Developing an Immersive Virtual Reality Aircrew Training Capability

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ABSTRACT

The Combating Terrorism Technical Support Office (CTTSO) and the Air Force Special Operations Command (AFSOC) are assessing the training effectiveness of an immersive virtual reality part task trainer (vrPTT) for AC -130 cockpit familiarization. AFSOC wants to move AC-130 checklist procedures and cockpit familiarization training from low-density/high-demand weapons system simulators to a widely available, low-cost vrPTT, while simultaneously migrating the tutorial courseware and instructor-led portions of the course to a higher fidelity, more immersive environment. This blended learning vrPTT will allow pilots to receive instruction and immediately proceed to practicing scenarios in a highly realistic, immersive Virtual Reality (VR) environment. It also reduces time in the simulators by allowing pilots to learn the procedures and develop muscle memory. The vrPTT was designed and developed from an extensive front-end analysis, including task performance interviews with AC-130 pilots and instructors. The system consists of a 3D VR representation of the AC-130 cockpit viewed through an Oculus Rift head-mounted display (HMD) and underlying equipment behavior models that produce appropriate responses to pilot inputs. Pilots interact with the virtual control systems via the integration of a Leap Motion infrared sensor that tracks the position and motion of all ten fingers. Tutorial content is laid over the equipment simulation, and an integrated intelligent tutor provides adaptive feedback during a scenario and to adjust the initial instruction for future exercises. This paper describes the front-end analyses performed to create the measures for the intelligent tutor, approaches to overlay courseware in a VR HMD environment, and the overall system required to achieve acceptance by the pilot user group. It also details future phases of this program, including a training effectiveness study comparing a control group of students in the simulator who have not used the VR system to those who have used the VR system.

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INTRODUCTION

Virtual Reality and Training Transfer

Virtual reality (VR) uses advanced computer technology to support real-time multisensory user interaction with a synthetic environment that closely simulates the real world (Dargar et al., 2015; Ganier et al., 2014; Wickens et al., 2013). VR holds promise for delivering effective training based on its ability to simulate the task performance environment with reasonable fidelity at significantly less cost than most physical simulators (Ganier et al. 2014; Wickens et al. 2013). Despite its potential, VR's effectiveness depends on well-planned design and implementation of the technology to ensure it is meeting the training need and performance goals. A poorly designed VR interface, for instance, can lead to misuse of the system or frustrated users who will choose not to adopt the technology, both resulting in a lack of acquisition of target skills (Chellali et al., 2016; Lackey et al., 2016; Wickens et al., 2013).

Training transfer refers to how well newly acquired knowledge or skills can be applied in a novel context. If some information from the training period results in effective task performance on a target (i.e., real-world) task, then it is said the training resulted in positive transfer (Wickens et al. 2013). Measuring transfer provides a valuable means to evaluate the effectiveness of VR training technology.

Research across disciplines indicates VR training may be just as effective as other hands-on training methods. Aircrew checklist training involves hand-eye coordination and complex motor skills. In the medical profession, for instance, research supports the use of VR for training fine-motor and decision-making skills associated with complex surgical tasks (Chellali et al., 2016; Johnson et al., 2011; Nickel et al., 2015). In a study involving interventional radiology skills (Johnson et. al., 2011), 14 medical residents were trained using a traditional apprenticeship method, then half of the participants received VR training on a specific procedure while a control group received only an information sheet on the same procedure. When rated by subject matter experts (SMEs) on the next real-life patient interventional radiology procedure they completed corresponding to the training case, participants who received VR training received a significantly higher overall performance score on the procedure compared to the control group (Johnson et al 2011). In the mechanics field, a study with 42 participants completing a tank suspension system maintenance task that involved a series of discrete fine-motor control procedures found that the VR-trained treatment group performed similarly to a comparison group and both outperformed a no-training control group (Ganier et al., 2014). Time taken to complete the procedure for both the VR group and the conventional training group was significantly lower than the no-training control group. The VR and conventional training groups performed equally well in terms of task completion time. No member of the VR or conventional group consulted the job instructions when completing the task, whereas 10 of the 14 members of the no-training control group consulted the instructions for six minutes on average.

Aircrew VR Part Task Trainer (vrPTT)

The Air Force Special Operations Command's (AFSOC) Counter Terrorism (CT) education and training program can benefit from VR within its existing training program. Currently, the program is deficient in low-cost task trainers and it can improve at building mind and muscle memory skills. At present, academic instruction and learning are accomplished using traditional classroom lecture and discussion, low-density/high-demand (LD/HD) operational aircraft, and full-motion simulators. This trainer deficiency requires commanders to allocate high-demand operational aircraft for training, resulting in reduced availability for real-world CT operations. Similarly, AC-130 mission simulators cannot conduct low-cost, distributed, full-mission profile continuation training and Joint Mission Essential

Task readiness/rehearsal training with geographically separated Special Operation Forces (SOF), Service, and Partner Nation forces. The limited simulator capacity prevents AFSOC from maximizing trainee performance potential through repetitive task exposure. In addition, modern and proven teaching methods, such as experiential learning and game-based learning, are not being used to their full potential. Finally, current education and training methods used to train AFSOC aircrews do not always account for rapid changes in new systems and proficiency skills to enable rapid adaptation to ever-evolving CT tactics, techniques, and procedures (TTPs).

