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Utilizing Immersive Technologies in the Air Traffic Control Domain

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The Federal Aviation Administration (FAA) holds a vital role in the United States, employing over 14,000 Air Traffic Control/Management (ATC/ATM) specialists responsible for managing roughly 43,000 flights each day. ATC education "wash-out" rates have shown that there is a disconnect between the training process and the implementation of cognitively demanding, safety-critical ATC duties. The purpose of this research was to investigate if, how, and where immersive technologies (i.e., augmented, virtual, and mixed reality) could be helpful within the ATC/ATM educational domain. To accomplish the overall research goal, subject matter expert (SME) interviews were conducted and a potential educational tool was developed and tested in two distinct research phases. Eighteen (N = 18) subjects volunteered to participate throughout both phases, and the tool was rated to be above average meaning the tool is usable in its current form; however, further development is suggested and expected.

In order to become an air traffic controller (ATC), potential candidates undergo a rigorous training process to prepare for the fast-paced, cognitively demanding, and high stressed safety-critical work environment. Despite a large number of interested applicants, training facilities experience "washout rates" as high as 70% (FAA, 2018). This inevitably increases the demand for newly trained ATCs who have successfully completed training; therefore, timely and effective training is imperative in order to meet the current demand.

During the early stages of immersive technology development, Kozak, et. al (1993) was noted as the first to investigate the use of VR within the air traffic control/management (ATC/ATM) domain. Although immersive technologies showed immense potential, insufficiencies in VR displays prevented these formats from being accepted as useful training tools. In recent years, immersive technologies have proven to be an incredibly beneficial learning tool in other complex domains (i.e., military (Bhagat, 2016), medical (Loukas, 2013), and engineering (Wickens, 2018)). This information combined with additional insights from Mackay, et. al (1999), Hoc, et. al. (1998), and the National Research Council's (1998) report on the future of air traffic control led the current research to adopt an exploratory research design aimed at confirming the statement made by Akselsson, et. al. (2000), that immersive technologies now possess the necessary capabilities to serve as effective tools within the ATC domain.

Methods

Research Design. The primary purpose of this research was to investigate the use of immersive technologies (i.e., augmented, virtual, and mixed reality) within the ATC/ATM domain and to determine where these technologies can be best integrated into an educational environment. To accomplish this, two distinct research phases were adopted. First, Phase I sought to gather contextual information about the potential of such tools; while Phase II sought to provide a potential solution in the form of a technological tool.

Participants. In total, eighteen (N = 18) subjects volunteered to participate throughout both phases. Ten (n = 10) participants engaged as subject matter experts (SMEs) interviewees while eight (n = 8) engaged in user-testing consisting of three males and five females with an average age of 23.5 years old (± 3.7). The only restriction was that all qualified participants must be of legal age (i.e., 18 years old) or above during the time of participation. It should be noted that due to COVID-19, special considerations were required.

Apparatus and Equipment. During Phase I & II semi-structured interviews, computer-based notes were taken and cross-referenced with audio recordings to ensure accuracy. During the data collection portion of Phase II, a web-based pre-survey tool was used to gather basic demographic information and gauge familiarity with the ATC/ATM domain and immersive technologies. A post-study questionnaire was administered upon completion of the interaction, with the incorporation of the System Usability Scale (SUS). Bangor (2008) and Lewis (2009, 2018) states that the SUS allows for the evaluation of a wide variety of products and services. With respect to the VR immersive tool development, an open-source 3D modeling engine, Blender, and a game engine, Unreal Engine 4 (UE4), were used. While an Oculus Quest 2 head mounted display (HMD) was used to display the developed tool to users in Phase II.

Procedure

The following components of the research will be divided into sections to provide sufficient detail related to specific aspects of the research.

Phase I. Prior to performing Phase I activities, a literature review was conducted to inform questions presented to SMEs during semi-structured interviews. It was necessary to develop a thorough understanding of the required approaches in designing and developing novel technology solutions for use in ATC trainee usability studies. Subsequently, technical experts who specialize in human-computer interaction and cognitive engineering were selected for engagement. Interviewees were asked to openly discuss their thoughts on the use of immersive technologies in the ATC/ATM domain.

Phase II. First, a second round of semi-structured SME interviews were performed to gain a rich understanding of what a future educational tool should do to help the ATC/ATM domain. Through consultation, it was clear that developing a map memorization tool would be the most beneficial to the ATC/ATM educational domain, and VR Avenue would be most suitable for testing spatial cognition This also provided greater control of software scalability and expandability.

