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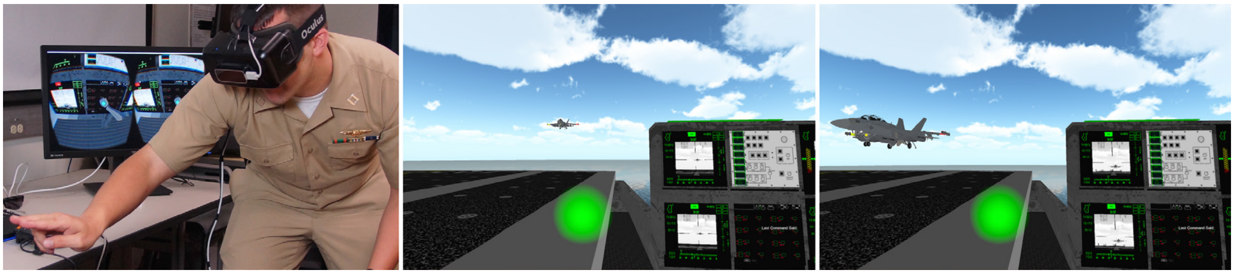

Fig. 1. Immersive virtual trainer for Landing Signal Officers

Abstract—A major training device used to train all Landing Signal Officers (LSOs) for several decades has been the Landing Signal Officer Trainer, Device 2H111. This simulator, located in Oceana, VA, is contained within a two story tall room; it consists of several large screens and a physical rendition of the actual instruments used by LSOs in their operational environment. The young officers who serve in this specialty will typically encounter this system for only a short period of formal instruction (six one-hour long sessions), leaving multiple gaps in training. While experience with 2H111 is extremely valuable for all LSO officers, the amount of time they can spend using this training device is undeniably too short. The need to provide LSOs with an unlimited number of training opportunities unrestricted by location and time, married with recent advancements in commercial off the shelf (COTS) immersive technologies, provided an ideal platform to create a lightweight training solution that would fill those gaps and extend beyond the capabilities currently offered in the 2H111 simulator. This paper details our efforts on task analysis, surveying of user domain, mapping of 2H111 training capabilities to new prototype system to ensure its support of major training objectives of 2H111, design and development of prototype training system, and a feasibility study that included tests of technical system performance and informal testing with trainees at the LSO Schoolhouse. The results achieved in this effort indicate that the time for LSO training to make the leap to immersive VR has decidedly come.

Index Terms— military applications, HMD, 3D interaction, usability

1 Introduction

Landing an aircraft in the middle of the ocean, even under perfect weather conditions, is an extremely hard job in which precision and timing play a crucial role. A group of four to five highly skilled individuals, called Landing Signal Officers (LSOs), work on top of the aircraft carrier to help the pilot land the aircraft safely. This group has effectively 20 seconds, between the pilot's start position until landing, to guide him or her toward an acceptable position to land on the deck. In addition to time constraints, the space limitation also influences the success of this operation. In some cases, when the plane's wingspan is large, even a small deviation from the centerline is not allowed, and if, in the LSOs judgment, the plane cannot land safely, it will be waved off and requested to make another attempt. According to the Naval Safety Center [1], the period between 2005 and July 2015, saw 108 landing-related mishaps on aircraft carriers, 99 of which involved the performance of LSOs in some fashion. A total of 41 of those events reported damage to property, and two events reported injuries to personnel. It is those strict performance requirements and the scale of potential damage, if a landing operation is not executed properly, that dictate the need for the extensive training regimen that both LSOs and pilots go through.

A major training device used to train all Landing Signal Officers (LSOs) for several decades has been the Landing Signal Officer Trainer, Device 2H111 (Figure 2). This simulator, located at the LSO School in Oceana, VA, is contained within a two story tall room; it consists of several large screens and the physical iterfaces of the actual instruments used by LSOs in their operational environment - Improved Fresnel Lens Optical Landing System (IFLOLS), Manually Operated Visual Landing Aid System (MOVLAS) and Landing Signal Officer Display System (LSODS). The young officers who serve in this specialty, will typically encounter this system for only a short period of formal instruction, as part of the Initial Formal Ground Training (IFGT) in LSO School. That training consists of six one-hour long sessions, during which each LSO needs to practice all LSO positions. The rest of the LSO's training outside of the school includes many hours of "on the job" training that involves actual aircraft landings. A shared understanding in the LSO community is that the number of hours in the 2H111 simulator that support simulated operations i.e. safe practice, is extremely low and inevitably leaves multiple gaps in training - (a) LSOs do not have the opportunity to practice before going to IFGT, (b) the number of

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hours in the 2H111 itself is too low, and (c) in general there is no opportunity for refresher training after an LSO leaves IFGT.

Fig. 2. 2H111 simulator.

The urgent need to provide LSOs with an unlimited number of training opportunities unrestricted by location and time, married with recent advancements in affordable, commercial off-the-shelf (COTS) immersive technologies, provided an ideal platform for the design and creation of a lightweight training solution (Figure 1) that would fill those gaps and perhaps even extend beyond the capabilities currently offered in the 2H111 simulator. This paper describes the process applied to do that work, and it details elements of the feasibility study that was conducted once the prototype system was created.