In coordination with the Combating Terrorism Technical Support Office (CTTSO), AFSOC sought a vrPTT solution to overcome this gap by providing a low-cost task trainer that allows AC-130 operators to acquire cognitive skills in an immersive, interactive, and automated VR learning environment.

METHODOLOGY

To design an appropriate VR task training system, the designer must understand how people perform these tasks in terms of requisite knowledge- and skill-based decisions and behaviors. According to Dargar et al. (2015), VR training applications can be classified according to the level of human behavior associated with the task (or tasks) to be trained. Citing Rasmussen (1983), the authors suggest that VR can be beneficial for training skill-based, rule-based, and knowledge-based behavior. Although the levels of human behavior can inform VR system design, cognitive task analysis (CTA) is an important step toward understanding underlying cognitive activity when performing a task and the expertise needed to accomplish critical steps (Klein, 1995). Therefore, the vrPTT design team began the project with a detailed front-end analysis (FEA) to provide recommendations for the establishment and implementation of a vrPTT to assist the copilot crew position in developing task-based muscle memory in support of Copilot Mission Qualification Training (MQT).

Front-End Analysis

As part of the FEA, a detailed job task analysis (JTA) was conducted, linking job training tasks to AF Mission Essential Tasks. This analysis was essential to and the basis for assessing training requirements and designing training programs and systems. Figure 1 illustrates the methodological approach, which was centered on validating training task lists for AC-130U copilots and UMSN-40 (Checklist A) specific task characteristics to determine training requirements. This methodology is based on the instructional systems development (ISD) process described in *Mil-HDBK-29612-2: Instructional Systems Development and Systems Approach to Training and Education* and *AF Handbook 36-2235: Instructions for Designers of Instructional Systems*. The basic ISD process was tailored to meet the unique requirements of this study.

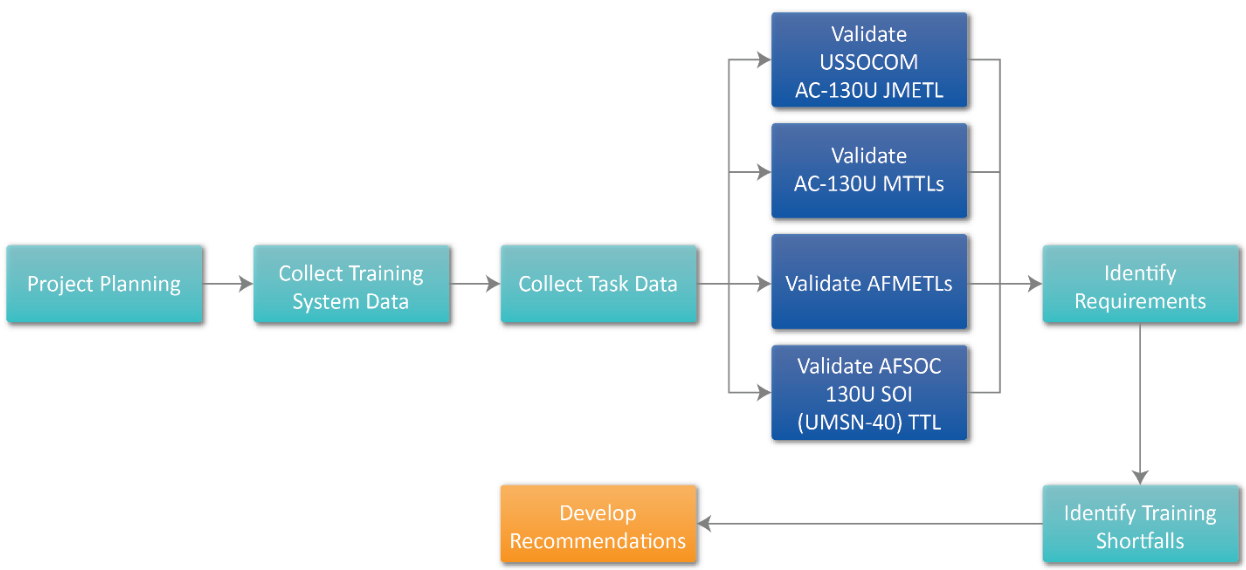

Figure 1. Methodological Approach

Training system and task data were collected at Hurlburt Field, FL, through interviews with instructor SMEs, observations of training devices (e.g., full-motion simulator) in use, and analysis of Government-provided documents. The result of the task data collection was a detailed checklist spreadsheet. This file captured task and subordinate task attributes, task performance outcomes and measurements, and the physical location of task movements while performing each checklist. The training task data for each checklist include:

