) = 0.61$, $p > .05$), with a similar result for the blind participants. Qualitatively, there was a majority preference for the continuous audio feedback (75%), which was deemed adequate, including the minimum volume of the sound and the absence of feedback when there is no deviation. However, discussion with the blind participants indicated that turning in the direction toward the audio feedback was counterintuitive, as this conflicted with their mobility training, in which they learn to listen to sounds and turn *away* from them, e.g., traffic or the cane hitting an obstacle. Although this was not an issue for our sighted participants, addressing the feedback from the blind participants was a priority and the design of the continuous feedback was revised accordingly for the main experiment.

4.3. Experiment: Performance Evaluation

The main experiment aimed to evaluate the participants' performance in walking straight with and without continuous auditory feedback. Nine blind participants (5f / 4m), ranging in ages from 22 to 71 years, were recruited through the INLB and Montréal Association for the Blind (MAB, `http://www.mabmackay.ca`) and compensated for their participation. One participant had very low vision and the others were all fully blind, mostly from birth. All participants used canes.

A similar methodology to the pilot was followed. The two conditions were continuous audio feedback and a control without feedback, presented in ABBA counterbalanced order, with 10 trials per participant in each condition. To familiarize participants with the audio feedback, two practice trials were first provided. In the control condition, the participants were asked to walk as they normally do, with their canes, in the direction they were positioned to face, and were stopped after walking 15 m. The average error was calculated to establish their baseline walking straight deviation.

The experiment took place in two different locations, both chosen for their safety. The first was the same as used for the pilot and the other was in a parking lot, secured for the experiment, at the MAB. Although we cannot entirely rule out any effects of the tiles themselves in the first setup, our observations during the experiment indicated that the subjects did not use the structure of the tiles, i.e., the grooves between them or the drains, for directional guidance. Furthermore, the results (see Figure 3(a) and 3(b)) did not indicate any significant difference between performance on a tiled vs. concrete surface for either mean deviations ($M_{tiles} = 5.02$, $SE_{tiles} = 0.51$, $M_{concrete} = 6.67$, $SE_{concrete} = 1.50$, $t = -1.04$, $p > 0.05$) or walking times ($M_{tiles} = 15.01$, $SE_{tiles} = 0.88$, $M_{concrete} = 15.28$, $SE_{concrete} = 1.25$, $t = -1.82$, $p > 0.05$).

4.3.1. Statistical Analysis

Before choosing the appropriate statistical test, the parametric assumptions were tested to determine the normality of the distribution. Both the $z_{skewness}$, $z_{kurtosis}$ (inferior to 1.96) and the Kolmogorov-Smirnov test indicate that the distribution was normal ($D(9)_{without} = 0.178$, $p>0.05$ and $D(9)_{with} = 0.209$, $p>0.05$; indicating no significant deviation from normality). However, the analysis revealed that participant 5 was an outlier, as he had significant problems keeping the device in place due to his physiognomy. The subsequent analysis was therefore performed only with the remaining eight participants.

Figure 3(a) shows the mean values of the error angle for each of the conditions (3rd bar). The feedback condition had a lower deviation to the straight line compared to the control condition. The results of a paired samples T-test demonstrate that on average, participants had a significantly smaller error in walking straight with the feedback (*M* = 3.95, *SE* = 0.44) than without feedback (*M* = 7.32, *SE* = 0.89, $t(7) = 2.813$, $p < 0.05$, $r = 0.73$).

This supports the hypothesis that the visually impaired would

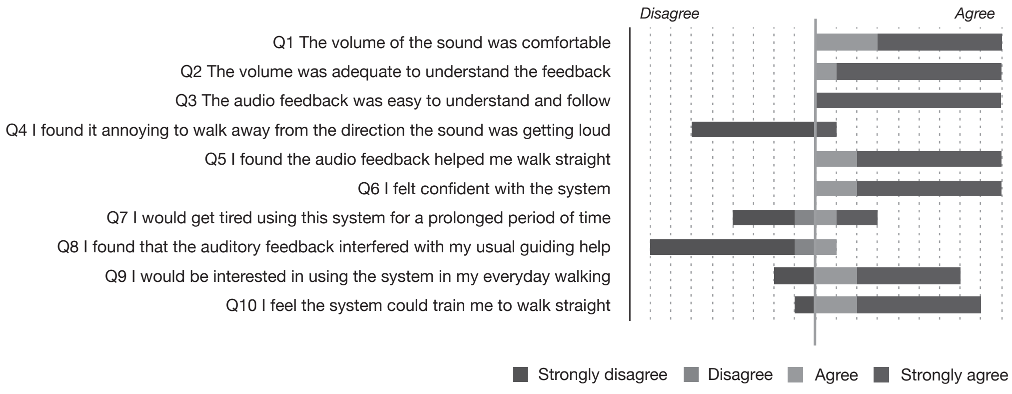


Figure 4: Responses to the Likert scale questionnaire, represented as a net-stacked distribution. The scale represents the number of answers for each question, with neutral responses omitted (questions 4 and 7).