2 Background

The use of Virtual Reality (VR) technology as a means of supplementing current training practices, and in some cases the only option available to acquire the skills needed in the real (operational) world, has been present for several decades now. Application domains like medicine and psychology [2][3][4][5], sport [6][7], firefighting [8][9], architecture [10] and military [11][14][15][25], represent only a few examples where this practice is becoming the norm. The military domain alone has been investing considerable resources to conduct research, build prototype systems and finally, to acquire and distribute training products meant to be widely used in the community. The use of virtual training solutions spans two general categories: (1) VR solutions that provide more effective training (people acquire knowledge and skills quicker then using traditional training approaches, they retain those skills longer, or the use of those solutions save human and material resources), and (2) VR solutions that represent the only effective way possible to acquire some skills (example: pilots practicing emergency procedures). The ultimate goal of training done with VR solutions is a positive transfer of skills and knowledge acquired in that practice, to similar situations in the real world. Studies have been conducted to investigate if that type of transfer does happen and what parameters influence it, either positively or negatively [12][13][14][15].

The elements of VR training systems - their technical characteristics (frame rate, delay, resolution); human perception of and reactions to them; as well as appropriateness and quality of the training approach including the richness of scenarios and virtual resources, and the length of exposure, are the characteristics that can influence the extent to which skills and knowledge get acquired in the first place, and then if their positive transfer to real work circumstances does happen. When it comes to many forms of military activity, the judgment of distance plays a big role in human performance, ultimately enabling the success or failure of a mission. Studies of human actions in VR systems suggest that the phenomenon of egocentric distance judgment should not be taken lightly - the compression of distance when evaluated in VR has been identified in several studies that examined the use of both head-mounted display (HMD) solutions [16][17][18] and large displays [19]; the same studies suggest that we still do not have a full understanding of the cause. This phenomenon is certainly of great interest to the LSO training community; much of their performance depends on individual judgment of egocentric distance. Instruments and sensor readings available to the LSOs do help in this job and they could alleviate those effects, however a formal user study would need to be conducted to show if contraction of distance does happen, if it does what is the extent to which it gets manifested with given system configuration (in our case COTS headset - Oculus DK2), and if repeated exposure to the system and scenarios changes its rate.

An additional phenomenon that needs to be considered is cybersickness [20][21][22][23], especially because a display device used for the system is an HMD. Studies suggest that the symptoms of cybersickness are more pronounced when users wore HMDs [24]. The physical movement (navigation) of an LSO on the platform is fairly limited, and the majority of navigation consists of head rotation. Wearing an HMD means that control over the viewpoint will be coupled, i.e. user control in this case is mapped to the needs of the LSO task (LSO watching and 'following' the plane as it approaches the landing area on the carrier, which is also advised as an effective method for minimizing cybersickness [20]. A study focused on a ship navigation scenario that used the same HMD employed in the LSO trainer, Oculus DK2, suggested that cybersickness did manifest itself to slight extent, however it was not reported to interfere with the ship navigation job with any of the 25 individuals who took part in that study [25]. The total exposure time in the study consisted of three 15-20 min long sessions.

3 Approach

The approach and a set of steps used to design and develop a prototype of the lightweight VR trainer for LSOs, observed several requirements:

(1) It was necessary to perform task analysis that was vetted by the subject matter experts (SMEs) from the LSO community. This was dictated by the stringent requirements of what the training system should support in terms of sensory cues (system feedback), simulated environmental conditions under which the user is typically expected to perform desired tasks (daytime and nighttime operations with pitch, roll and heave of the ship's motion being present), tools and materials being used, user input, the type of user performance including standards of performance that needs to be achieved, and the metric associated with it that the system needed to enable;

(2) The prototype training system needed to support all major capabilities and training objectives currently supported by the 2H111 simulator. Both the instructors and trainees were already familiar with the technical and training capabilities of 2H111 and any new training system would inevitably be compared with and evaluated against those training capabilities. Additionally, a lightweight training system was seen as a training solution that LSOs would use prior to their training in IFGT with 2H111; producing a consistent family of training solutions and making them as similar as possible would make their adoption much easier and faster;

(3) It was necessary to acquire a thorough understanding of users' training needs, their view of benefits and shortcomings of training with 2H111. Whenever possible a new training solution had to avoid any of the shortcomings or deficiencies already identified in 2H111, and try to bring the value and capability that 2H111 could not fulfill.

4 Task Analysis

The main objective of task analysis is to identify and confirm a detailed breakdown of individual and team tasks and steps in each task done by all individuals who support a certain action (operation), while also identifying timely order of all steps and a purpose of each step [26]. This includes all sensory cues that a user would be presented with, the actions expected by the user and standards of performance expected in each step, communication (if any) with other individuals who support the same task as well as the environment and conditions under which each task needs to be conducted.

For this prototype system, we decided to analyse the three most important positions on the LSO team: Controlling LSO, Backup LSO, and Deck Caller LSO. The other two (Book Keeper LSO, also known as the "Writer" and Timing LSO) were outside of the scope of our proof-of-concept prototype system. The details of task analysis were constructed using information available in LSO NATOPS Manual from 2013 [27]. Our working knowledge of more recent changes in practices were first vetted by the LSO School for their validity, and then integrated with information from the Manual. The full details of task analysis for each of three selected positions can be found in document [28].