- Task Identification Number
- Task
- Subtask
- Task Function(s) (i.e., physical, visual, verbal)
- Task Cues
- Location of Task Movement
- Task Performance Indication
- Task Performance Measurement
- Task Difficulty
- Skill Learning Levels
- Knowledge Learning Levels

Following the detailed data collection, the data were validated and used to identify requirements for training those tasks. After examining the current training with respect to the training requirements, the team developed a set of recommendations for the vrPTT system.

The principal recommendation from the FEA was to revise the USMN-40 (Checklist A) lesson to be self-guided, incorporating as the primary means of instruction the vrPTT Level 4 interactive multimedia instruction (IMI). USMN-40 (Checklist A) is currently an instructor-led lesson/discussion focusing on checklist procedures with no mechanism to produce visual stimuli or audio cues for the students to practice procedural tasks. Incorporating the vrPTT would supply full cockpit visualization through an interactive 3D high-definition VR environment integrated with an automated intelligent virtual instructional tutor. This training device would provide a means of building muscle memory and cognitive skills using task performance standards prior to engaging in AC-130 operations. The intelligent tutor could assist students in the performance and feedback capacity that an instructor traditionally provides before they progress to the UMSN-107 full crew mission simulator lesson. As indicated in an Instructor Pilot interview, simulator training time for UMSN-107 averages one hour longer owing to student cockpit familiarization. Incorporating the vrPTT into training would alleviate instructor manpower requirements for the UMSN-40 (Checklist A) lesson and reduce simulator training time for UMSN-107. It would also alleviate the requirements on LD/HD operational aircraft and full-motion simulators.

Design

The AC-130U Copilot Mission Qualification Course, UMSN-40 (Checklist A) lesson will use the vrPTT to allow students to practice all preflight and normal ground checklist procedures, including before starting engines, starting engines, before taxi, engine shutdown, taxi, two-engine shutdown for ordnance loading/downloading, and two-engine starting after ordnance loading/downloading. The students will also perform after-takeoff checklist procedures—sensor alignment, prestrike, post-strike, descent, and before landing—and normal post-landing and engine-shutdown checklist procedures, IAW Technical Order (TO) 1C-130(A) U-1, without instructor assistance. The vrPTT will be a portable system that can be used at any location and include the AC-130U flight deck modeled from flight station 245 forward, including models of the flight deck instrumentation, switches, and circuit breakers.

The projected time for an advanced student to complete all instruction and performance of checklist tasks (base plus both options) is calculated to be 2 hours and 20 minutes. This seat time assumes the student performs each step of each checklist correctly on the first attempt and does not account for additional practice hours initiated by students or additional time required to remediate on failed checklist tasks. Therefore, depending on their initial training state, students may spend anywhere from 25 to 60 additional minutes training with the vrPTT, for a total seat time of 2 hours, 45 minutes to 3 hours, 20 minutes. Based on the projected throughput of eight copilot students per year, the total annual instructional hours for UMSN-40 (Checklist A) will be 22 hours to 26 hours, 20 minutes.

The target audience for the UMSN-40 (Checklist A) lesson is copilots exhibiting the characteristics described in Table 1.

Table 1. Copilot Population Characteristics

CHARACTERISTIC	COPILOT POPULATION
AVERAGE AGE	23
AVERAGE EDUCATION	4-Year Accredited Degree
QUALIFICATION STANDARDS	Copilot students are expected to meet all aircrew Personnel Qualification Standards in accordance with AFI11-202V1_AFSOCSUP.
ATTRITION RATES	No data are available for AC-130U Copilot attrition. The AFSOAWC Pilot Instructor SME indicated that there have been no course drops during his tenure.
CLASS SIZE	The approximate number of projected Copilot students per class is two.
LEARNING/APTITUDE DEFICIENCIES	Initial prerequisite training programs are anticipated to effectively remove students with learning and aptitude deficiencies.
PIPELINE SOURCES	• Graduate of course C130H2PIQ1LP or equivalent. • Mobility pipeline from the C-130 Basic school. • Qualified crew members from SOF mobility programs. • Qualified crew members from Strike programs.
ENTRY-LEVEL REQUIREMENTS	• Currently qualified for flying duty and completed course C130H2PIQ1LP or equivalent. • C-130 Qualified Flight Physical. • Physiological training must remain current for at least 90 days after scheduled completion date. • Survival training: Graduate of SV-86A, Water Survival and S-V80-B, Emergency Parachute training, or equivalent. Students are highly encouraged to complete S-V80A prior to training to prevent mission readiness delays upon graduation. • Must have a Secret security clearance and Top Secret application request submitted by class start date.

