Increasing Accessibility of Spatial Awareness for the Visually Impaired in VR

Aiden Gimpel
Ontario Tech University Student
Oshawa, Ontario
aiden.gimpel@ontariotechu.net

Christian Riggi
Ontario Tech University Student
Oshawa, Ontario
christian.riggi@ontariotechu.net

***Abstract*—Beginning with the idea of improving accessibility to spatial awareness for visually impaired users of virtual reality, we developed a working wizard of oz prototype that uses audio and haptic feedback to increase the confidence and level of spatial knowledge of those users. From the start, we used the design thinking process to gain insight into our target users. We researched and found other solutions that have been attempted and came up with our first idea for a solution. Using the body storming process, we created a use case and persona for our user to test and observe our prototype idea. Using the information we gained from the body-storming process, we improved and enhanced our feature to meet the user's needs, while still doing testing with users throughout. With the user interface that we created to help the user complete our prototype, we gained more data using surveys for SUS, TLX, and PQ. Using all of that data, the final product was analyzed, improved one final time, and completed.**

***Index Terms*—Virtual Reality, Spatial Awareness, Accessibility**

I. Introduction

Throughout our entire project's development, we have gone off the underlying fact that visual feedback is how spatial awareness in VR [1]. We aimed to remedy this by incorporating feedback features that were not reliant on visual feedback. In our research, we found various methods that aimed to accomplish this. These methods varied from using a treadmill for the user to walk in place while they held a virtual cane to detect walls and the ground [2], to a glove for blind players that provided haptic feedback when playing the correct notes in guitar hero [3]. With our 4-month timeline and limited resources/budget, we opted for a simpler solution. We developed a working **wizard of oz prototype** that uses audio and haptic feedback to increase the confidence and level of spatial awareness, of visually impaired users. Using iterative prototyping and user thinking design from the start allowed us to create a working solution, test it, and improve it multiple times after getting feedback, researching other solutions and creating surveys for our users. This process was integral to the success of this project, and if one piece was missed, it could have prevented the growth of the solution that we came up with. Using this process every step of the way allowed us to guide the project's evolution in the right direction and end up with a solid final product.

II. Methods

Starting from the ideation phase, we used the design thinking process to help us create a problem statement. We first created a survey to learn more about users' spatial awareness when using VR [See Figure 1]. After compiling our data, we were able to make a problem statement and a potential solution involving audio and haptic feedback. On top of the design thinking process, we also researched other known solutions to help us gain knowledge about the topic in more depth [reference the papers from the proposal]. We also created a Gannt chart to be able to keep track of our deliverables and understand what needs to be completed and when [See Figure 2]. Once our idea was created, we needed to test the idea [See Figure 3] before going into too much depth with the development to see if it was viable and if there needed to be any large changes. For this, we used the bodystorming process by creating a persona [See Figure 4] and a use case [See Figure 5], and using an actor and an observer to test the use case. We took notes about the process, and after both participants acted and observed, we wrote down their feedback as well. The use case that we presented to the actors was to wear the turned-off VR headset and walk around within a boundary on the floor. The actor could not see and would rely on us making beeping sounds with our mouths and tapping their controllers to indicate if they were getting close to the edge of the boundary. The goal was to be able to provide the user with feedback on the boundary's edge without using any visual cues. We used this process to gain information about what kind of sound to play for audio, how to add haptics, and if the feature break immersion. After putting our newly gained information to use, we created our prototype with Unity in VR using a Meta Quest 2. Originally, the project started as an area where the player can walk around using the analog sticks. It had an invisible boundary that would play a constant beep sound and vibrate the controllers when they were approaching the edge. We originally also wanted to make the headset vibrate, however, after bodystorming, we learned that if we vibrate the headset it could cause issues such as headaches and annoyance. We then changed the sound that it made from a constant beep into a more soothing south that increases pitch as you get closer. After learning that it would be useful to control the volume of the warning audio, we added a UI menu that the player can open to set the volume and level of controller vibration. The last thing we did before creating our final prototype was to create a new survey to gain information about System Usability Score (SUS), NASA-TLX, and Presence Questionnaire (PQ) followed by our users testing the project in person. Using the information gained, we made some small tweaks and added vocal audio in the project for the user to be able to tell what volume they want to set the warning sound. It also helped us be able to tell if the warning sound breaks immersion from the voice in the scene or if the user was still able to focus on the voice. Using all these processes throughout different stages of our development led us to complete a final prototype.