Tool Development. A cross-platform modular approach provided the greatest flexibility for development. This workflow allowed for interaction techniques and mechanics developed for the initial prototype to be extended across future iterations of the tool.

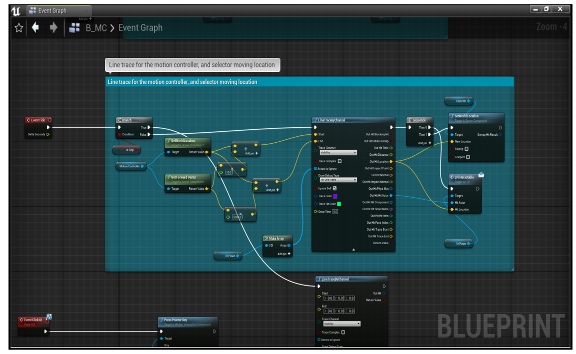


Figure 1. Unreal Engine Development

Several design and user considerations (i.e. color, feedback, and intended population) impacted development. The color palette implemented coincides with the colors used by the FAA on official IFR maps ATC industry standards without overstimulating the user. As for feedback, visual feedback was chosen to guide and caution the user. Considering intended-populations, the interface is predominantly geared towards corrective lens users and right-handed users although users with glasses and left-handed individuals can still utilize the tool with minor adjustments.

With respect to software development, a selected sectional (provided by the *FAA's Aeronautical Information Services Aeronautical Chart Users' Guide)* was uploaded and populated with critical information in layered form. Figure 1 above represents visual snapshots of development within the Unreal Engine software. To maintain the accuracy of the data embedded in the prototype, a multi-step workflow was used to extract symbols from a geographic information system (GIS) and import into the game engine. Many data points, such as intersection points, were identified by target points in the software. Since these could not be extracted, 3D models were developed that could be placed on the markers so that their relative coordinate space was identical to the GIS imported markers. Finally, the layers were exported from Blender as 3D models (.fbx) and imported to UE4 for game engine manipulation and packaging. UE4 is a necessary choice for creating interactive immersive reality applications using the desired geographical data, and does not allow for GIS plugins, as it references its unique coordinate system that defines the architecture of the engine. However, the object models exported from Blender can be imported and scaled in UE4; and mechanics can be developed for data interaction.

Table 1. Usability Study Tasks

Task Number	Task
1	Rotate controls left-right move up-down, move forward-back
2	Find and select the help menu, then tell us what the controller says
3	Toggle the laser pointer off then on
4	Point the motion controller at map data and confirm that the map data illuminates
5	Toggle on/off the layers menu
6	Turn off victors, intersections, and NAVAIDs
7	Turn off ALL layers and Turn on ALL layers
8	Find and name all 6 Airspaces
9	Find and name 5 airports in the Columbus 3 MOA airspace
10	Name the 4 victor lines coming from Greenville
11	Find Airport Columbus AFB, Tell us its information

Usability Tasks: A pre-study survey asked users to rate their ATC-relevant skills such as memorization and the ability to understand new technologies quickly on a 5-point Likert scale. Participants were also asked if they had any specific ATC experience. Users performed a task analysis intended to explore and test the functionality of the platform, control manipulation, and interface design and interaction. Table 1 outlines the tasks presented to each user within the ATC VR HMD which increased in difficulty as the evaluation progressed while Figure 2 represents a user interacting with the tool within the experimental environment and point-of-view perspectives of the actions performed.

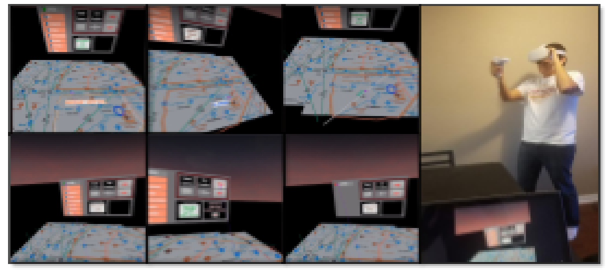
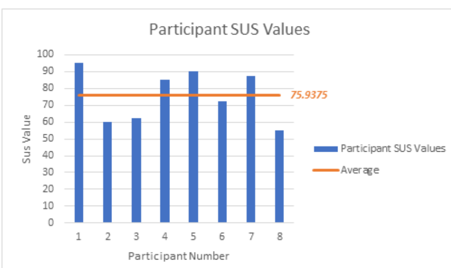


Figure 2. VR ATC Point of View and User Interaction

Results

A collection of information was obtained in various forms to draw meaningful conclusions with respect to confirming that immersive technologies now possess the necessary capabilities to serve as effective tools within the ATC domain. Feedback from SME interviews and design recommendations have been discussed in previous sections; therefore, the following sections will report results pertaining to the user-testing and usability aspects of the research. Using the Systems Usability Scale (SUS), participants were asked to score 10 items with one of five responses that ranged from Strongly Agree to Strongly Disagree.

