CIS II: Critical Review

Multisensory Navigational Aid for Visual Prosthesis Users

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Project Summary

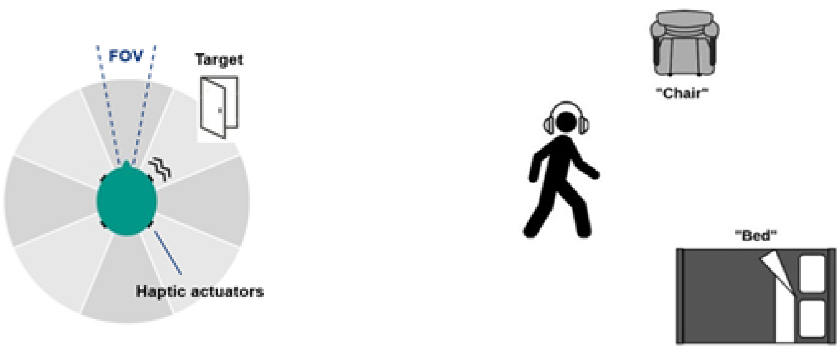
The Argus II retinal prosthesis system has certain limitations making it difficult for users to independently navigate a space. The artificial vision provided by the Argus II (Figure 1) is not the same as actual sight and offers a limited field of view. The perception of this artificial vision also varies between users – some are able to distinguish different light intensities whilst others can only distinguish the on/off states.

Camera Image | Output Stimulation Image | Perceived Image

Figure 1: Artificial vision obtained with Argus II

Thus, the goal for this project is to develop haptic and auditory feedback systems that work cooperatively with the Argus II retinal prosthesis system to aid users in independent navigation. The supplementary systems are designed to assist with target navigation and object localisation. These additional systems should be intuitive, such as having a minimal learning curve, as well as maintain a low cognitive load.

The objective for the haptic feedback system is to guide users' gaze direction towards their target using a haptic feedback headband device. The auditory feedback system aims to help users locate obstacles using sound played through open ear bone conduction headphones. Names of obstacles will be played to the users through the headphones and sound like it is coming from the direction of the objects.



(A) (B)

Figure 2: Objective of the proposed (A) haptic feedback system and (B) auditory feedback system

Paper selection

Two papers were chosen to be reviewed in this assessment – one for each of the proposed feedback systems. The paper by Kaul, et al. "Around-the-Head Tactile System for Supporting Micro Navigation of People with Visual Impairments" [1] was chosen as it relates to the proposed haptic feedback system. The second paper, "Auditory Spatial Perception Using Bone Conduction Headphones along with Fitted Head Related Transfer Functions," by Voong and Oehler [2], was chosen as it explored a means to determine a best-fitting head related transfer function (HRTF) profile for unique users. They also utilised bone conduction headphones as their choice of auditory feedback device which is the same as what is being investigated in our project.

For the purpose of this assessment the analysis of each paper will be presented separately as indicated below.

Haptic Paper

Problem Summary and Background

The authors of this paper identified a problem similar to that stated earlier – those who are visually impaired cannot independently navigate a space. They thus aimed to investigate the effectiveness of a haptic feedback device in assisting with micro navigation. This is closely related to the objective of the proposed haptic feedback system of our project. A haptic feedback cap was previously developed by the authors, called HapticHead (Figure 3), for virtual and augmented reality (VR/AR) applications. They thus explored a new application for their device in their paper. The HapticHead resembles a swimming cap with a chin strip fitted with 24 haptic actuators.

Figure 3: HapticHead

In their haptic feedback implementation, the authors made use of two techniques. One is a set of commands relaying instructional information; the other is continuous feedback for directional guidance. Their continuous guidance feedback was such that the three actuators closest to the direction of the optimal path were actuated. Thus, in practice, the haptic actuator located on the users' forehead should always be on – indicating to the users that they are on the correct path. This feedback method was not altered in any way during their investigation.

Method

For their investigation, the authors followed an iterative approach. Their developed haptic patterns were evaluated and refined numerous times based off of participant feedback and navigational tests.

