Integration of Virtual Reality with Intelligent Tutoring for High Fidelity Air Traffic Control Training

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Abstract: Air traffic control plays a significant role and service by ground-based air traffic controllers (ATC) in providing specific and clear advisory guidance to pilots at every stage of a flight. Specifically, the air traffic control purpose is to ensure safety procedures and protocols are adhered to avoid collisions, and to ensure organized and systematic flow of air traffic on the ground and in the air. In this paper, we present the design and implementation of an immersive and collaborative Virtual Reality (VR) training platform that is scalable and cost-effective compared to traditional method of training ATCs in a physical mock-up of a 360-degree air control tower simulator. The use of immersive VR technology through Head Mounted Display (HMD) would not only solve the space constraints but also immerse users in their tasks while supporting better management and analysis of the complex data produced during training. Through the integration of intelligent tutoring that actively tracks the training progress of the trainee, the system facilitates personalized training that has been shown to significantly improve the learning experience.

1 INTRODUCTION

Virtual reality (VR) is increasingly being adopted as a technology choice to enable users to experience the immersion of a virtual world through 3D near-displays. The advance in technology allows VR to be embedded into education curriculum, to train trainees with varying competency levels (from novice to experts) on complex and multi-faced scenarios within a controlled and safe environment. There are many advantages that come with a VR-enabled training environment, such as enhancing learning engagement and interactivity. providing diversified multi-modal training (off site and on site) resulting in smaller physical footprints and space use, and allowing trainees multiple repeats of the training/procedures at their own pace and time. The use of VR can also circumvent the need of a large physical space for training, or to reduce or eliminate the inherent risk to the training, especially in the area of aviation training. However, many of the VR training systems lack architectural support for personalized training which has been shown to significantly improve user's learning experience. In this paper, we describe the development of a VR platform that reproduces an air traffic control tower in an interactive and immersive environment. It aims to seamlessly integrate the benefits of intelligent tutoring to enable the system to automatically track, guide and diagnose the trainee's progress in terms of his/her learning experience. Based on the performance of the learners, the system will progressively adapt the instructional activities to ensure that proficient level of competencies is achieved at every stage of the training.

2 BACKGROUND AND CHALLENGES

This section highlights some past works that were done in air traffic control training. Specifically, it discusses the use of multiple fidelity simulations that help orientate trainees in understanding air traffic control processes and activities, including voice phrases to use in guiding pilots when landing and

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taking-off. It highlights some challenges of existing simulation methods and how VR presents an attractive and cost-effective solution for personalized training through the integration of intelligent tutoring system.

2.1 Air Traffic Control Training and Simulations

Air traffic control training covers a wide spectrum of concepts and operations that collectively equip the controllers to handle how air traffic flows are directed and orchestrated. In addition to learning the academic aspect of the work, they are required to perform on-site facility training. Therefore, the use of simulation in training becomes an important bridge to fill the gap between academic theory and on-site facility training in which real-time traffic data will be used and procedures exercised. The simulation training in tower traffic control needs to be highly visual and immersive that closely matches on-site facility training.

The training of ATCs goes through a four-stage process. The air traffic academic course uses classroom instruction to introduce the basic concepts of aviation and air traffic control. The part-task training consists of lectures and basic laboratory activities. It introduces more complex aspects of air traffic control with some hands-on activities using low to medium fidelity simulations. In the next phase of skill building training, trainees are exposed to high fidelity simulation environment that closely replicates the control tower in the form of 360-degree air traffic control tower simulator similar. The final stage of the training is to expose the trainees to the on-site facility with close monitoring and supervision.