III. Results

Once our users had the opportunity to test our project in Unity, we gathered valuable data through SUS, NASA-TLX, and PQ. In regards to the system usability scale, we are fairly pleased with the results. The average score from all 6 participants that tried our project was 74.58 [See Figure 6]. This score is considered good under the SUS scoring system, however, we wanted to see how we could make improvements. Examining this further, even-numbered questions that were associated with negative tones, had lower scores, signifying most users did not have negative feedback toward our project. However, some users felt that were inconsistencies within the project when it came to the spatial audio not being played correctly, or the dynamic audio sometimes encountering bugs where it would not slow down or increase in speed. Regarding the odd-numbered questions which carry a positive tone behind them, these had higher scores associated with them, as most users enjoyed the quality of our project [See Figure 7]. However, some users found the system difficult to use and provided a lower score on these questions. We then got our users to answer a NASA-TLX questionnaire [See Figure 8]. The average mean for our TLX score from 6 participants, was 31.94. Normally, this score would be very concerning. However, because the performance category of the TLX questionnaire was reversed, it would sway the results of the other scores. Thus we are not too concerned with the average mean as it has been adjusted due to the reversal. Looking at the diagnostic sub-scores, users rated our performance to be high with a score of 73.33[See Figure 9]. This was great to see knowing that users felt the performance of the project was viewed well rather than poorly. Other diagnostics such as mental, physical, effort and frustration had low scores ranging from 20 - 30, signifying that these diagnostics did not prove to be overwhelming to the user. However, the temporal score was placed at 43.33 signifying that the temporal effort users were putting into the game, and the time needed to complete a task was much longer than expected. Since the task relies on our users intentionally trying to exit the designated playspace, we expected that the temporal diagnostic would be scored higher, as it is an unnatural task to ask someone who is playing VR. Finally, we had our users answer a presence questionnaire [See Figure 10]. We were pleased to see that the average score was 132.86 out of 168. This goes to show that the sections surrounding presence were viewed well with our project. For the most part, the average score per category ranged from 75% - 82%, highlighting that most categories were viewed in a positive light. Categories such as, *'Possibility to Examine'* had a lower average of 16/21. In instances like these, we set out to see how we can improve categories that had a lower rating for the final version of the project.

IV. Discussion and Conclusion

A lot was learned throughout the process of creating this project. Every stage of the development had something new to learn about the process. Using research and implementing design thinking, helped us to create a solid starting idea that we could improve and iterate on as we go. We learned that it is important to always go back to the user for more information that you can gain to improve the feature. Every time we had a user test the product or participate in our bodystorming exercise, we gained useful insights into what we should add, change, or remove from our current design. Along with this, constant iteration on the prototype itself is very important for keeping on schedule and being able to meet those users' needs properly. We could not just change one thing and ignore everything else as that only helps a few users at best. We also learned that giving the user some control over the feature helps a lot with making them feel more comfortable when walking around. Once users were able to control their volume and vibration level, they felt that the feature was easier to use. After our final tests, some last feedback that we gained was to have a voice in the scene to act as a focal point for the user. This is because it helps the user be able to tell the volume that they want to set their warning sounds so it does not break immersion and they can still focus properly on what is happening in the scene. Overall, every step of the process came together well and helped us greatly to accomplish our goal and create a possible working solution for a VR feature that increases spatial awareness for visually impaired users using audio and haptic feedback. After iterating, and using our gained knowledge and information, the project that we created culminates everything well together and meets many user's needs in the process. This was all able to be accomplished due to this process that we used.

V. Appendix

References

[1] Strickland, J. (2007). How virtual reality works. How Stuff Works, 29.

[2] Kreimeier, J., & Götzelmann, T. (2019, May). First steps towards walk-in-place locomotion and haptic feedback in virtual reality for visually impaired. In Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (pp. 1-6)

[3] Yuan, B., Folmer, E. (2008, October). Blind hero: enabling guitar hero for the visually impaired. In Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility (pp. 169-176).