The major conclusion reached after the task analysis was done, concerned the absence of haptic sensory stimulation in the lightweight prototype system, i.e. the lack of physical instrumentation that the 2H111 simulator incorporated. Specifically, the physical renditions of Manually Operated Visual Landing Aid System (MOVLAS) and Landing Signal Officer Display System (LSODS), as well as interactions with those instruments were simulated by devising a virtual representation of LSODS (user interaction enabled via several interaction modalities) and using the Xbox controller to interact with the model (encoded behaviour) of the MOVLAS. Given the fact that the acts of pressing the real buttons and switches, when compared to 'pressing' the virtual buttons, was not considered a major training objective, it was concluded that the absence of the physical instruments would not diminish training value of the prototype system. Close attention was paid to comments generated by the users in our informal usability study when they had the opportunity to experience the lightweight prototype system, and none of them found this decision objectionable. The lightweight specification of the prototype - having the entire training environment virtual and least dependent on additional infrastructure - was preserved. All visual and auditory cues were kept as LSOs would expect them to be in the operational environment. Additionally, large majority of tasks done in LSOs job are of visual and auditory nature, which in turns provides a best basis for our decision to develop fully virtual system.

It is important to note that usual methodology for the user-centered design and evaluation of Virtual Environment user interfaces that includes (1) user task analysis, (2) expert guidelines based evaluation, (3) formative user-centered evaluation, and (4) summative comparative evaluation [29][30][31], needs to be extended to satisfy requirements specific for training system. This training-oriented design and evaluation methodology includes two additional steps: one step consist of validation of real-world phenomena simulated in Virtual Environment, and it is performed once the task analysis and design of the system are completed, but before step (2). Validation concerns "The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model." [32]. This work is typically done by employing two basic approaches - objective validation using different forms of quantitative analysis, and subjective validation that involves Subject Matter Experts – SMEs [33]. The step concerned with summative comparative evaluation in the context of training systems could be designed as training effectiveness study. Also, an additional step is typically added after summative evaluation - it incorporates a transfer of training study as a way of evaluating the ultimate effectiveness and efficiency of the training system; the main purpose of this step is to establish firm understanding of the extent to which skills acquired in training system do carry on and transfer to target environment (this is often real word environment). In our experience both validation and evaluation of training effectiveness are done quite irregularly, which unfortunately increases a possibility of those systems exhibiting bellow satisfactory performance when they get used, raising a mistrust among training audience and eventually being rejected by their intended users [34].

5 Survey of User Domain

The main objective of the user domain survey was to acquire an accurate understanding about the current state of training practices in the LSO community, and LSOs' perception of different elements of training with the 2H111 simulator - its benefits and good characteristics as well as negative issues that were identified as obstacles in training practice.

A web survey using the open source LimeSurvey tool was conducted to capture an array of qualitative and qualitative information from LSOs of different qualification status. Prior to its distribution, the survey was submitted to NPS Institutional Review Board (IRB) for their review. After a review the committee determined that the survey did not include collection of personal identifying information and as such it did not require IRB approval.

A total of 35 LSOs responded to our survey - Table 1 shows the qualification categories and number of LSOs in each category. Among the 35 LSOs only six individuals did not attend the IFGT training sessions i.e. they were not familiar with the 2H111 simulator. These included one Squadron LSO, two Field LSOs, and three No Qualification LSOs. This meant that 29 LSOs were able to provide comments about their experience with the 2H111 simulator. When asked if money and time were taken out as limitations, would it be beneficial for an LSO to attend LSO School for a refresher as part of his/her workup cycle to practice individual LSO positions, 93% of pooled LSOs responded with 'Yes', and for training as a wave team (team skills) 96% of LSO responded with 'Yes'.

Table 1: Categories of LSO surveyed.

LSO category	#
Staff LSO: LSO able to control all aviators in all aircraft during FCLP and aboard ship under all operating conditions. Attainment of the highest level of qualification and experience gained as a result of performance in subordinate categories.	6
Training LSO: LSO able to control all pilots, including student and replacement pilots, in the specific model aircraft the LSO is carrier qualified in, both during FCLP and aboard ship.	4
Wing LSO: LSO able to wave all fixed-wing aircraft models that are attached to the air wing during FCLP and aboard ship in all conditions and operate the MOVLAS in both day and night conditions.	6
Squadron LSO: LSO able to wave the same airframe that he or she is carrier qualified in aboard the ship in both day and night conditions and operate the MOVLAS in day conditions. Need to have IFGT completed.	7
Field LSO: LSO able to wave the same airframe (the same aircraft model) that he or she is qualified to land on the carrier ("carrier qualified") during FCLPs and during necessary emergency recoveries at home.	9
No Qualification: Newly appointed LSO.	3
TOTAL:	**35**

Major survey questions addressed the LSO community's understandings about the skills that needed to be acquired for their level of LSO qualification, the process of skill acquisition and skill retention, as well as strengths and weaknesses of the 2H111 simulator. The results were not used as absolute determinants of what the lightweight LSO prototype system should or should not support, but rather as starting information that was discussed in the light of major system design goals and vetted by colleagues from the LSO schoolhouse. In that regard the underlying meaning of 'user-centered' approach was that it was 'user-informed' rather than 'user-dictated'.