When a student starts the vrPTT for the first time, he or she will progress through a demonstration of the trainer and will be instructed on how to use the system, then the checklist selection screen will appear. (For returning students, current progress through the checklists will be shown on the checklist selection screen.) Each checklist will have an instructional mode and a practice mode. Once the student selects the instructional or practice and mode, he or she will be prompted to put on the head-mounted display (HMD) to begin.

Instructional Mode

During the instructional mode, the student will be guided through performing the steps of the checklist. The instructional mode will use text, audio, and cockpit highlighting to present the UMSN-40 instructional content, including the information found in the Instructor's Guide.

Practice Mode

Inside the practice mode, students will have a virtual checklist present on their laps inside the virtual environment. They will be required to progress through the checklist as they would in real life. Some checklist tasks will begin with a realistic prompt from the system, such as an audio file of the engineer calling out the task name. As the student completes a task on the checklist, the intelligent tutor will conduct a persistent performance analysis and provide support in real time, as required. The level and timing of this support depends on the skill deficiency identified by the intelligent tutor. Deficiencies will initially be based on student response time (e.g., amount of time to flip a switch) and may in the future include measurements of the extent of search activity (e.g., amount of motion of goggles). Longer response times and greater search activity are both indictors of lower skill proficiency. Support strategies in the form of hints will occur in both visual on-screen and audio formats based on the skill state of the student.

Additionally, following an incorrect response, the system will provide feedback indicating the correct answer, and will require students to repeat that task or series of tasks correctly (Figure 2). Students will not be given any feedback for correct responses at the completion of the task. Once a student completes a checklist without receiving support from the intelligent tutor on more than 30% of the subtasks, the student will be considered to be fully proficient in the checklist. The vrPTT will provide a main menu that indicates the status of each checklist, including which checklists were successfully completed without any hints, and which checklists must still be completed. A student will graduate from the vrPTT when all checklists have been successfully completed in instructional mode and in practice mode.