FIGURES

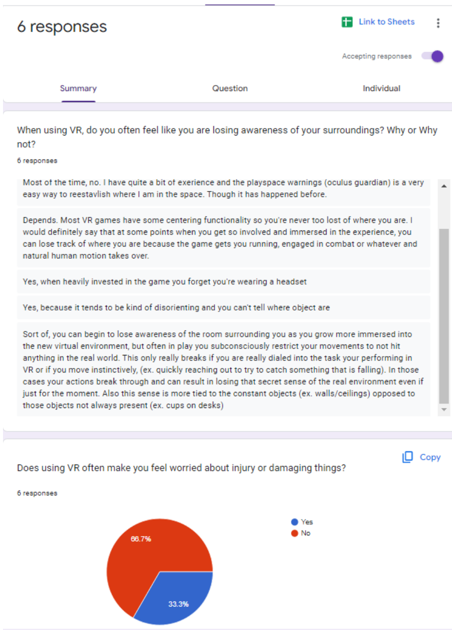
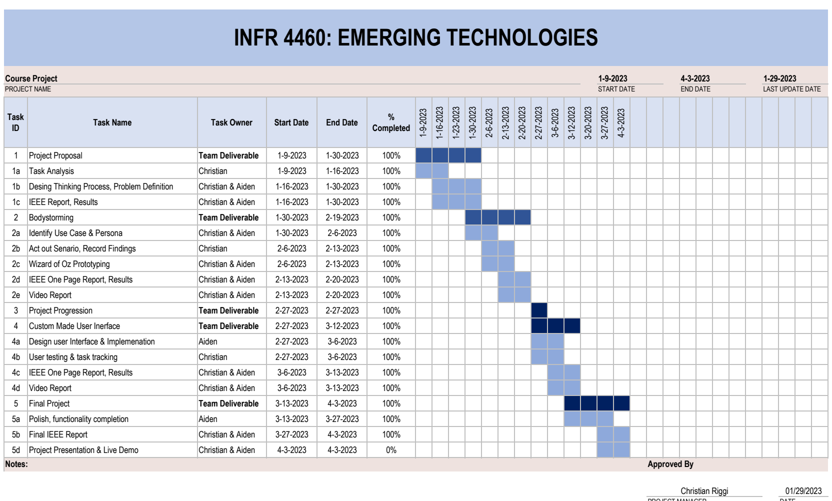


Fig. 1. Image showcasing our initial survey, used to gauge how users felt with their spatial awareness in VR



INFR 4460: EMERGING TECHNOLOGIES

Course Project — PROJECT NAME | **1-9-2023** START DATE | **4-3-2023** END DATE | **1-29-2023** LAST UPDATE DATE

Task ID	Task Name	Task Owner	Start Date	End Date	% Completed
1	Project Proposal	**Team Deliverable**	1-9-2023	1-30-2023	100%
1a	Task Analysis	Christian	1-9-2023	1-16-2023	100%
1b	Desing Thinking Process, Problem Definition	Christian & Aiden	1-16-2023	1-30-2023	100%
1c	IEEE Report, Results	Christian & Aiden	1-16-2023	1-30-2023	100%
2	Bodystorming	**Team Deliverable**	1-30-2023	2-19-2023	100%
2a	Identify Use Case & Persona	Christian & Aiden	1-30-2023	2-6-2023	100%
2b	Act out Senario, Record Findings	Christian	2-6-2023	2-13-2023	100%
2c	Wizard of Oz Prototyping	Christian & Aiden	2-6-2023	2-13-2023	100%
2d	IEEE One Page Report, Results	Christian & Aiden	2-13-2023	2-20-2023	100%
2e	Video Report	Christian & Aiden	2-13-2023	2-20-2023	100%
3	Project Progression	**Team Deliverable**	2-27-2023	2-27-2023	100%
4	Custom Made User Inerface	**Team Deliverable**	2-27-2023	3-12-2023	100%
4a	Design user Interface & Implemenation	Aiden	2-27-2023	3-6-2023	100%
4b	User testing & task tracking	Christian	2-27-2023	3-6-2023	100%
4c	IEEE One Page Report, Results	Christian & Aiden	3-6-2023	3-13-2023	100%
4d	Video Report	Christian & Aiden	3-6-2023	3-13-2023	100%
5	Final Project	**Team Deliverable**	3-13-2023	4-3-2023	100%
5a	Polish, functionality completion	Aiden	3-13-2023	3-27-2023	100%
5b	Final IEEE Report	Christian & Aiden	3-27-2023	4-3-2023	100%
5d	Project Presentation & Live Demo	Christian & Aiden	4-3-2023	4-3-2023	0%