First, the authors interviewed two individuals who worked at an institution that assisted with visually impaired children and teens to determine which commands would be needed for their system. They decided upon 4 commands – 'start,' 'stop,' 'up,' and 'down.' The 'up' and 'down' instructions were used for stairs. Following so, 4 haptic patterns for each command was developed (totalling in 16 patterns). To determine the most intuitive pattern for each command the authors evaluated the patterns with 11 participants. Participants were asked to chose which command they thought best corresponds to the pattern played to them. The authors were thus able to determine which pattern was the most intuitive for each command by choosing the patterns that the participants got correct the most. These chosen 4 haptic patterns were then revaluated with 10 different participants to confirm their intuitiveness. With these 4 commands and their continuous guidance, the authors evaluated their system's effectiveness in providing micro navigation with 15 participants and a small obstacle course. The obstacle course composed of cardboard obstacles and a wooden step. Three predetermined routes through this obstacle course were preprogramed into their system. The participant group was comprised of seeing and visually impaired individuals however they were all blindfolded for this test. Each participant completed 24 runs through this obstacle course (each of the 3 routes in both directions 4 times). After this test the authors refined their haptic patterns based upon the feedback received from the participants. With these final adjustments, the obstacle test was performed one last time with 5 visually impaired participants. This time, each participant completed 48 runs through the obstacle course. This concluded the authors' investigation.

Key Results and Significance

As a result of their investigation, it was decided to omit the 'start' command as the authors found that it was clear to the participants when the navigation was starting without the need for the feedback command. They decided to add an additional 'attention' command to bring the users' attention back to the navigation if they were straying off the optimal path. It was found that the 'stop' command was too abrupt and disruptive to be used frequently for small deviations from the path. The final haptic command patterns resulting from the authors' investigation are illustrated in the figure below.

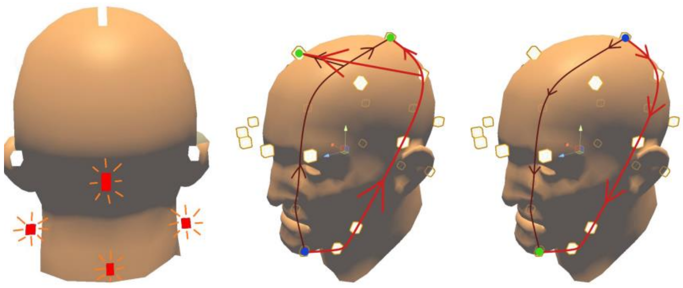
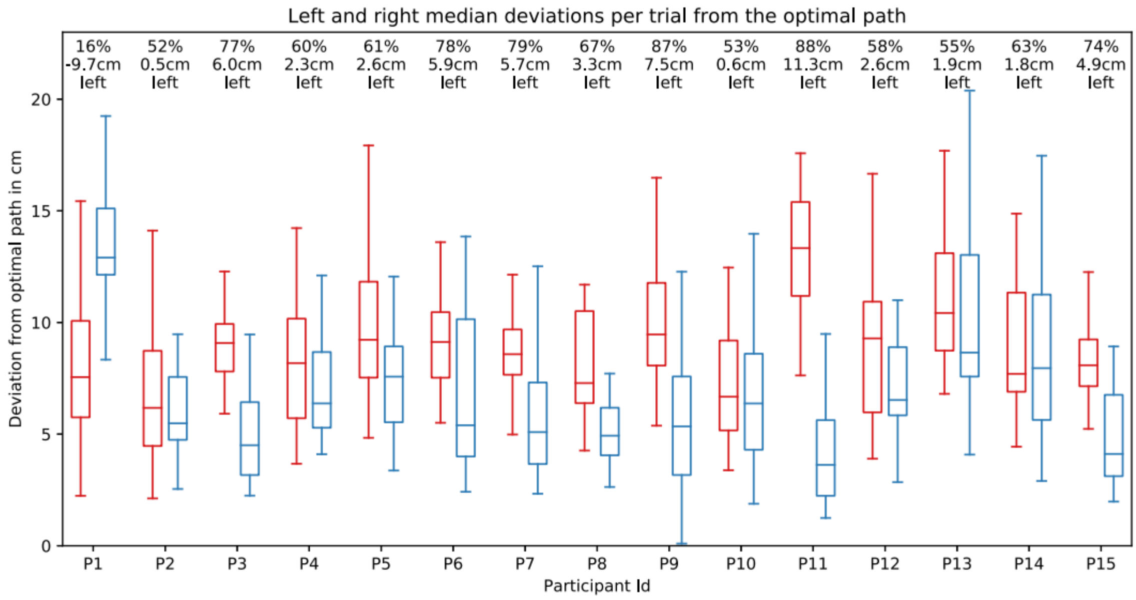