2.2 Challenges

To train the air tower traffic controllers, the training centre is equipped with an air traffic control training tower setup that provides 360 degrees simulation of a traffic control room (Aerospace Operations Division. 2018). The physical room is installed with 360 degrees projected screen of the airfield and its surrounding. However, there are four main challenges with these kinds of simulation-based training systems:

- The size of the control room often limits the number of air traffic control tower trainees that can be trained at any point in time. As a result, the trainees have limited hands-on learning in such a highly skilled and detail-oriented role.
- The training is often restricted to allocated pockets of slots, while the remaining time is spent on academic aspects of the training.
- In the training control room, at least one instructor needs to be present to coordinate the training procedures and operations. He or she is required to orchestrate complex scenarios of plane landing, taxiing, and departing. Additionally, unexpected scenes such as change of weather or accidents may be injected to the scenario to simulate unexpected turn of events. All these translate to the need for the instructor to be present which may form a bottleneck in the training process which does not facilitate a trainee to practice independently.

While the control room provides realistic and high-fidelity simulation of the air traffic and control in a classroom setting, it does not track or monitor the learning progress of trainees. As such, personalized instructional quality of the training may be lacking.

3 IMMERSIVE SOLUTION FOR AIR TRAFFIC CONTROL TRAINING

Air traffic control is a demanding work requiring intensive training in an immersive environment that simulates the actual on-site facility. Although the 360-degree air traffic control tower provides an immersive environment and experience to train the controllers, the prohibitive cost and limited availability of such facilities make it not readily accessible to the trainees. As such, there is a need to find new techniques that bridge the technological gap of providing immersive experience in training air traffic control tower trainees and making the solution scalable and accessible.

3.1 Virtual Reality Platform

In this project, we aim to build a VR platform that reproduces an air traffic control tower in an interactive and immersive environment. Importantly, the platform aims to enable anytime, anywhere and anyplace access to hands-on training in a distributed and multisensory operating environment. Equally important, the platform aims to replicate the actual learning environment as much as possible to ensure learning is not compromised.

Air traffic control is a highly skilled and spatial work. In addition to equipping Singapore with state-of-the-art research in this area, we believe it is equally important for us to beef up on the training of the workforce to cope with the increased number of flights and traffic as Singapore continues to position itself as the transport hub in the region.

4 BENEFITS

On-the-job-training alone is one model that does not fit well with air traffic control training. Instead, the use of advanced simulation devices and setup in a controlled environment is required and utilized in every phase of air traffic control training programs.

Specifically, the following are the benefits:

- Scalability and Low Cost. The number of available simulators will eventually affect the number of air traffic controllers that can be trained. In order to meet the demand, current simulation practices and equipment need to be evaluated.
- Sustainable High-Fidelity Simulations and Training. Training like the 360-degree air control tower requires high setup cost and space which can create a bottleneck to high-fidelity training. In addition, these systems are often expensive to run and maintain which will make maintenance and simulation updates more challenging.
- Self-paced and Independent Learning. Projected increases in air traffic controllers will require innovative ways to provide quality training that supports intelligent and personalized tutoring. The VR system may employ speech recognition and synthesis to provide guided instruction in training complex scenarios without the physical presence of the instructors.

5 SYSTEM ARCHITECTURE

Shown in Figure 1 is the system architecture of the implementation setup that encompasses the intelligent tutoring system and the virtual reality simulation engine. The simulation engine is comprised of the standalone VR headset that is worn by the trainee. Instead of using the built-in speakers and microphone of the Oculus Quest VR headset, the trainee is required to wear a Bluetooth-based headset to ensure high fidelity reception of sound and pickup of voice signals. Audio signals from the headset are streamed directly to and from the desktop server via