Notes:

Approved By

Christian Riggi — PROJECT MANAGER | 01/29/2023 — DATE

Fig. 2. Image showcasing the Gantt Chart which we used to track the progress of the project and deliverables.

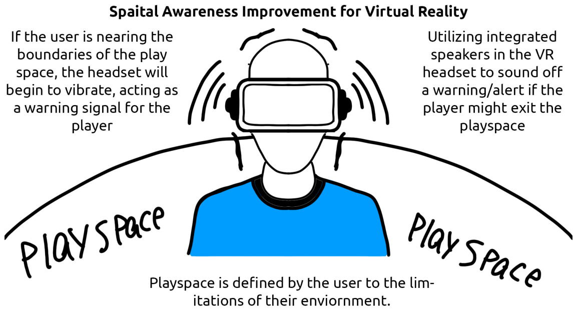


Fig. 3. Early stage concept art of our prototype.

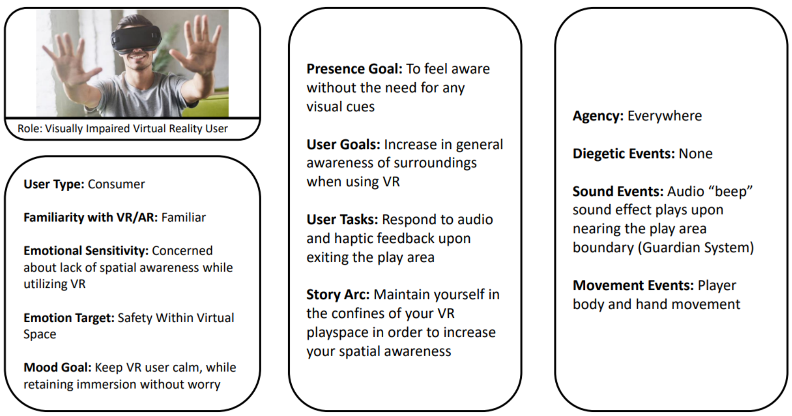


Fig. 4. Image showcasing the "Persona" of our intended users for our product.

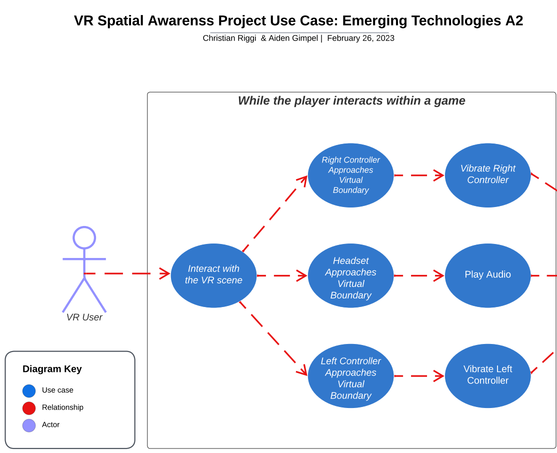


Fig. 5. Image showcasing the use case of a user interacting with our prototype.