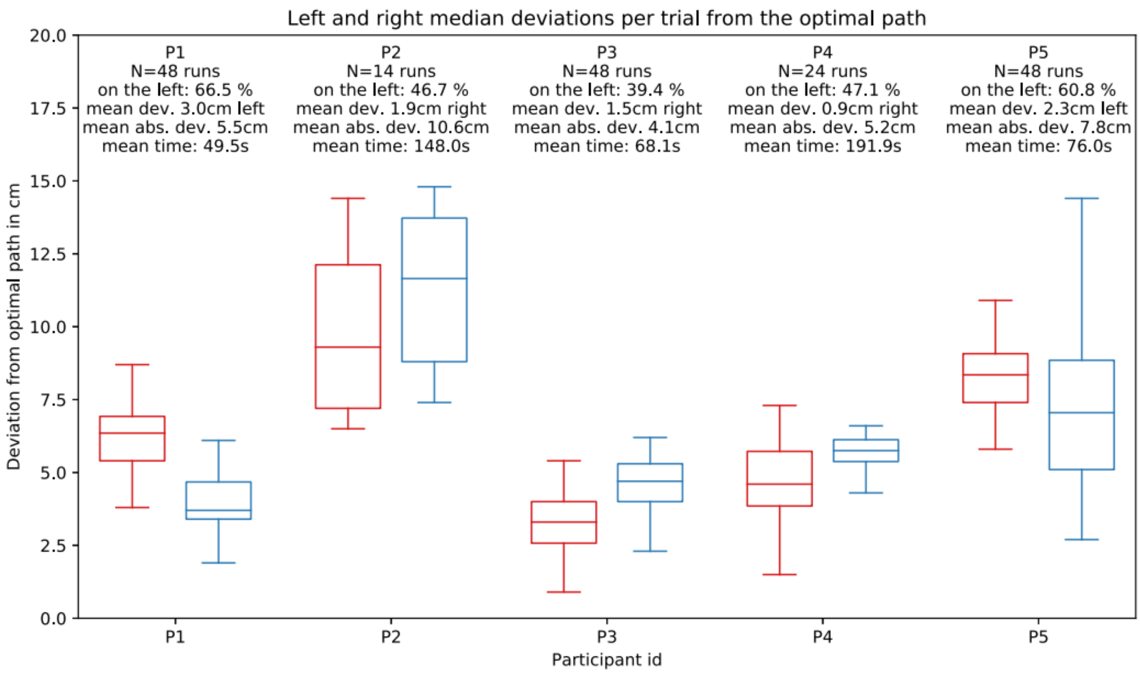
Figure 4: Final haptic command patterns

The 'attention' command was produced by actuating 4 actuators located at the back of the head for a total of 75ms. The 'stop' was achieved by actuating 11 actuators on the head on for 75ms and off for 37.5ms 3 times for a total of 300ms. The 'up' and 'down' commands were similar, both were dynamic patterns totalling 575ms. The 'up' command was achieved by actuating the actuators starting from the chin, moving up the sides of the head and ending at the top of the head. The 'down' command is simply the opposite – starting at the top of the head, moving down the sides and ending at the chin. After the first obstacle test, the authors found that they needed the 'up' and 'down' patterns to be much quicker. Thus, they decided to play each pattern once instead of twice as they had initially developed. In the final haptic pattern intuitiveness, the authors also examined how short the duration of the dynamic 'up' and 'down' patterns could be and still be effective and distinguishable by the users. They found that 575ms was the shortest duration possible. Dynamic patterns were also chosen for the 'up' and 'down' patterns as they found that while users are able to localise static patterns better, they are uncomfortable. Thus, our project will aim to develop quick dynamic haptic patterns where possible. The authors also found that localisation of the actuators on top of the head was not precise, as such, our project will also aim to utilise the side haptic actuators in conjunction with the top ones wherever possible in the proposed haptic feedback system.