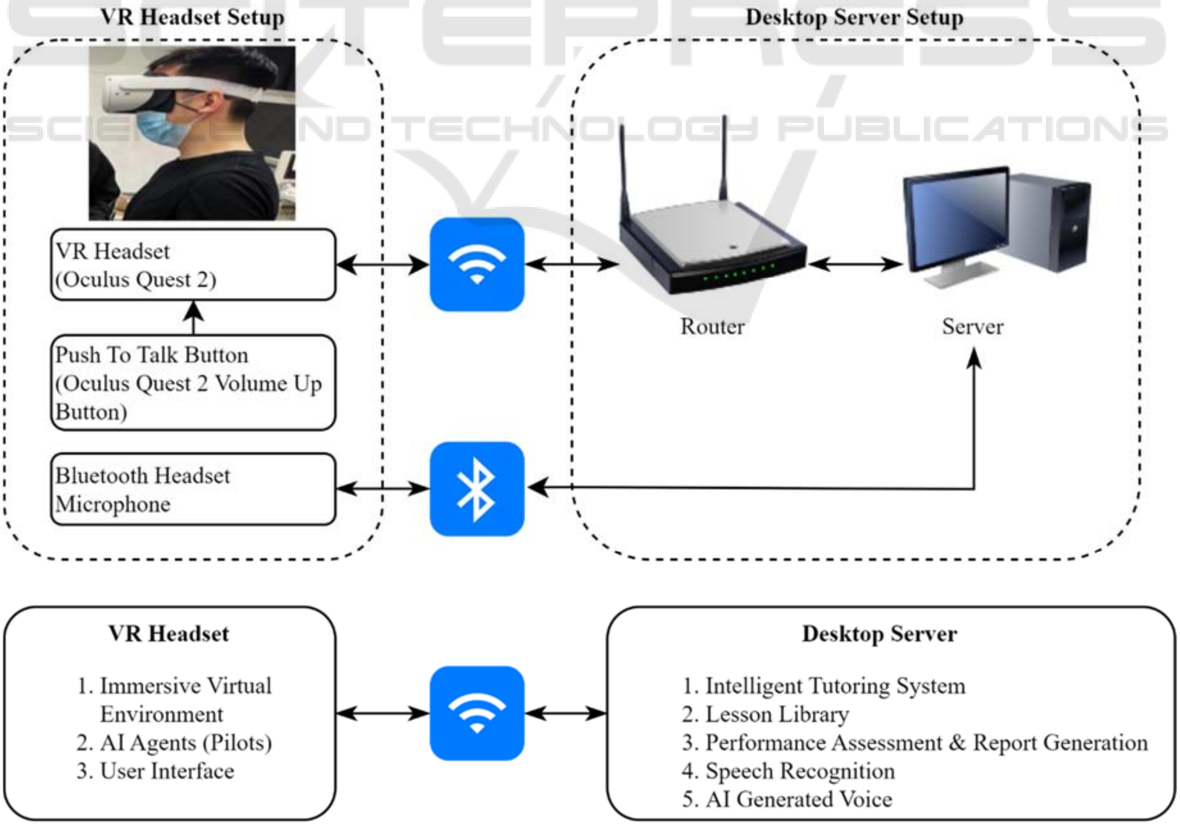

Figure 1: System Architecture.

Bluetooth protocol. To facilitate communication between the traffic controller and pilot, the volume up button of the VR headset is used as the *push-to-talk* button to emulate switching from voice mode to transmit mode. The VR headset is connected to the desktop server via the Wi-Fi router to provide cross-platform device communications through TCP/IP communication protocols. AI software agents are proxy agents that are used to generate responsive, adaptive and behaviours of pilots as non-player characters with human-like intelligence. These agents that are hosted within the VR headset are controlled by the intelligent tutoring system that is residing in the desktop server. The limited computing capacity of the VR headset is unable to handle speech recognition and AI voice generation (Bakhturina et al., 2021). As such, the digitized audio signals (streamed to and from the Bluetooth headset) are processed within the desktop server that is equipped with GeForce RTX 3080 GPU processor to deliver high performance and near real-time speech and voice processing. The programs within the VR headset are created with C++ and running in an Unreal engine environment while the programs within the desktop server are created with Python in a Linux environment. The setup allows a single desktop server to serve multiple clients.