Paticipant	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
	I think that I v	I found the	I thought the syst	I think tha	I found the	I thought there	I would imagine tha	I found the	I felt very c	I needed t	Score
1	1	2	2	2	4	4	4	2	2	2	52.5
2	4	1	5	1	5	1	5	1	5	1	97.5
3	2	1	3	3	4	2	4	2	3	3	62.5
4	5	2	4	1	4	2	5	1	4	1	87.5
5	4	2	4	2	2	2	4	2	4	2	70
6	3	2	4	2	4	1	4	1	4	2	77.5
									Average:		74.58

Fig. 6. Image showcasing the average SUS score from 6 users who tested our project.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Disagree	1	2	0	2	0	2	0	3	0	2
Disagree	1	4	1	3	1	3	0	3	1	3
Neutral	1	0	1	1	0	0	0	0	1	1
Agree	2	0	3	0	4	1	4	0	3	0
Strongly Agree	1	0	1	0	1	0	2	0	1	0

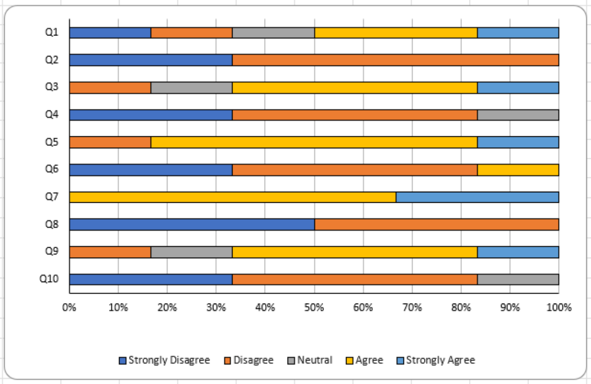


Fig. 7. Image showcasing the SUS results for even and odd-numbered questions as a bar graph.

	B	C	D	E	F	G	Individual Scores							
							Weighted							Raw/Unweighted
User #	Mental	Physical	Temporal	Performance	Effort	Frustration	Mental	Physical	Temporal	Performance	Effort	Frustration	Mean*	Mean*
0/Ex	55	10	75	25	80	40	165	10	225	125	80	80	45.67	47.5
1	10	10	10	30	10	10	0	0	0	0	0	0	#DIV/0!	13.3333
2	20	10	10	70	20	20	0	0	0	0	0	0	#DIV/0!	25
3	30	10	10	90	20	20	0	0	0	0	0	0	#DIV/0!	30
4	70	20	10	90	20	60	0	0	0	0	0	0	#DIV/0!	45
5	20	20	20	100	40	70	0	0	0	0	0	0	#DIV/0!	45
6	20	70	20	60	20	10	0	0	0	0	0	0	#DIV/0!	33.3333

Fig. 8. Individual TLX scores taken from users who tested our project.

Raw/Unweighted	
Overall	19.17
Diagnostic Subscores	
Mental	28.33
Physical	23.33
Temporal	43.33
Performance	73.33
Effort	21.67
Frustration	31.67

Fig. 9. Raw/Unweighted diagnostic scores calculated from individual scores on the TLX questionnaire.

	Related Questions	User 1	User 2	User 3	User 4	User 5	User 6	User 7	Average Per Category
Realism	3 + 4 + 5 + 6 + 7 + 10 + 13	31 / 49	46 / 49	31 / 49	41 / 49	40 / 49	44 / 49	39 / 49	38.85714286
Possibility To Act	1 + 2 + 8 + 9	20 / 28	28 / 28	19 / 28	25 / 28	22 / 28	25 / 28	23 / 28	23.14285714
Quality of Interface	14 + 17 + 18	6 / 21	3 / 21	6 / 21	8 / 21	8 / 21	5 / 21	4 / 21	5.714285714
Possibility To Examine	11 + 12 + 19	13 / 21	15 / 21	15 / 21	18 / 21	15 / 21	16 / 21	20 / 21	16
Self-evaluation of Perfor	15 + 16	8 / 14	14 / 14	12 / 14	12 / 14	11 / 14	13 / 14	12 / 14	11.71428571
Sounds	20 + 21 + 22	15 / 21	19 / 21	14 / 21	17 / 21	16 / 21	18 / 21	16 / 21	16.42857143
Haptic	23 + 24	10 / 14	13 / 14	11 / 14	12 / 14	11 / 14	12 / 14	11 / 21	11.42857143
Total (Out of 168)		112	153	117	138	128	144	138	
Average	132.8571429								

Fig. 10. Scores from each participant on the presence questionnaire, culminating to an average of 132.86