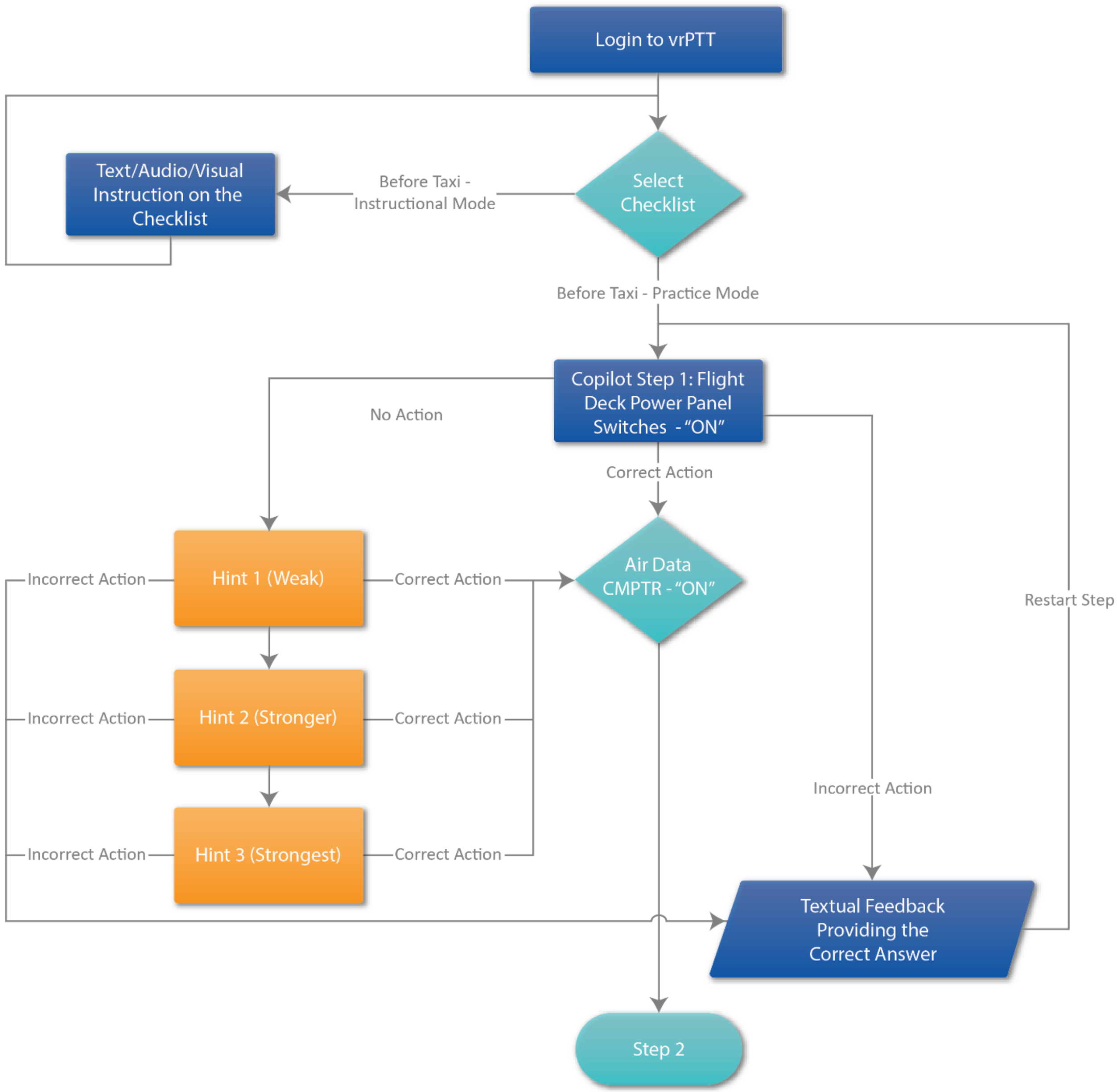

Figure 2. Sample Instructional Flow Through the vrPTT

During a checklist task, student inputs and omissions are recorded by the simulation system and fed to the intelligent tutor via real-time performance data streams. Adaptive learning algorithms will use these data to advance student proficiency over the duration of the course through systematically implemented hints. The intelligent tutor will track and feed student responses and performance over time into the adaptive algorithms, effectively allowing the intelligent tutor to learn about each student and further develop customizable support solutions. The intelligent tutor is based on an adaptive learning approach that improves on traditional branching strategies, as it controls the strategy and timing of hints in real time based on student state. This approach keeps task difficulty in the student's zone of proximal development and therefore eliminates the need for "remediation" in its traditional sense.

Each checklist step has one or more performance tasks associated with it. Some performance tasks can be measured (e.g., the student pushes the correct button), while some must be inferred using performance indicators (e.g., the student looks at the correct gauge and it is inferred the student knows that the gauge shows the correct reading). The intelligent tutor monitors the student time to complete these performance tasks and indicators to determine the student's skill state, which in turn activates the appropriate hints and the timing of their delivery. Students will demonstrate navigational skills and operational knowledge on these tasks and indicators (Table 2). Navigational skills are broken down into two levels: gross and fine navigation, where gross navigation refers to the general proximity of the target instrument, while fine navigation refers to the specific location of the instrument. Operational knowledge is likewise broken down into two levels: knowledge of instrument states and knowledge of instrument functionality, where instrument states refer to the beginning and end states of an instrument, while instrument functionality refers to the actions required to manipulate the instrument states. These navigational and operational skills are the foundation on which the lesson design strategy is built.

Table 2. Student Performance Measurement Types

Measurement Category	Category Sub-Type	Description
Navigational Skills	Gross Navigation	Students can identify the general area in which an instrument is located
	Fine Navigation	Students can locate the specific instrument
Operational Knowledge	Instrument State Knowledge	Students know the desired beginning and end states for an instrument
	Instrument Functionality Knowledge	Students know the actions required to properly manipulate an instrument

The lesson design provides a framework for the intelligent tutor to monitor student inputs, evaluate proficiency of skills and knowledge, and adapt support for individual needs. The evaluation results of these performance tasks and indicators will inform the intelligent tutor of skill and knowledge deficiencies as well as the level of support required. Students demonstrating a gross navigational skill deficiency will receive a guiding arrow hint to bring the target instrument into their virtual field of view, while students demonstrating a fine navigational skill deficiency will receive a glowing panel and/or instrument hint. Operational knowledge is supported utilizing on-screen text and will target a deficiency in knowledge of either instrument state or instrument functionality. Once the intelligent tutor identifies the appropriate hint strategy, the level of support will be inferred. Students who require a higher level of support will receive the appropriate hint sooner, while students requiring a lower level of support will receive the appropriate hint later. The lesson design strategy provides the framework for the intelligent tutor to utilize a combination of an appropriate hint strategy and appropriate timing to keep the learner in his or her zone of proximal development.

The intelligent tutor determines the appropriate hint strategy from a range of possibilities depending on past and instantaneous student performance (Table 3). The implementation of these hints depends on the type of checklist step and current performance of the student.

