Sonification of Pathways for People with Visual Impairments

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ABSTRACT
Indoor navigation is an important service, currently investigated both in industry and academia. While the main focus of research is the computation of users' position, the additional challenge of conveying guidance instructions arises when the target user is blind or visually impaired (BVI). This contribution presents our ongoing research aimed at adopting sonification techniques to guide a BVI person. In particular we introduce three sonification techniques to guide the user during rotations. Preliminary results, conducted with 7 BVI people, show that some of the proposed sonification technique outperform a benchmark solution adopted in previous contributions.

CCS Concepts
• **Human-centered computing** → **Empirical studies in accessibility**; • **Social and professional topics** → **Assistive technologies**, **People with disabilities**

Author Keywords
Visual Impairment; Sonification; Indoor Navigation.

INTRODUCTION
Recent contributions investigated indoor navigation assistance for blind or visually impaired (BVI) people [6, 8]. Two orthogonal issues arise: detecting users' position with high accuracy (required to provide guidance to BVI users), and conveying navigation instructions to the user. We consider the latter problem and, in particular, how to guide the user during rotations.

This contribution presents our ongoing research in this field, including the adoption of sonification techniques to instruct a BVI person to rotate by a given angle. Sonification is the technique of rendering sound in response to data and interactions [5, 7]. We explore three sonification techniques, and we compare them with a single impulse benchmark solution adopted in previous works [1, 11].

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Preliminary results of an experimentation with 7 BVI participants suggest that some of the proposed techniques are significantly more precise in guiding the user with respect to the benchmark, and some further improve when combined with the benchmark approach.

PROBLEM DEFINITION
In this work we consider smartphone-based indoor navigation systems (INS) for BVI people. INS track the user's location and heading direction within the environment, and compute a route from a source to a destination. We assume that the user's location is correctly computed by INS and the destination is inserted using existing assistive technologies for mobile devices (e.g., screen reader). We also assume that the device heading corresponds to user's heading; this implies that the user is holding the device in such a way that it rotates together with the user's body. This is a strong assumption as it disregards the case when the user "points" the device towards a different direction than her body. Following a common practice in navigation systems, INS compute routes as sequences of nodes connected by line segments. Consequently we identify two forms of instructions: when the user is at a node and needs to rotate towards the next line segment and when the user is walking along a straight path connecting two nodes.

In this contribution we focus on the former case, in which users can only turn left or right. This is particularly relevant for navigation, since a small rotation error can lead to a significant distance offset during the following frontal movement step. These errors are more frequent in correspondence to turns that differ from 90°, and can result in the user taking an incorrect path and possible facing hazards [2].

There are other two requirements: first, instructions should be intuitive and easy to follow; second, audio instructions should not be provided in stereo, as users are unlikely willing to wear headphones as this prevents them from hearing background sounds which are fundamental during mobility e.g., for danger avoidance [3, 4].

SONIFICATION OF ANGULAR DISTANCES
The objective is to guide a BVI person to rotate by a given angle. Many sonification techniques have been proposed to guide BVI people [9, 10]. Nonetheless, the problem of guiding a BVI person during a rotation is still open.

Previous results presented what we call the "ping" technique [1, 11]: the user is first instructed to rotate left or right with verbal messages (e.g., "Turn Left") and then a "ping", namely an impulsive sound, is played as soon as the target angle is reached. We use this technique as a benchmark and explore three alternative sonification techniques.

Our techniques continuously modulate sound parameters to convey the rotation quantity. We speculate that such interaction will guide the user to the desired rotation more precisely. Specifically, we have implemented the following techniques:

- *Intermittent sound (IS)* — This sonification is based on triggering impulsive sounds at a variable rate depending on the angular distance from target direction. It recalls sound warnings typical of a car's parking assist system;
- *Amplitude modulation (AM)* — We generate an amplitude-modulated sound, where the amplitude variations are driven by a frequency that rises when approaching the target. Consequently, when far from the target, the user perceives a pulsing sound, when on target a continuous one;
- *Musical scale (MS)* — The distance from the target angle is subdivided into eight circular sectors, corresponding to grades of an ascending major scale. While approaching the target, the user enters new areas, triggering new notes; when the target has been passed, a descending grade is performed.