We were interested to learn what skills, knowledge (facts, information) and concepts are most difficult to acquire - those would be very good candidate items to support in training system if the same is to bring big benefits to the trainees. As Figure 3 shows, the 'eye calibration' and 'judgment' were selected by the LSOs as hardest to learn. The 'eye calibration' (determining the aircraft position as it relates to the ideal glideslope angle), engages visual stimuli presented to the LSO, and the emphasis in the training system will be on their correct representation at any point in time. The 'judgment' is related to LSO's situational awareness and is a mix of understandings acquired by the LSO that are related to space, time, communication with the pilot and interaction with other LSOs as well as the confidence the LSO has about his or her decision. This type of skill gets acquired over time and with exposure to the large number of scenarios and situations when they practice waving the aircraft. Being that the essence of the lightweight LSO prototype system is to be affordable and available to LSOs for their training any time and anywhere, this system has excellent chances to fill that training gap.

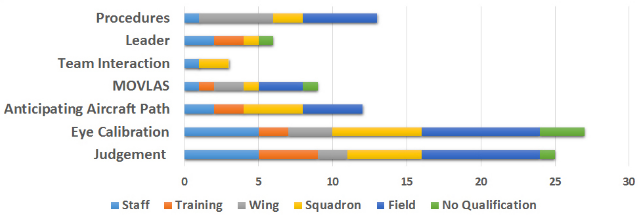

Fig. 3. Skills, knowledge and concepts qualified as most difficult to acquire by an LSO.

Figure 4 illustrates the results we got for questions related to the skills, knowledge and concepts that are perceived by LSOs as 'most perishable' if they do not have the opportunity to wave the aircraft for an extended period of time. The knowledge of correct procedures was qualified by far as the most perishable skill, with 'eye calibration' close behind it. Both of those skills could benefit from having access to a portable lightweight system that would simulate a number of aircraft passes and provide LSOs with opportunities to practice waving of the aircrafts. This is especially important in a situation when, once the LSOs complete their IFGT training sessions and are back with their squadrons, they generally do not get the opportunity to use the 2H111 simulator again to refresh their skills.

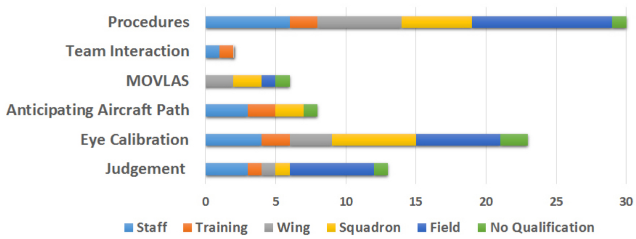

Fig. 4. Skills, knowledge and concepts perceived as most perishable to an LSO when he or she goes for an extended period of time without waving.

Comments related to the perceived quality of the 2H111 training environment and results of training, were also in the information we collected. The survey pooled the information about the advantages of training with the 2H111 simulator for three LSO positions (Controlling LSO, Backup LSO and Deck Calling LSO), and as expected, different skills were at the center of attention for different LSO positions. This is not surprising being that each LSO position performs different tasks and has different concerns. The advantage of training with the 2H111 for Controlling LSO is the ability to train for situations with the carrier deck pitching and with team/procedural flow. For Backup LSO this was LSODS usage and team/procedural flow, and for the Deck Calling LSO it was 'developing scan' (monitoring the situation on the deck) and situational awareness. Of note is that the Backup LSO and Deck Calling LSO are two LSO positions that do not have the ability to receive practice during FCLPs, which at the same time means that training simulation is the only viable option for their training. All of these situations and skillsets are possible to practice in the lightweight LSO trainer.

The LSOs' view of the drawbacks of training with the 2H111 simulator when compared to the training they receive through Field Carrier Landing Practice - FCLP (basically 'on the job' training), i.e. the major concepts that FCLPs can prepare an LSO to do at sea, that the LSOT (2H111) cannot replicate, include 'administration' (this includes situational awareness (SA) or pattern management e.g., aircraft spacing, fuel states, pilots' trends, and administration of issues 'on the ground'), LSO-pilot interaction and observing aircraft characteristics (Figure 5). This result points to the areas where more development should be directed if one is to expand current training capabilities of the 2H111 simulator, and enable a superior training solution. It is feasible that all of these capabilities could be supported in a simulation.

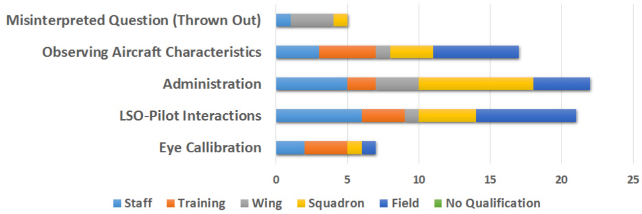

Fig. 5. Major concepts that FCLP can prepare a LSO to do at sea, that 2H111 simulator cannot replicate.