For the obstacle course tests, the authors provided quantitative results in the form of median deviation from the optimal path. This result from both obstacle tests is shown below.



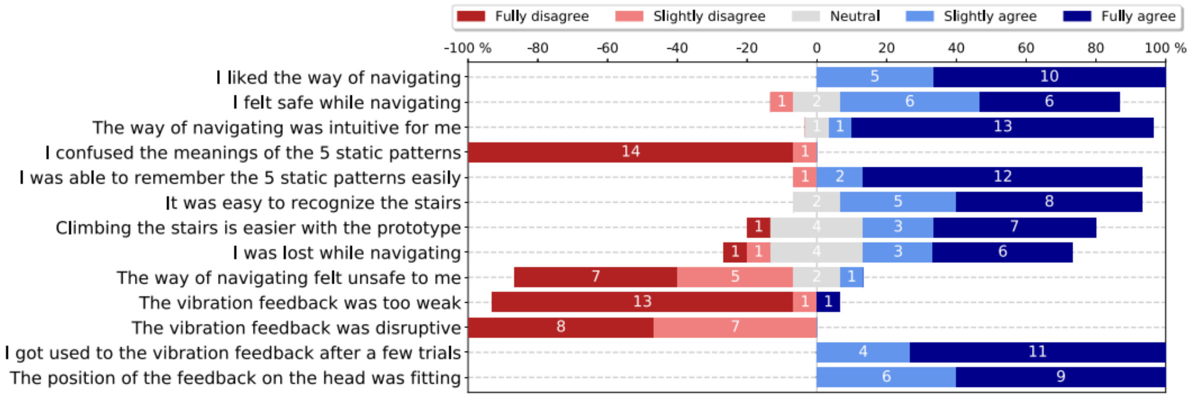
(A)



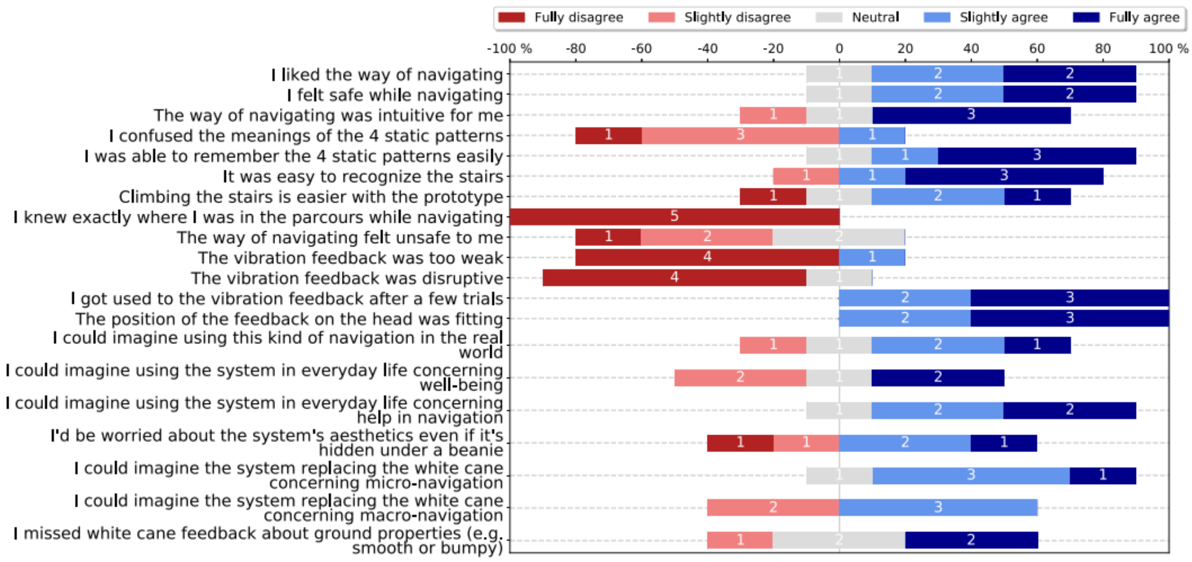
(B)