6 INTELLIGENT TUTORING SYSTEM

Figure 2 above shows the Intelligent Tutoring System, as a core component of the development that drives the training processes and learning pedagogy of the air traffic. This system can be viewed as a 'human tutor', backed up with a complex virtual architecture (with data analytics) to address to the needs of the learners. The system is comprised of three essential modules that closely interact with one another to enable personalized, incremental, and adaptive learning of the training contents. These modules aim to capture three types of knowledge that include 1) the expert knowledge of the content structure and its atomic content inter-dependencies 2) knowledge about the trainee's competencies and progression, and 3) knowledge of the teaching environment and learning pedagogy of the training. In addition, the ITS is furnished with the user interface module that agglomerates various user interfaces to track and monitor trainee's interaction with the system through hand gesture tracking, gaze tracking, voice interaction and text prompt, among others.

(Yuce et al., 2019). The system is comprised of three essential modules that closely interact with one another to enable personalized, incremental, and adaptive learning of the training contents.

6.1 Expert Knowledge Module

The expert knowledge module captures the lessons' flow and contents from the perspective of a domain expert. The domain expert in this case is the air traffic controller training model that represents the lesson content, facts, concepts, and training rules that would progressively equip the trainee to acquire knowledge and skills in the domain. The knowledge captured is derived from a domain expert that is comprised of not only the lesson content on Air Traffic Control but also the possible phrases that are valid ATC phraseology.

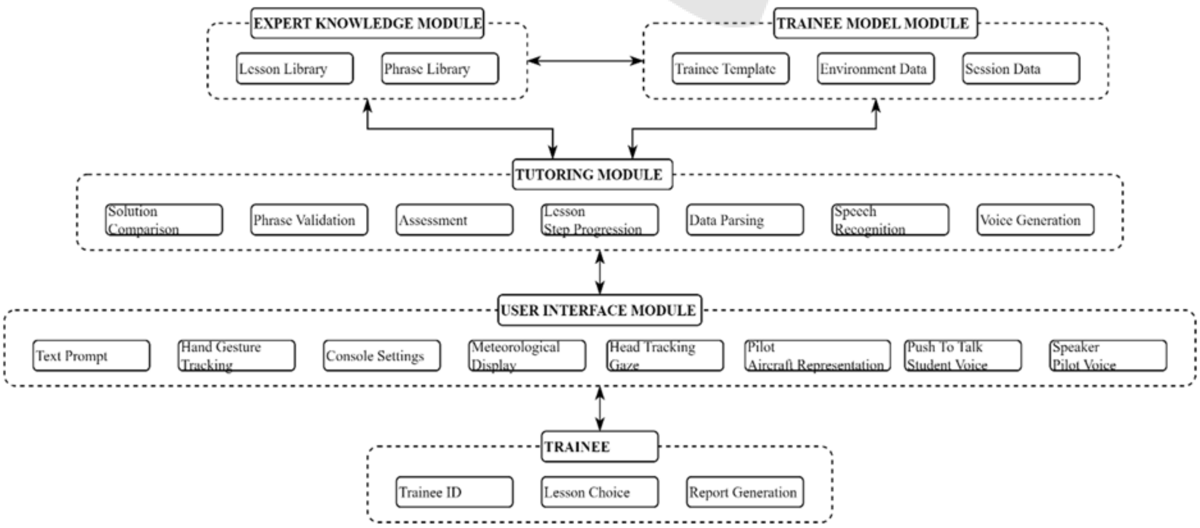

Figure 2: Intelligent Tutoring System.