Table 3. Hint Categories

Hint Category	Hint Strength	Hint Description
Navigational	Weak	Visual arrow pointing to an area of the cockpit
	Medium	Panel illumination
	Strong	Instrument illumination
Operational	Strong	Text-based content presented in close proximity to the instrument

Within the navigational hints category, there are different levels of hints. Weaker navigational hints, such as visual arrows, will direct student attention to the general region of the cockpit where the instrument resides. The next level of navigational hint is a panel illumination around the border of the panel where the instrument resides. The strongest type of navigational hint is an instrument illumination around the border of the instrument itself (Figure 3).

Figure 3. Stronger Navigational Hints

The operational knowledge hints consist of text-based content presented in close proximity to the instrument, providing specific information related to the correct instrument value or functionality. If a student requires an operational knowledge hint, it is considered a strong hint.

Weaker hints provide minimal support to advanced students, while stronger hints provide major support to novice students. Likewise, slower-to-occur hints provide minimal support to advanced students, while quicker-to-occur hints provide major support to novice students.

The intelligent tutor determines the appropriate hint timing from a range of thresholds depending on past and instantaneous student performance. The range of thresholds varies to fit the proficiency of the student, but can occur within a couple of seconds for a novice. These quick hint thresholds are assigned to novice students who are deficient in many skill and knowledge areas, while slower hint thresholds are given to advanced students who are proficient in many skill and knowledge areas. The implementation of these thresholds depends on the checklist step difficulty as well as the past and instantaneous student performance. For example, novice students presented with a high-difficulty task will likely require more support and cockpit familiarization, so they will receive quicker hints to reduce frustration and build muscle memory. Similarly, advanced students presented with a low-difficulty task will likely require little to no support to successfully complete the task, so they will be given a slower hint threshold. As student skill and knowledge states are established, the intelligent tutor will improve student proficiency through systematically adapting hints to more challenging structures. For novice students, this adaptation is a shift from strong hints to weak hints, while advanced students shift from weak hints to no support at all.

The intelligent tutor accomplishes this by tracking a student's skill and building on its knowledge belief of the student. Supposing that student proficiency can range on a scale, say, from 1 to 5, the intelligent tutor assumes initially that a student is equally likely to be at any one of the given proficiency levels. As student performance improves, the intelligent tutor will update its belief regarding that student's proficiency by reallocating probability toward a distribution that reflects the student's cumulative performance. For example, if a student continually performs all tasks without hints, the intelligent tutor will update the belief of his or her proficiency by positing a higher probability that the student is higher on the proficiency scale, closer to 5. Over time, this trend in performance will result in a belief distribution that accumulates over a certain proficiency level that most likely represents or captures that student's overall ability.

Given the nature of following a checklist, hints follow a particular sequence. Hints are arranged in a series that supports the checklist tasks and will be displayed depending on the performance of the student. For example, if the student must set the flight deck power panel switches to the "ON" position and the VR goggles identify the switch is already in the student's field of view, the navigational arrow will not be displayed. If the student is unable to identify which switch to set, the switch will glow. Since setting a switch to "ON," however, is not a difficult task, and the student will likely accomplish this without support, on-screen text guidance will be delayed.

In addition to hints throughout the training, at the conclusion of each checklist students will receive an overall performance assessment that indicates whether they passed or failed that specific checklist sequence. All student performance data will be stored in the system, providing the flexibility in the future to create a separate interface to generate reports on student usage, performance, and trends. A report-generation interface, however, is not a part of the current scope of work.

Implementation of the current vrPTT design will allow students to practice checklist procedures independently at a pace and frequency tailored to individual cognitive and psychomotor development needs. Owing to the open architecture design and configuration of the vrPTT system, however, this design will provide the flexibility to add additional crew stations and facilitate collaborative training scenarios in the future.

Hardware/Software Design

Table 4 lists the hardware and software used in the vrPTT system to support the design requirements discussed above.

Table 4. vrPTT Hardware/Software

Component Type	vrPTT Solution
Laptop Computer	Intel i7 processor, Nvidia GTX1080 video card, 4K display support, 32 GB RAM, 512 GB SSD (e.g., MSI GT73VR Titan Pro)
3D Engine	Virtual Battle Space (VBS) with FLEX-air flight models
Head-Mounted Display	Oculus Rift CV1
Bare-Handed Controller	Leap Motion

Prototype Testing

On January 31 and February 1, 2017, two prototype testing sessions were held at Hurlburt Field, FL. In total, 18 stakeholders tested the prototype system, which consisted of the practice mode for the first six steps of the copilot's "Before Taxi" checklist. The focus during the prototype testing was threefold:

1. Test the fidelity of the bare-handed interaction within the virtual cockpit environment
2. Test the intelligent tutor functionality and suggest enhancements
3. Evaluate the overall ability of a vrPTT system to train checklist tasks

RESULTS

Initial prototype feedback was positive; Lt Col John Tharp, 19 SOS/CC Commander stated in an e-mail after the demo, "I can see where a program like this would be a fantastic augmentation to our syllabi and would have the students more ready (sic) when they enter the simulator or an actual aircraft…I can see it being a medium that could have amazing impacts in augmenting learning here at the 19 SOS." Informal user testing of the prototype system, however, identified a number of enhancements that will be required to ensure end user acceptance of the vrPTT system.