Full details about the rest of the questions asked in the survey, and the accompanying analysis can be found in document [28].

6 Prototype System Design and Development

6.1 Design Goals

Before we started with a design of prototype LSO training system, several goals were adopted:

1. This training system should support all major capabilities and training objectives currently supported by the 2H111 simulator. In addition to those, an effort was made to leverage immersive VR technology and a set of input devices available to us to incorporate capabilities that were not supported by the 2H111 simulator.
2. System should truly remain a *lightweight* training system using only COTS components. If the LSOs are to be able to take it wherever they go, and have it even on the aircraft carrier, the system had to be accommodated on a laptop computer. This also required full optimization of the model where 3D resources would support the creation of highly realistic scenes, but would not restrict the high frame rate needed for smooth simulation in a stereoscopic headset.
3. Considerable effort will be invested to achieve high(er) frame rate: this was also necessary to avoid exacerbating the symptoms of cybersickness [23]. Additional rationale for keeping the frame rate high and avoiding cybersickness lies in the fact that the skills LSOs need to acquire are very complex and they will need extended exposure (multiple hours) to training material and training situations, to master them. The prolonged time wearing the headset would also

play a role in causing cybersickness [20][23] and designers of this type of training systems need to make every effort to get the elements of the system right. Any discomfort or other obstacles to use of the system on a regular basis would inevitably influence its adoption rate negatively and in the worst case it would cause the rejection of the training solution by the user community concerned [34].

4. In terms of input devices and interaction modalities that system would support, a decision was to integrate a solid variety of typical COTS input options that would be made available to the trainees and instructors. This fulfills two major objectives: it allows for flexibility - it supports personal LSO preferences when they interact with the system, and it enables a backup mechanism if one mode of interaction fails.

6.2 System Architecture, Development and Programming Environment

The prototype system was built using Alienware 17 R2 laptop with Intel Core i7-4980HQ CPU @ 2.80 GHz, 16 GB RAM and GeForce GTX 980M GPU. A set of input and output devices consisted of two Xbox Controllers (one for a trainee LSO and one for instructor), headphones with microphone, Oculus DK2 headset and Leap Motion Controller attached to Oculus DK2 (Figure 6). Oculus DK2 has a resolution of 960 x 1080 per eye, with max refresh rate of 75 Hz, field of view (FOV) 100 degrees, and weight of device: .97 lbs.

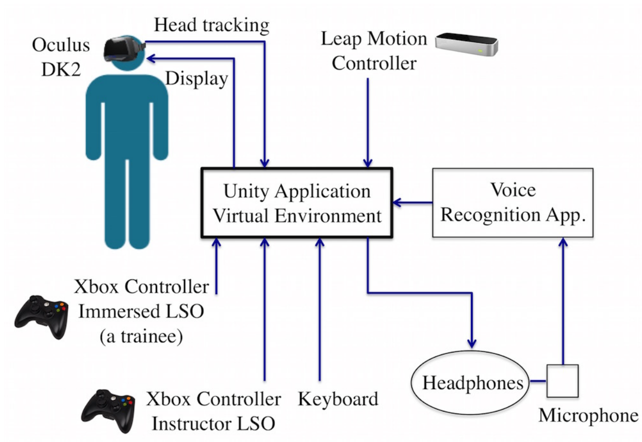

Fig. 6. Hardware and software architecture.

The development and programming environment consisted of the Unity game engine, Blender for model editing, 3DS Max for model editing, Photoshop for texture manipulation, and Audacity as audio editor.

6.3 3D Resources, Behaviors and Audio Resources

Several models of aircraft were purchased from the Turbo Squid 3D models website; Figure 7 and Figure 8 show two 3D models of the aircraft used in application (size of all 3D models put together was 478K vertices.) One comment that we received from LSOs was that the level of realism of 3D models in the 2H111 simulators was too low and that the community would benefit from having 3D models of higher fidelity both in terms of their geometry and textures. The overwhelming agreement on this issue was the main incentive for acquiring and incorporating high resolution 3D models of the air assets and aircraft carrier; this, in turn, created a bigger demand on processing power if the frame rate was to be kept at a high rate, and effort was invested to do optimization of the models i.e. to reduce their size while keeping the level of realism high. Model of the aircraft carrier was acquired from Google's 3DWarehouse and custom textures for the platform were created using Photoshop (Figure 9).

Part of the LSO's decision-making during recovery of the aircraft includes anticipation of the wave motion and the effects of a pitching flight deck that needs to be compared with the trajectory of the aircraft. In order to create a realistic and believable scene a 3D model of the water (ocean) with underling physics (behaviour) needed to be added. The visual water effects used in our prototype system came from a Unity package, and simple behaviour for movement of the ship was added to the application. Skybox assets used to simulate a variety of environmental conditions like clear day, clear night, and overcast day, were leveraged from the standard Unity collection.

Fig. 7. T-45C 3D model rendered in LSO prototype trainer (size: 110K vertices).