Figure 5: Median deviations (red = left, blue = right) from the optimal path for each participant for the (A) first obstacle test and for the (B) second test

As can be seen in Figure 5, the maximum deviation, left or right, for the first obstacle test was about 20cm whilst for the second test was about 15cm. The authors also provided qualitative results by interviewing the participants after the test. Participants were queried about how they felt about the intrusiveness of the system, how safe they felt, what drawbacks they thought the system had among others.



(A)



(B)

Figure 6: Questionnaire feedback after (A) first obstacle test and (B) second test

The focus for this assessment was placed on the intuitiveness and safeness of the system as intuitiveness is one of the goals of our project and safety is always crucial. Overall, majority of the participants stated that they felt the system was intuitive and felt safe.

It should also be noted that the average time taken for each user to complete a run during both the obstacle course tests decreased with the number of runs. All the runs were completed one after the other on the same day thus showing that if participants were confused by the haptic feedback in any way the feedback commands and continuous guidance instructions could be quickly learnt. This is an encouraging result as one of the goals for our project is to have a minimal learning curve for our supplementary systems. Overall, the authors showed that it is possible to effectively guide users using haptic feedback. Since no other means of feedback was used in their investigation, the haptic feedback is effective even as a standalone navigational aid.

Critical Assessment

In terms of my assessment of this study, the iterative approach taken by the authors can be appreciated. For a user-centric device such as this, that would potentially be used every day, it is critical that it is intuitive, easy to use and feels safe to the user. A means to verify whether these conditions are met is to perform numerous user tests; as the authors did. Secondly, during the command pattern intuitiveness tests, the participants were not told if their answers were correct or not during the test. This strategy is to be commended as it minimises any learning effects. In the real-life implementation of this system there will undoubtably be learning by the users however, the purpose of this intuitiveness test was to evaluate the intuitiveness of the haptic patterns thus minimising any potential learning is desired.

There are a few areas that could have been improved upon in this study. First, very few participants were included in their tests. For the obstacle course test, only 20 participants were included in total across both tests, only 5 of which tested the final iteration. In order to have a better representation of the partially impaired population it is recommended to include participants to test their system. They also tested the pattern intuitiveness test with seeing individuals, although the impact of this on the results is probably at most negligible as being able to see does not offer any advantage or disadvantage to perceiving the haptic feedback but this should be taken note of as their study was targeted toward assisting those with visual impairments. Finally, the paths in their obstacle course test were predetermined and preprogramed. In a real-world application of this system a predetermined path would not exist unless it is integrated with some sort of path planning system. Thus, to properly evaluate the real-world performance of their system, it should be integrated and evaluated with a path planning system.

Auditory Paper

Problem Summary and Background

Simulated HRTFs are useful in VR and AR applications in aiding in creating fully immersive virtual environments. However, each individual's personal HRTF is unique as it is determined by personal head features such as ear and head shapes. Therefore, using one generalised HRTF profile for every individual is not recommended. This paper explores one means to determine a best-fitting HRTF profile for unique individuals out of a pool of HRTF profiles. The authors selected 8 HRTF profiles to create their pool – 4 from the CIPIC database and 4 from the LISTEN database. The approach taken by the users include two phases and is detailed below.

Method

The authors proposed method for determining a best-fitting HRTF profile is to use an adapted Swiss-style tournament. During each match two sounds will be played using two HRTF profiles. The user then picks a winner. This tournament style does not eliminate any contenders thus all 8 HRTF profiles are used until the end of the tournament.

Two sounds were used in this evaluation. One is the sound of a car driving around the participant and the other is the sound of a drone flying across in front of them. For every match in the tournament, the participants were asked to pick which profile they preferred and this was deemed the winner of that round and received a point. At the end of the tournament the HRTF profile with the most points for that participant was the winner.