Improved Hand Tracking and Gesture Recognition

The vrPTT system uses a Leap Motion infrared (IR) sensor mounted to the front of the Oculus Rift HMD to allow bare-handed tracking within the vrPTT environment. Bare-handed tracking was a specific requirement of this project to enable users to build muscle memory and to prevent "negative training" that may come from using a controller to interact with the virtual environment. There are inherent limitations, however, to a single-point IR sensor solution. Namely, if line of sight from the IR sensor to the user's fingers is blocked by an arm or hand, the system has no way to accurately resolve the precise position of the fingers. Without precise finger positions, a user has no ability to effectively interact with the cockpit controls. To solve this issue, while still allowing bare-handed interaction, the development team is integrating multiple Leap Motion sensors into the vrPTT system. One ("local") Leap Motion sensor is mounted on the HMD, but the other(s) ("remote") can be placed anywhere and can move continuously and randomly while in use without impacting the data. Data from all Leap Motion sensors are integrated seamlessly using multiple threads and presented to the vrPTT system in the reference frame of the local Leap Motion, seeming to originate from a single sensor. The mathematics required to combine hand data from multiple sensors is highly optimized. Demonstration simulations using this software achieve comparable visual frame rates to identical simulations using a single sensor and the base Leap Motion software.

Because of the limitations of the single Leap Motion sensor hand tracking, gestures such as turning a dial were not possible to implement in the prototype system, which detracts from one of the goals of the vrPTT system—to improve muscle memory. The development team is using the multiple Leap Motion solution to improve gestures and make them as similar as possible to actual gestures used in the field.

Measurement of Visual Tasks

VR training immerses users in visually complex, realistic mission environments, requiring them to perceive and process critical information from visual cues. The FEA showed that 309 of the 654 (47%) copilot checklist tasks are visual tasks. Assessing user perception of appropriate information from any type of visual cue, however, is notoriously difficult without interrupting cognitive presence in the simulation. The development team will be implementing a solution for measuring that a user has looked at an object. This solution will mirror the Oculus' native hands-free navigation by placing a dot in the center of the user's field of view and requiring the user to center that dot over the instrument he or she is required to look at for a defined length of time. While this solution will serve its purpose for the vrPTT system, it will slightly disrupt the timing of the checklists. Therefore, areas of future research should examine how to effectively measure visual tasks within a VR environment.

DISCUSSION

Next Steps

The next delivery of the vrPTT system is in August 2017. The August delivery will be the first draft version of the entire vrPTT system described above, including all 16 copilot checklists, student login capability, both instructional and practice modes for each checklist, and the adaptive intelligent tutor. AFSOC will have 90 days to complete user testing of the system. During this time, it is anticipated that AFSOC will allow a cohort of copilot trainees to complete their checklist training using the vrPTT. The students completing training via the vrPTT will then be assessed to compare their performance to that of copilots who completed the traditional classroom training. It will also be useful to have expert copilots use the system to gather data on their performance to compare to that of new trainees. Data to be examined may include:

- Average time spent in the full-motion simulator on cockpit familiarization after vrPTT checklist training
- Instructor assessment of students who completed the vrPTT checklist training compared to instructor assessment of students who completed the classroom training
- Analysis of user performance data within the vrPTT (e.g., time to proficiency, comparison to expert performance)
- User feedback on the vrPTT system

All data collected will be compiled into an evaluation report that summarizes the effectiveness of the training, any deficiencies in the vrPTT system, and recommended changes or enhancements. The evaluation report will drive the final development of the vrPTT system, which will be delivered in February 2018.

Future Enhancements

Collaboration

While the individual checklist procedure training provided by the current vrPTT solution provides measureable value, there is significant added value in tying multiple vrPTT systems together to allow users to collaborate within the same virtual environment. Virtual collaboration allows entire aircrews to conduct mission rehearsals, including threat recognition and avoidance, without requiring access to an operational aircraft or requiring that the crew members be co-located. A collaborative mission rehearsal capability would save time and money, and allow for low-risk practice of mission tasks while developing the crew's shared mental model (Stout et al., 1999).

xAPI Integration

Experience API (xAPI) provides a means of tracking and storing fine-grained learner performance data. Using xAPI, vrPTT performance data could be stored in a Learning Record Store (LRS) alongside performance data from other training. In other words, analyses on learner performance data would not be limited to performance data from a single training source, but rather could be examined holistically. As related to the vrPTT and collective training, analytics could be developed to evaluate the individual performance of a number of different crew member combinations working together to determine effects on overall collective performance. This approach would allow further definition of the individual performance measures and behaviors that result in the most successful collective performance. The vrPTT could then be modified to train and promote the identified individual performance measures and behaviors.