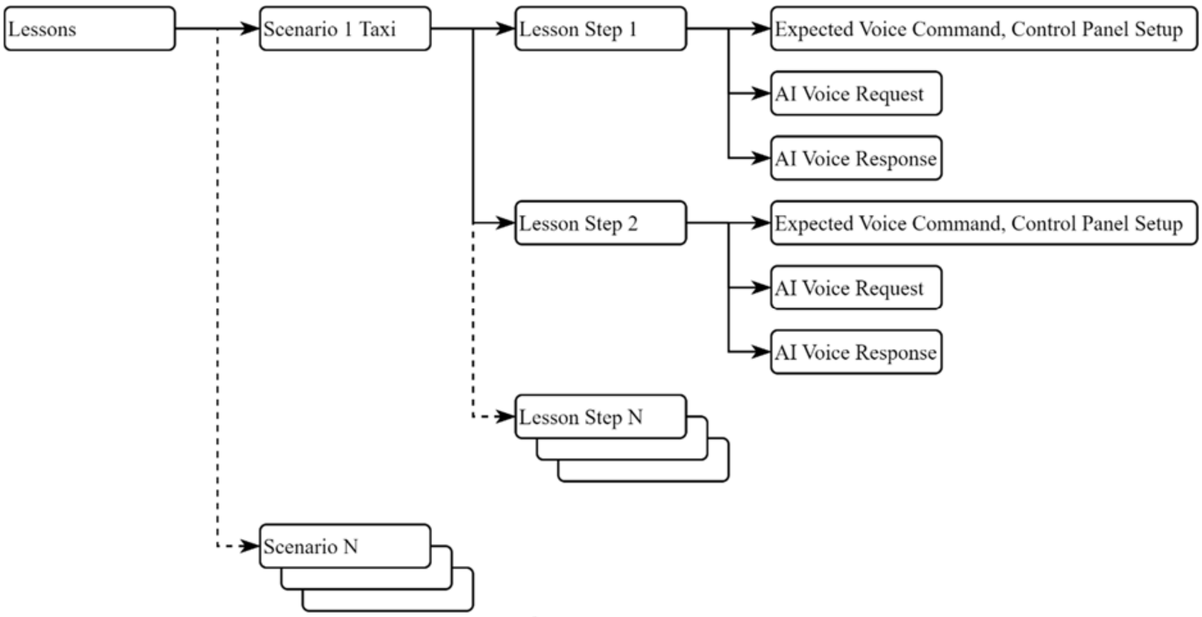

Figure 3: Expert Knowledge Module.

Figure 3 shows how the lessons' contents are organized in the domain expert module. The logical lesson progression is based on the concept of Zone of Proximal Development in which trainees familiarize themselves with basic taxi procedures, console controls and the aerodrome environment to handling difficult scenarios that involve conflicts and accidents. The use of text prompts guides the trainee on what phrases to use to respond to pilot. Each scenario comprises of lesson steps which in turn comprises of necessary information for the ITS to facilitate users' learning experience.

6.2 Trainee Model Module

An instance of the trainee's profile is retrieved whenever the trainee logs on to the system and starts a lesson. If the trainee is newly recognized, a template of the trainee model is created, and its environment data is populated from that of the attributes from the expert data together with the session data. The environment data in the trainee's profile helps the expert knowledge module to understand the context of the training and the trainee's learning experience and progress. For example, an important attribute being tracked is the location of the aircraft that is used as a signal to initiate pilot requests. This is because each location in the aerodrome environment has a specified phrase associated with the lesson type. The session data stores all performance assessment data of the trainee to be processed at the end of the session.

6.3 Tutoring Module

Figure 4 shows how the tutoring module helps to disseminate information from the expert knowledge module to the user interface module and vice versa. Specifically, it provides personalized tutoring to the trainee based on the trainee profile and learning progress. Essentially, it emulates a human-like tutor to decide how to teach and what to teach as it progressively equips the trainee with the necessary knowledge and skills to become a competent air traffic controller. There are three levels as below where the trainee may fall under their skill sets.

- Trainee cannot accomplish the tasks with assistance. This is when the tasks are outside the zonal proximal development of the trainee in which he/she will not be able to complete the tasks even with guidance.
- Trainee can accomplish tasks with assistance. With additional guidance, the trainee is close to completing the tasks assigned and master a skill set.
- Trainee can accomplish tasks without assistance. Here, the trainee can complete tasks by themselves and has mastered the skill set required.