After this tournament phase was completed, the participants partook in the second phase of the investigation. In this phase, all 8 HRTF profiles were still included. The participants were asked to locate the direction of the origin of random sound stimuli with each of the 8 HRTF profiles.

For both phases ambient sounds were added. The authors performed both phases of their method using bone conduction and conventional headphones. Only the results of the bone conduction headphones will be detailed as that is what is of interest for our project.

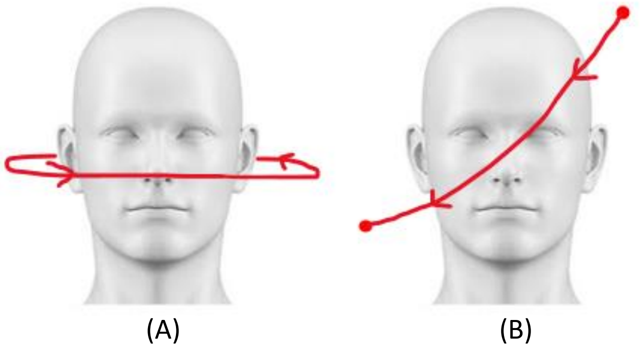


Figure 7: Movement of simulated sound for (A) car sound and (B) drone sound

Key Results and Significance

As for the results of their study, the authors found that for 5 out of the 9 participants the best localisation results was achieved when they used the 1^{st} or 2^{nd} winner HRTF profiles from the first phase. And 6/9 of the participants had the best or second-best localisation results for the 1^{st} or 2^{nd} winner HRTF profile.

These results do not seem to be overwhelmingly positive. Their participant group size is small and only 8 HRTFs are used in this study which may not be sufficient. Thus, it is worth considering that if more HRTF profiles were included would better results have been achieved.

Finally, for our project a question that would be nice to have answered is how long the evaluation took for each participant. It is difficult to compare this method to a more standard individualised HRTF obtaining method since the time taken is not mentioned by the authors. Though, despite this, the proposed method from this paper shows that it could be possible to match a general HRTF profile to individuals and this process could be less tedious than obtaining individual HRTF for each. However, it will also be worthwhile exploring alternative options for individualising HRTFs as well for our project.

Critical assessment

Some things that the authors did well in their research was that they also included ambient noises in both testing phases, this mimics real-world situations more closely, although real-world ambient noises would not be simulated. Additionally, it is a good strategy to still include all 8 HRTFs in the second phase as this acts as a validation to see any correlation between the HRTF profile that users prefer and the HRTF that gives accurate sound localisation for that user.

There are a few things that the authors could have improved upon. One was to include more participants, they only had 9 in this study. Adequate diversity is probably not achievable in a participant group this small; it would not accurately represent a sample of the general population. In addition, as stated earlier they only used 8 HRTFs in their study which is potentially inadequate. Furthermore, the authors also did not detail which directions they used for the stimuli in the second testing phase. When using simulated HRTFs, some directions are easier to identify than others. There is a commonly observed discrepancy in locating the direction of a sound between the front and back. It is unclear whether all directions were evaluated in their investigation. The authors also were not clear in defining their problem statement. They did mention VR/AR applications of simulated HRTF but did not detail if their proposed method would be implemented in those cases. This could be why they did also did not state if their method reduced the front/back discrepancy often experienced when using generalised HRTFs – it is simply not clear if that would have been important in their application or not.

Conclusion

Through the review and assessment of the two papers detailed above, a direction of development for the haptic and auditory feedback systems of our project is guided. Both papers performed useful evaluations relating to each system and key takeaways can be used in the supplementary systems' developments.

References

[1] Oliver Beren Kaul, Michael Rohs, Marc Mogalle, and Benjamin Simon. 2021. Around-the-Head Tactile System for Supporting Micro Navigation of People with Visual Impairments. ACM Trans. Comput.-Hum. Interact. 28, 4, Article 27 (August 2021), 35 pages. DOI:https://doi.org/10.1145/3458021

[2] T. M. Voong and M. Oehler, "Auditory Spatial Perception Using Bone Conduction Headphones along with Fitted Head Related Transfer Functions," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), 2019, pp. 1211-1212, doi: 10.1109/VR.2019.8798218.