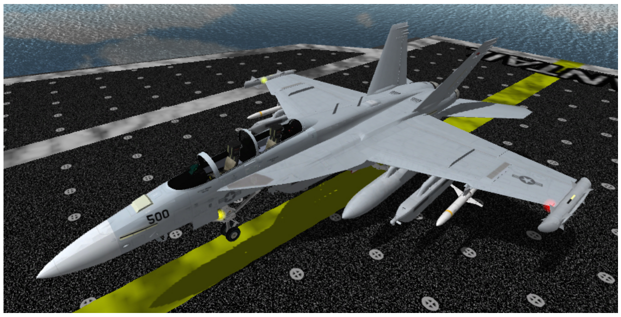

Fig. 8. EA-18G 3D model rendered in LSO prototype trainer (size: 50K vertices).

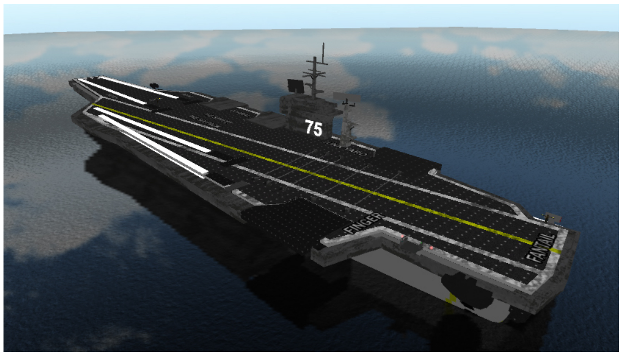

Fig. 9. Nimitz Class carrier model acquired from 3DWarehouse, and rendered in LSO prototype trainer (size: 9K vertices).

Figure 10 shows side by side comparison of two implementations of the Landing Signal Officer Display System (LSODS): one from the 2H111 simulator (top image, night time, physical rendition of LSODS from the aircraft carrier) and the other from the LSO prototype training system (bottom image, day time, virtual 3D model). Full specification of LSODS design and functionality was obtained from the LSO schoolhouse, and in that regard the virtual LSODS was identical to the one used in 2H111 simulator.

Fig. 10. LSODS comparison between 2H111 simulator (top image) and LSO prototype trainer (bottom image).

Audio resources - different sounds used in simulation - were received from LSO schoolhouse, and in that regard they were exactly the same as they are in 2H111 simulator. While the production of a new, richer and more realistic set of audio resources is something that would need to be added to the system, it was outside of the scope of the work on the proof of the concept prototype system.

6.4 Input Devices and Interaction Modalities

One of our design goals was to support a selection of input devices and interaction modalities; the reason lies in the desire to offer flexibility and choice that would allow for personal LSO preferences when interacting with the system, but also to have multiple ways of doing the same thing as a backup if one mode of operation starts to malfunction. In that regard, for example, LSO could use the Xbox controller to select buttons on LSODS, or he (she) could opt for exploiting the Leap Motion Controller and point-and-press virtual buttons with a virtual hand that mimics the motions of the LSO's own hand.

Trainee's Xbox Controller was used to (a) replicate the functionality of the Pickle device that LSOs use in their operational environment, (b) support LSODS manipulation, and (c) for navigation in 3D space. Instructor's Xbox Controller was used to select and present different scenarios to the trainee. A keyboard is typically not used in immersive environments and our intention was not to have it as regular input device - we predominantly used it for debugging purposes during the development phase. As a back up input capability, it was also programmed to support LSO's navigation through 3D scenes, interaction with LSODS, and it enabled instructor's selection and manipulation of the scenarios.

A Leap Motion Controller was added to enable easy interaction and manipulation of the virtualized LSODS similar to the interaction they would have with the system in real world conditions (2H111 simulator, much like the environment on the aircraft carrier, also provides physical button inputs). Figure 11 shows a user demonstrating this interaction. Our tests have proven that the best (most precise) interaction using generic capabilities of Leap Motion Controller are achieved if a user points to and selects the elements of the virtual environment with two fingers put together (index and middle finger) as shown in Figure 11.

Fig. 11. User demonstrating interaction with LSODS using Leap Motion Controller.

Virtual hand in Figure 12 does the same, as it mimics the motion and pointing gesture of the real hand. The size of the targets, i.e. virtual buttons needed to be changed - eight push buttons in the control panel were made about 50% larger when compared to the size of the real buttons, to enable needed accuracy in target selection and reduce the error rate.

Fig. 12. Stereoscopic displays showing LSODS with LSO's virtual hand.

6.5 Speech Recognition System

The communication between LSOs and pilots is done using their voices over UHF radio. It is widely considered that the best tool an LSO can use to facilitate a safe recovery of the aircraft is his or her voice. Experienced LSO will be able to 'read' a lot about psychological state of the pilots by listening to their voices. Likewise, reassuring tone of LSO's voice will be able to put the pilot at ease and help build mutual trust needed in this complex operation.

Several different approaches were tested in search for the best speech recognition system. The first two approaches attempted to leverage libraries available in Unity and Unity's asset store, however neither of them worked in satisfactory fashion. The final solution adopted and used in prototype system was our custom made speech recognition application that run independently and which communicated with Unity through network messaging (UDP).

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Each LSO voice call carries two elements in it - one is the word or phrase itself (e.g., power—aircraft is low/slow), and the other one is inflection in the voice ("power" vs. "POWER!") that adds extra layer of meaning for the listener, in this case the pilot. The ideal speech recognition system would be able to discern both elements in LSO's command with the correct meaning and inflection. At the time of developing lightweight LSO prototype training system, we did not have ready access to known viable solution, and that was left for the future development phase.