Figure 5 shows how trainee's voice commands are processed. Voice is transcribed into text by the speech recognition engine residing in the desktop server. The text is then corrected for any spelling errors and each

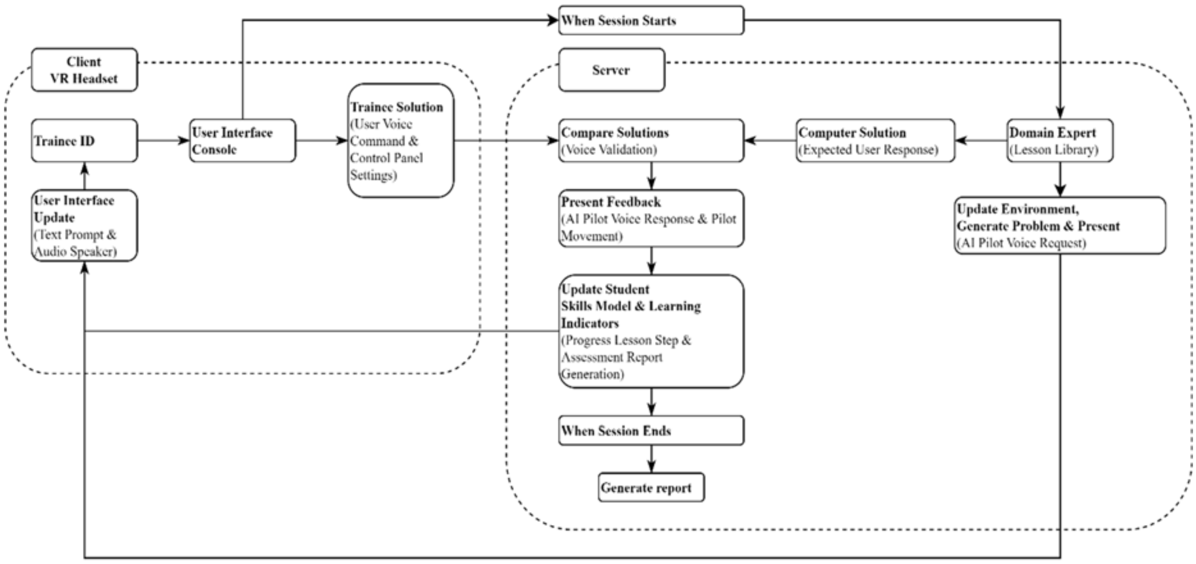

Figure 4: Tutoring Module.