benefit from the auditory feedback and that it would help them to walk straight in a chosen direction. Although the mean error was the main criterion for success, it is also important to consider the time taken to travel the same distance between the two conditions. If it turned out that participants are able to walk straighter with feedback, but do so significantly slower, the benefit would be called into question, especially in a practical context such as crossing a wide street. Thus, the same statistical tests were performed on the mean times for the two conditions. The normality tests ($z_{skewness}$, $z_{kurtosis} < 1.96$; $D(9)_{without} = 0.171$, $p > 0.5$ and $D(9)_{with} = 0.196$, $p > 0.05$) confirmed that the distribution was normal. Participant 5 was also excluded from this analysis, for the same reasons described above.

Figure 3(b) shows the mean time for completion of both conditions (3rd bar). Although participants took slightly longer to travel the 15 m in the feedback condition, a paired samples T-test shows that there was no significant difference in completion time between the control ($M = 14.60$, $SE = 1.03$) and feedback ($M = 15.61$, $SE = 0.98$, $t(7) = -1.852$, $p > 0.05$) conditions.

4.3.2. *Qualitative Questionnaire*

The questionnaire administered for this experiment focused on overall usability of the feedback and user preferences. This consisted of 10 questions to be answered on a Likert Scale from 1 (strongly disagree) to 5 (strongly agree). The questions were mostly identical to those used in the pilot, except for those concerning the design of the auditory feedback, which were replaced by general usability questions. The distribution of answers is represented in Figure 4. An additional final question asked the participants which use cases they could foresee as most useful for them.

The participants responded entirely in agreement or strong agreement to the positively phrased questions related to comfortable volume level (Q1), adequacy of the volume (Q2), ease of understanding (Q3), helped them walk straight (Q5), and confidence with the system (Q6). In terms of the choice of direction of audio feedback (Q4), responses were varied. Six of the participants approved of our decision to have the audio indicate the direction from which they should turn away, consistent with their mobility training, but two participants had no opinion, and one participant disagreed. Despite the overall validation of our design, this may be a parameter best left to personal preference.

With respect to negative aspects of the system, responses were less uniform, with the question of fatigue (Q7) being the most varied. Only one participant agreed that the feedback interfered with using the cane (Q8), an important consideration since the system is intended to be used in conjunction with such a walking aid. Interestingly, one participant suggested the opposite, commenting that the feedback actually helped him concentrate more, in particular for maintaining an appropriately sized arc of cane sweeping while walking. The participant who was concerned about possible interference with the cane was one of only two who were not interested in using the application in their daily routine (Q9), both noting that it was difficult to concentrate on both the environmental sounds and the audio feedback. Overall, the other participants agreed (78%) that they would be interested in using the application in their daily routine.

Similarly, all but one participant agreed that the Walking Straight system could be useful to train them to walk straight (Q10). This question was posed to assess the viability of using the application in a mobility training context, teaching blind users skills that would persist even after they stopped using it. Anecdotally, it is worth mentioning that a mobility trainer who accompanied one of the participants also tried the application and was enthusiastic about the possibility of using it in this manner.

The final question concerning use cases received a number of suggestions, including: in winter, e.g., snowy, conditions, when the "walkable" path may be significantly narrower than the entirety of the sidewalk, a wide space with no sidewalk, when crossing streets (mentioned by five participants), entrance to big stores, open spaces (two participants), and a street without motor vehicle traffic. On a particularly promising note, several participants asked when the system would be available, and expressed interest in using it on an ongoing basis.

5. DISCUSSION & FUTURE WORK

The experimental results confirmed the benefits of using auditory feedback to help the visually impaired walk straight. Qualitative feedback from participants suggests that our system could be used in daily walks or potentially for training purposes. Indeed, using a similar system to train visually impaired people, Guth [3] noted beneficial effects up to five months after the cessation of training, noting that the training reduced, although did not entirely eliminate, veering. The results also helped validate the design of the auditory feedback, a continuous tone delivered to the ear on the side of the deviation, and silent otherwise. However, the experiment also underlined several issues that need to be addressed, as described in the following subsections.

5.1. Sensor Accuracy

Sensor reliability is the most important issue we faced. In the evaluation, using only a face-up orientation for the phone, we estimated the drift at the end of each trial, and found values as high as 23 degrees. Surprisingly, this error did not always lead to higher deviation, which suggests the possibilities that drift accumulation was non-uniform throughout the trial or that our estimates, conducted by approximate visual alignment by the experimenter, were themselves inaccurate. An improved measurement technique to characterize the actual gyro drift that occurred during each experimental trial would be useful, for example, using the camera pointed at the ground to determine orientation relative to a marker.