In our experimentation, we implemented the mentioned approaches alone, and coupled with the additional ping sound when on target. The former approach was useful to compare sonification techniques, the latter to evaluate the possible improvements made by additional impulse as a reinforcement.

PRELIMINARY EXPERIMENTAL EVALUATION

The experimental protocol involved 7 BVI participants. We evaluated the three sonification techniques described above, respectively with and without the ping reinforcement, as well as the ping alone, for a total of 7 conditions. During the training phase the participants were introduced to the sonification techniques, and during the test phase they performed rotation tasks. A final questionnaire was administered to obtain a subjective evaluation of the experience. The average time to complete the whole experiment was about 30 minutes per participant.

The training and the tests were administered using a mobile app running on an Android Pixel 2 device. The app recorded participants' angular position at a frequency of 100Hz using the device inertial sensors. Participants sat on a swivel chair, with the smartphone anchored to the armrest (left or right, depending on user's handedness). The activity took place in a silent room, without headsets nor any additional feedback.

For each trial, the participants were instructed to turn left or right with a verbal message, followed by one of the proposed sonification techniques. The participants could end the trial with a tap on the screen when confident to have reached the desired angle. We specified three pre-defined angles: narrow (50°), medium (80°), and large (130°). In total 84 trials were tested, resulting from 7 conditions (sonifications) $\times 3$ angles $\times 2$ directions (clockwise and counterclockwise) $\times 2$ repetitions. Trials were completely randomized.

RESULTS AND DISCUSSION

We report the analysis of two metrics among those collected:

Rotation error is the angular error between the target direction angle for the rotation task, and the user's direction angle at the end of the task;

Rotation time is the time required to complete a rotation task;

Zero crossings count measures the number of times the user crossed the target angle before ending the task. A high zero crossings count means that the user adjusted the orientation multiple times by going back and forward over the target angle before being confident of the direction.

Our experiments reveal that the *MS* technique ($M = 4.43°$, $SD = 5.63°$) was less error prone than the *ping* baseline ($M = 6.49°$, $SD = 4.91°$), and the difference was found to be statistically significant using a Wilcoxon signed ranks test ($p = .02$). However no statistical significance was found between *IS* ($M = 6.11°$, $SD = 4.99°$) and *AM* ($M = 8.20°$, $SD = 5.33°$) techniques, and the baseline. We think that the high rate pulsations in the proximity of the target direction, which characterize these techniques, make it harder to precisely pinpoint the target direction.

Considering the rotation time, *AM* results to be the fastest ($M = 6.39$s, $SD = 1.18$s), with statistically significant difference with respect to *ping* ($M = 7.65$s, $SD = 2.21$s). Conversely, *MS* is the slowest on average ($M = 9.63$s, $SD = 4.69$s), but the difference with *ping* is not statistically significant. The fact that rotating with *MS* requires longer could be motivated by the fact that this technique also has the higher value for the zero crossing count metric ($M = 1.83$, $SD = 1.42$). However, also for this metric, the difference with *ping* is not statistically significant.

CONCLUSIONS AND FUTURE WORK

Nowadays precise indoor positioning is becoming a reality, thus fostering the design of indoor navigation systems for BVI people. Audio instructions to guide users are a fundamental part of these systems. In this contribution we report our ongoing research, showing that it is possible to improve existing approaches and guide users with higher precision. In particular, we found that the *MS* technique is significantly more precise than the baseline, while not requiring significantly longer to perform the rotation.

In the future we intend to conduct a deeper evaluation of the proposed sonification techniques, possibly comparing them with different ones, including those based on stereo sonifications that can be used, for example, with bone conducting headphones. Also, in this contribution we considered rotation instructions only, which are provided at nodes (e.g., intersections), while in the future we will also consider how to provide instructions along the line segments connecting two nodes. Finally, an important aspect that we will investigate is how to deal with approximation, which is inherently associated with location and heading.

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