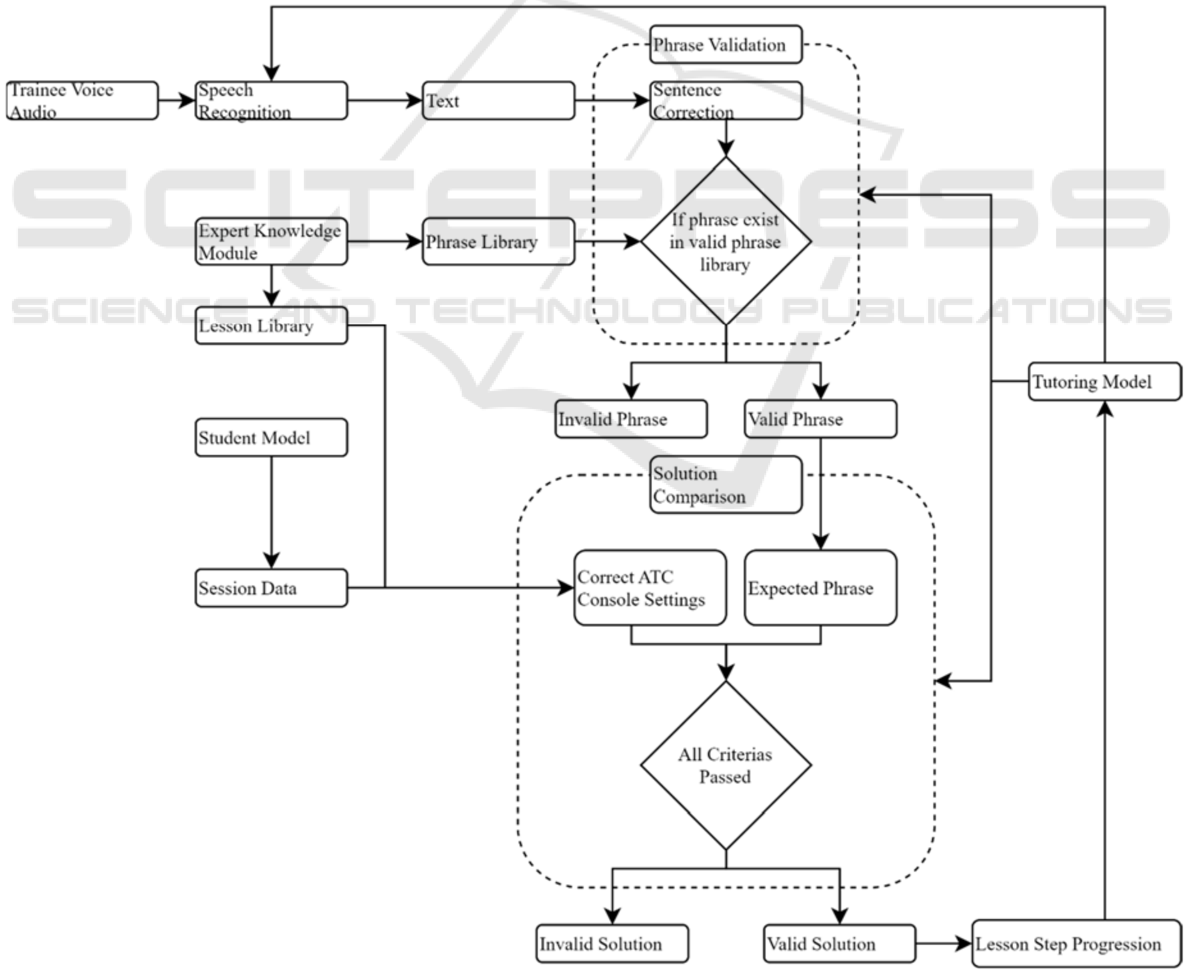

Figure 5: Trainee Solution.

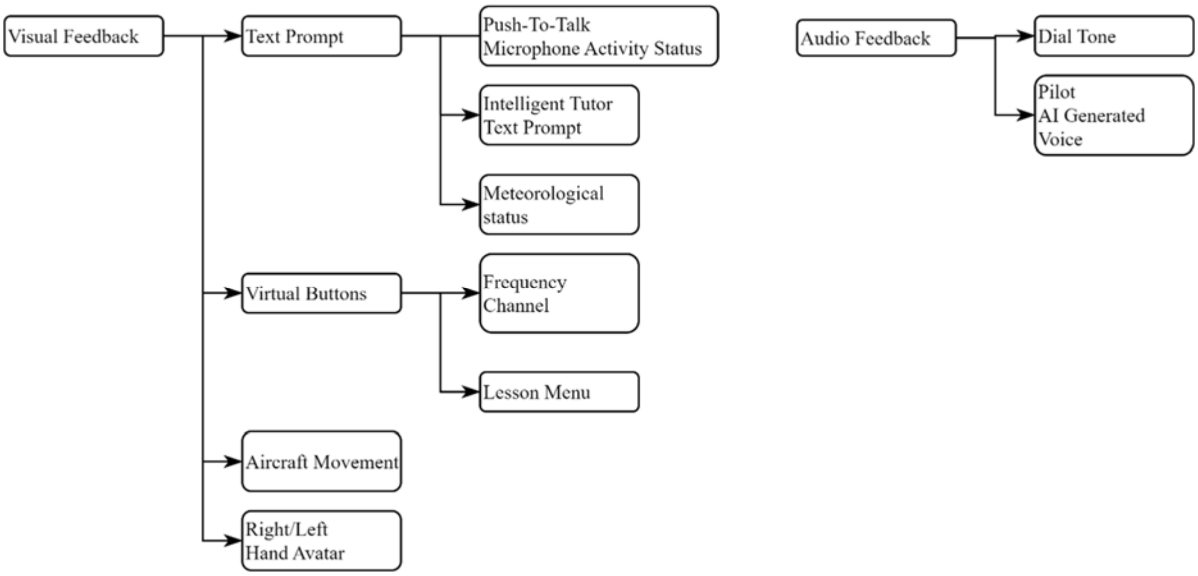

Figure 6: User Interface Module.