Gaze Tracking & Intention Recognition

Visual information is a crucial component of most tasks within VR trainers. Research has shown that individuals exhibit anticipatory gaze behavior during task execution (Gesierich et al., 2008), and the trajectory and features of an individual's gaze contain salient information about the tasks he or she is trying to perform (Quintas et al., 2012; Quintas et al., 2013). By analyzing features of the eye and the trajectory of the gaze direction in the context of a defined task, it is possible to recognize the operator's intentions (Doshi & Trivedi, 2008; Doshi & Trivedi, 2009; Windridge et al., 2013). Future research in this area should focus on developing an automated means of tracking users' gaze and intention within VR systems.

Summary

This paper focused on the analysis, design, and development of the vrPTT, which are critical phases to ensure that the system is addressing AFSOC's training needs. Initial feedback on the vrPTT system suggests that it has the potential to positively impact copilot checklist training, while reducing time spent in the full motion simulator. The 90-day evaluation data will be used to identify new, and confirm already proposed, enhancements to the system. The future additions of gaze tracking, xAPI integration, and the ability to collaborate within the same VR environment will allow this technology to support the full training spectrum, from initial qualification through mission rehearsal.

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REFERENCES

Chellali, A., Mentis, H., Miller, A., Ahn, W., Arikatla, V. S., Sankaranarayanan, G.,...Cao, C. G. L. (2016). Achieving interface and environment fidelity in the virtual basic laparoscopic surgical trainer. *International Journal of Human-Computer Studies*, *96*, 22–37.

Dargar, S., Kennedy, R., Lai, W., Arikatla, V., & De, S. (2015). Towards immersive virtual reality (iVR): A route to surgical expertise. *Journal of Computational Surgery, 2*(2), 1–26.

Doshi, A., & Trivedi, M. M. (2008). A comparative exploration of eye gaze and head motion cues for lane change intent prediction. *IEEE Intelligent Vehicles Symposium*, 49–54.

Doshi, A., & Trivedi, M. M. (2009). Investigating the Relationships Between Gaze Patterns, Dynamic Vehicle Surround Analysis, and Driver Intentions. *IEEE Intelligent Vehicles Symposium*, 887–892.

Ganier, F., Hoareau, C., & Tisseau, J. (2014). Evaluation of procedural learning transfer from a virtual environment to a real situation: A case study on tank maintenance training. *Ergonomics, 57*(6), 828–843.

Gesierich, B., Bruzzo, A., Ottoboni, G., & Finos, L. (2008). Human gaze behaviour during action execution and observation. *Acta Psychologica 128*, 324–330.

Johnson, S. J., Guediri, S. M., Kilkenny, C., & Clough, P. J. (2011). Development and validation of a virtual reality simulator: Human factors input to interventional radiology training. *Human Factors, 53*(6), 612–625.

Klein, G. (1995). The value added by cognitive task analysis. *Human Factors and Ergonomics Society Annual Meeting, 39*(9), 530–533.

Lackey, S. J., Salcedo, J. N., Szalma, J. L., & Hancock, P. A. (2016). The stress and workload of virtual reality training: The effects of presence, immersion, and flow. *Ergonomics, 59*(8), 1060–1072.

Nickel, F., Brzoska, J. A., Gondan, M., Rangnick, H. M., Chu, J., Kenngott, H. G.,...Muller-Stich, B. P. (2015). Virtual reality versus blended learning of laparoscopic cholecystectomy: A randomized controlled trial with laparoscopic novices. *Medicine, 94*(20), 1–8.

Quintas, J., Almeida, L., Brito, M., Quintela, G., Menezes, P., & Dias, J. (2012). Context-based understanding of interaction intentions. *The 21st IEEE International Symposium on Robot and Human Interactive Communication*, 515–520.

Quintas, J., Menezes, P., & Dias, J. (2013). Context-based perception and understanding of human intentions. *The 22nd IEEE International Symposium on Robot and Human Interactive Communication*, 346–347.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, *13*(3), 257–266.

Stout, R. J., Canon-Bowers, J. A., Salas, E., & Milanovich, D. M. (1999). Planning, shared mental model, and coordinated performance: An empirical link is established. *Human Factors, 41*(4), 61–71.

Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2013). *Engineering Psychology and Human Performance* (4th ed.). New York: Routledge.

Windridge, D., Shaukat, A., & Hollnagel, E. (2013). Characterizing Driver Intention via Hierarchical Perception–Action Modeling. *IEEE Transactions on Human-Machine Systems 43*(1), 17–31.