7 Feasibility Study

The major goal of the feasibility study was to provide early indicators of whether or not COTS technology could support a development of the lightweight LSO trainer. The study included tests of technical system performance, informal tests of human perception and understanding of visual and auditory cues done with the volunteer trainees at the LSO Schoolhouse, as well as an assessment of LSOs receptiveness to the idea of using this type of system.

7.1 Technical System Performance Measurement

The measure of overall system performance was done using the framerate the system could generate while processing the 3D models and behaviours made available in the simulation. The best performance was achieved using Oculus' "Extended Mode," instead of the preferred "Direct to HMD" mode (Figure 13). The drop, i.e. oscillation in the framerate between the highest value (60 FPS) and the lowest value (37 FPS) during the full quality settings, was noted. The framerate of 60 FPS was generated when a smaller portion of scene was in field of view, and 37 FPS resulted from viewing the scene where six aircrafts were lined up on the deck (Figure 14). While both values are still very high, the effects that jitter could have on cybersickness [20][23] are reason enough to investigate and optimize system performance; the goal would be to alleviate, or (if possible) completely remove jitter and ensure a more stable framerate.

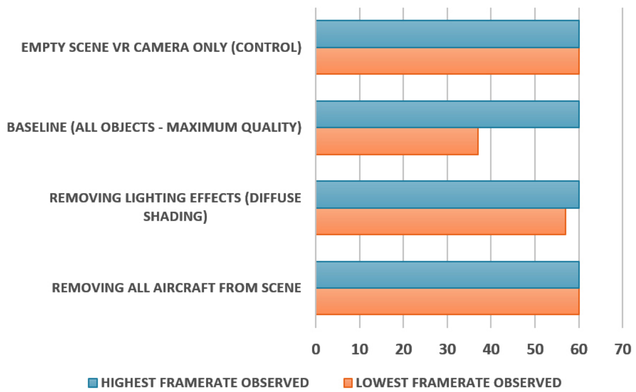

Fig. 13. Framerate performance in frames per second (FPS) with Oculus 'Extended Mode'.

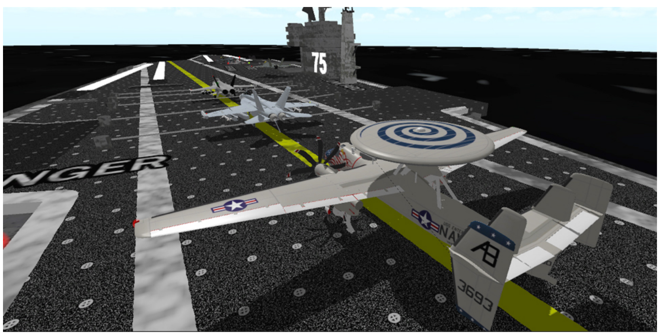

Fig. 14. View of the scene that caused the framerate to drop to 37 FPS.

7.2 Cross Comparison of Training Capabilities

At the end of prototype development we conducted cross comparison between technical and training capabilities of two systems (side by side comparison was also done with LSO performances in the real world).

Some of the differences were known even before this development started: (a) the lightweight LSO prototype training system was portable, unlike 2H111; (b) 2H111 had restricted FOV - fixed projectors and screens limit the visual experiences of LSOs; (c) 2H111 simulator predominantly supports team training i.e. all positions need to be present, while the lightweight LSO prototype training system can more easily support training of individual positions (other positions could be simulated and be shown as virtual agents in LSOs FOV); (d) third person view is very easy to support with the lightweight LSO prototype training system to enable novel learning points (view of the entire scene and scenario from the air, to support easier learning of the overall concepts of aircraft approach to the carrier), while the same is impossible in 2H111.

The rest of the comparison between those two systems was done by pooling opinions of volunteer LSO trainees who had the opportunity to see a demo of the system that was brought to the LSO schoolhouse (details commented in Section 7.3).

7.3 Informal Demo Feedback

LSO Schoolhouse provided us with opportunity to demo the nearly finished lightweight LSO prototype training system, and in that process learn the first impressions that LSOs had about the system; thirteen LSOs were provided with this experience. The goal of this visit and the feedback we would get, was to help us acquire an independent view of the system's capabilities and correct elements of the system if the time available for prototype development would allow for it (all individuals were asked the same set of questions).

7.3.1 Speech Recognition System

We found that overall the speech recognition system worked very well, with some false positives being the issue. As stated earlier, a superior system would support recognition of inflection in the voice of the LSO and pilot, and this feature will be pursued the in the future version of the system.

7.3.2 Visual Cues

The consensus among LSOs who tried the system, was that rendering of the scene and scenarios visually looked better than they had expected. The suggestion that we adopted was to acquire high-resolution 3D models of the planes and aircraft carrier, which we added to the final version of the prototype training system (Figures 7, 8 and 9). Additional comments concerned the incorrect strobe light patterns for the aircraft and the lack of the "day ID light" that exists on the Super Hornet variants; altering both would be trivial.