word is matched to the closest word that exist in our vocabulary and validated as an ATC phrase (ICAO Doc, 2016). If it is validated as a standard ATC phrase, it is considered a trainee potential solution to be then compared to the expert model solution together with the ATC console settings. If the solutions matched, the performance is recorded and the lesson progresses. To contextualize and boost the transcription accuracy of rare and domain-specific words or phrases, the speech repository is in-house trained with over 7-hours of voice audio data collected.

6.4 User Interface Module

Figure 6 shows the user interface module that is embedded with the necessary components for the trainee to visually study the environment and understand the situation with the ability to communicate and interact with the server via hand gesture tracking and push-to-talk voice. The user's gaze is also tracked via the VR headset headtracking. Since gazes are a natural and intuitive interaction modality for human beings, it allows assessment of trainee's cognitive and visual orientation of the aerodrome as aircraft lands or takes off. This would allow the ITS to understand trainee's level of confidence, immersiveness and learning experience as he/she navigates the air traffic through visual tracking and communication with the pilot. We believe that gaze-based interaction is one dimension in user interface that could enhance trainee's experience by having the ITS track the visual attention of trainee in air space from the control tower. As the trainee progresses until all lesson steps are completed, a report of the trainee's performances is generated for the trainee and ATC instructor to review. The simulated environment includes a panorama view of the airport runway, sight lines and views to all parts of the airfield from the perspective of the control tower. Within the control room, the trainee is able to gain access to various dashboards and control buttons to facilitate proactive monitoring of aircrafts' positions and control status. In addition, it features an application control interface to enable trainee to control, initiate and select the lesson for training (Alkhatlan & Kalita, 2018). To begin a lesson, the trainee is required to enter a login ID for identification via the application control interface which is routed to the desktop server for verification. This allows the ITS to create a profile of the trainee for performance assessment and recording. The domain expert module selects a lesson scenario from its lesson library database and sets up the environment in the VR headset A pilot agent requests a command from the trainee serving as the air traffic controller. A problem is presented as audio request from the ITS controlled pilot. In which case, the trainee is required to appropriately respond to the request by issuing a voice reply through the microphone. After the trainee responds with a voice command, the solution from the domain expert is compared to that of the trainee. Text transcribed through speech recognition engine is compared with the expected user response to validate the voice command from the trainee. If the voice command given is valid, the pilot agent will respond appropriately otherwise, the trainee is informed of his/her error through the user interface.

7 CONCLUSION

Simulation-based training has advanced rapidly over the last decade as computing resources become more available and powerful. This has accelerated the advancement in immersive solutions to provide high fidelity and real-time interactive simulations. Air traffic control is a highly skilled and spatial-oriented work that requires intensive training and hand-on experience in which simulation is used extensively. This project is innovative in bringing air traffic control training to individual trainees in the form of personalized training that can be self-paced and directed towards independent learning. The innovation applied in this project lies in the aggregation of the following approaches:

- The first approach is to apply the concept of composability in the design of the VR simulation engine that supports flexible and configurable objects. This would form the platform for the system to support dynamic configuration of training procedures and scenarios that leads to individualized learning.
- The second approach builds on the first to support multi-model training schemes. The first scheme supports traditional approach of classroom-based and instructor guided training, while the second scheme automates the process through computer guided training by integrating domain expert knowledge and intelligent speech processing.
- The third approach is to apply the concept of intelligent tutoring system to automate monitoring of trainee's learning progress to adapt instruction and contents to facilitate self-paced and independent learning.

In our future publications, we plan to present details of the system implementation and evaluation of various modules, including user experience assessment of the system.

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