Interpretation of SUS scores required calculations to normalize raw scores to produce a percentile ranking. Research states that a SUS score above 68 is considered above average while a score below that threshold would be considered below average indicating the user rated the platform to be unusable to some extent. As can be seen in Figure 3, the average SUS score for the developed VR HMD ATC map visualization tool was 75.93 with a standard deviation of 14.41.



SUS SCORE	GRADE	RATING	
95	A	Excellent	P1
60	D	Poor	P2
62.5	D	Poor	P3
85	A	Excellent	P4
90	A	Excellent	P5
72.5	B	Good	P6
87.5	A	Excellent	P7
55	D	Poor	P8

Figure 3. Participant SUS values

This indicates that the tool was rated to be above average. Higher scores on odd questions add to a SUS score while higher scores on even questions result in decreased SUS values. As can be seen in Figure 4, odd-numbered questions scored higher while even-numbered questions scored less on average, resulting in a higher overall SUS score. Of particular note, Question 4 asks

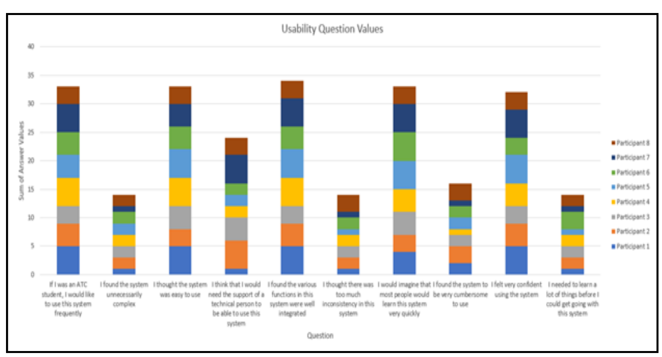


Figure 4: Stacked Bar graph with SUS values

whether users feel as if they would need the support of a technical person when using a system. This question scored around twice as much than its corresponding even-numbered questions. It can be inferred that there were some problems with explaining how the tool worked and/or it did not have enough built-in to be self-explanatory.

Discussion

Analysis of the post-survey demonstrates that the visualization tool is beneficial. All users liked the look of the product and six rated a positive interaction rating with the product, while the other two users gave a three out of five rating. Users found the tool easy to use, not unnecessarily complex, and felt the features were well-integrated. The GUI was found to be informative and clear to understand. One user asked to have "*a mutual guide to scaffold learning in the environment.*" Implementing a training/instructional element to the visualization tool can help satisfy this comment. Additionally, when asked about their overall interaction with the visualization tool, users had relatively positive comments.

Many users found the visualization tool, after a brief learning process, to be fairly easy to use and helpful. The question: "*Would you need the support of a technical person to use this product*" was the only one met with a mixed response. Three users felt that they needed the help of a technical person while using the tool while four users did not feel this need. It can be determined that the tool would benefit from a tutorial program that clearly shows how to use the visualization tool. Many users suggested that a search bar be implemented into the interface. Other suggestions included a map legend and bigger text. Majority users asked for brighter, friendlier colors, however, air traffic products do not use bright colors and many SMEs point to not using color at all. The improvements made in this iteration of the visualization tool will help bring a more effective tool to the intended population of users (i.e. intermediate and expert ATC/ATM specialists) which will then aid in creating a more effective final product.

Conclusion

The current exploration yielded information that will be extremely useful in the continuation of this tool's development and the development of future modules (i.e., AR map visualization and other tools for early ATC training). The team was able to build and test a VR educational tool with a novice population and gain a better understanding of the usability of such a tool within this context. This stage consists of the overall exploration of utilizing immersive tools within the ATC domain. Subsequently, the research team hopes to begin investigating the use of this educational tool and other immersive technologies (i.e. AR) with an ATC/ATM intermediate and expert population.

Acknowledgements

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