As mentioned in Section 3, our initial implementation worked best with the device in a flat orientation. Blum et al. [22] carried out a study on sensory reliability with different smartphones in different orientation/body position combinations to determine if device orientation or location on the body has a significant impact on sensor accuracy. They observed a wide variance of drift across different walks, varying from an average drift of less than 0.1 degree/s across the entire walk to a significant drift over time accelerating to over 4 degrees/s. Moreover, the head position, with the device resting flat, performed worse than the other positions, including hanging vertically on the chest. These results suggest that the vertical position would be more appropriate from a sensor standpoint than the tested flat orientation, and be more practical since it would allow the user to carry the device more easily, e.g., on a neck strap. Therefore, we have modified the sensor reading to work effectively in a vertical orientation as well.

In terms of our intended application, it appears that sensor reliability is a significant obstacle to broad deployment under realistic conditions, although over a short distance, sensor drift may be acceptably low. Over longer distances, such as within a navigation application, this would, however, be more problematic. Ultimately, these issues can only be resolved by improved sensor technology. While awaiting the integration of more reliable gyros in future generations of smartphones, we will investigate the potential of augmenting such sensors with a better compass or employing sensor fusion with video input from the camera.

5.2. Application issues

Another problem is devising a practical yet acceptable harness that holds the device securely and comfortably, in a fixed position on the user's body, e.g., against the torso, as done in our experiment. In our experience, the two belts seen in left of Figure 5 would loosen over time, allowing the iPhone to move and therefore provide incorrect information about the user's deviation. Furthermore, the aesthetics of the actual mounting system clearly pose a problem that could impact user acceptance and in turn, limit our ability to deploy the system under ecologically valid conditions. However, a likely candidate to improve the mounting, as mentioned above, would be to adopt a vertical orientation of the device, held against the torso as shown in the right Figure 5.

Another important issue is the initial selection of the desired heading. For our experiment, the iPhone had to be aligned with the straight line drawn on the ground. Since this alignment was performed manually by the experimenter without the benefit of accurate instrumentation for verification, small initial offsets could manifest as a significant deviation by the end of the trial. This would need to be supplemented with a validation mechanism to ensure an accurate specification of the desired initial orientation, and eventually even be automated. Similarly, it may be important to determine the centred position within the crossing. One promising approach for these purposes is to employ computer vision algorithms using images from the smartphone camera to detect crossings [23, 15, 16]. Integrating Walking Straight with such techniques will be investigated to provide guidance and orientation cues both to the crossing and on the crossing. More generally, the Walking Straight application would likely benefit from integration with path guidance, for providing both navigation instructions and deviation correction cues, to realize the full system envisioned.

Figure 5: Current mounting system (left): the iPhone is lying on an L-shaped rigid piece of plastic, strapped with a flexible belt case, attached both around the body and the neck and supplemented with an additional more rigid belt. The new neck-worn case (right), developed after our walking straight experiments, shows the iPhone held in a solid waterproof plastic case and suspended by laces.

Finally, the experiments described here served primarily as a feasibility assessment. We sought to verify the effectiveness of determining deviation using the built-in sensors of a smartphone and producing basic auditory feedback in a manner that helped minimize veering on a straight path. To this end, the application was tested under more tightly controlled conditions than would be feasible in a practical deployment. This was done to avoid potential sources of bias that might be introduced by the environment, e.g., background audio cues or physical interference. Before we can progress to testing under more ecologically valid conditions, adequate audio feedback will be further investigated, so that it is clearly audible, yet perceived as background sound to avoid monopolizing the user's attention for safety and comfort reasons. More elaborate mappings, using pitch and other auditory variables, possibly in combination, will be explored.

6. CONCLUSION

Despite training, blind people still experience difficulties with veering. The "Walking Straight" application was developed to help reduce this problem by providing real-time audio feedback from a lightweight, accessible, aesthetically acceptable, multi-purpose platform such as a smartphone. Different auditory feedback designs were evaluated experimentally and their performance assessed in terms of reduction of veering. A pilot study demonstrated that a continuous tone played in the ear on the side of the deviation would be the most beneficial, especially as this was consistent with mobility training. Testing with nine visually impaired participants resulted in an average reduction of deviation to nearly half that in the control condition.

Our system addresses an important need of the blind community and the participants in our study were enthusiastic about the application, eager to use it on an ongoing basis. Nevertheless, the evaluation highlighted several issues that first need to be addressed to ensure that it is useful in an independent, reliable and safe manner. These include, in particular, automatic selection of the correct heading and design of an aesthetically acceptable harness to keep the device fixed on the user's body. Sensor reliability should also be improved, using sensor fusion techniques for instance. Our next objectives are to integrate detection of crossings and user guidance to crosswalks from video input, as well as building a more complete solution that provides veering assistance between two arbitrary locations.

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