Figure 15 shows rendering of the daytime and nighttime aircraft recoveries, with necessary visual cues being presented to the LSOs (nighttime condition will have anti-collision light strobe patterns). LSOs were able to discern all important visual cues in both daytime and nighttime conditions.

A typical scene that shows LSO view during MOVLAS interaction demonstrates great similarity of visual cues seen by LSOs in 2H111 simulator and LSO immersed in VR environment via lightweight prototype training system (Figure 16).

The extreme case of visual task and object recognition that Deck Caller LSO needs to do is to see the signals from the Arresting Gear Officers (AGO) who are located at particular locations on the flight deck (Figure 17). Two virtual humans were positioned at those locations (scale of all 3D models was kept at life-size) and LSOs were asked if they were able to recognize them. All LSOs who tried the system reported as being able to see those figures from the position that corresponded to usual Deck Caller LSO position.

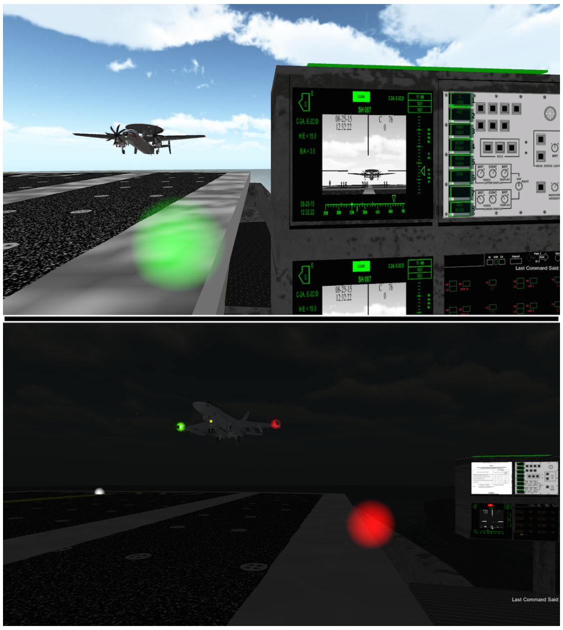

Fig. 15. Daytime and nighttime recovery of the aircraft.

Fig. 16. MOVLAS interface capability with LSODS in both the 2H111 simulator and lightweight LSO prototype trainer.

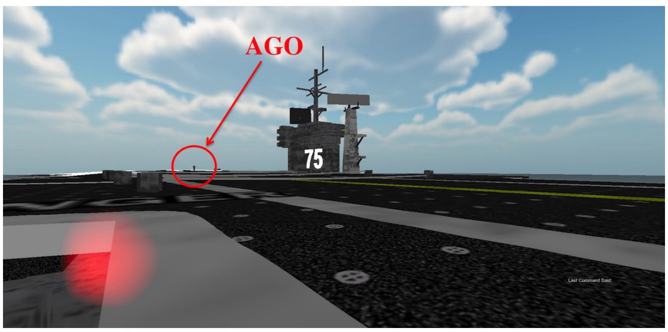

Fig. 17. Portion of Deck Caller LSO's perspective with Arresting Gear Officer being visible on the flight deck.

The overall agreement among the LSOs during the demonstration was that all elements needed to be observed by two LSO positions supported by the prototype were easy to discern from the environment, and that the prototype could support the training of their specific roles.

7.3.3 Landing Signal Officer Display System (LSODS)

The consensus among the LSOs was that the visual representation and functionality (logic embedded in the model) of the LSODS was done very well (Figure 10). The documentation from LSO schoolhouse helped us develop a fully virtualized version of LSODS that did not have discrepancies with what LSOs would experience in the 2H111 or in an operational environment.

LSOs who tried the system commented that some fonts and symbols on the display could be read only in near-optimal condition (LSO directly in front of LSODS and at a relatively close distance from it). There was, however, shared understanding that this was happening due to the low resolution of the display inside the headset.

8 Discussion and Future Work

The results of our feasibility study confirmed that we were able to support all primary design goals initially set up for the prototype LSO training system:

1. *Support major 2H111 training objectives*: The effort of developing the prototype training system committed to fulfill all major training objectives currently supported in 2H111 simulator. All visual and auditory cues needed to support the LSOs tasks (our effort focused on two LSO positions), were painstakingly integrated. The same capabilities were checked against the performance of 2H111 simulator. In some cases, like LSODS and audio files, we used the very same resources used in 2H111 simulator. The element that, by the nature of the lightweight system, we could not and did not try to replicate, concerns haptic sensory information (input and output). The use of physical instrumentation that accounts for haptics in 2H111 simulator, was identified as not being a major training objective; therefore the use of virtual version of the same instrument (predominantly virtual LSODS) was considered to be 'good enough' solution in the overall experience of the LSO trainee. Some elements of the prototype LSO training system were evaluated by LSOs as being superior when compared to the same elements in 2H111 (e.g., quality of rendering and level of realism, FOV for individual LSO).
2. *Use COTS to develop a lightweight VR training system*: The effort needed to prove that it is possible to use commercial off-the-shelf (COTS) technologies to design and develop a lightweight virtual reality (VR) training system for the Landing Signal Officer community. The system that resulted from this effort used an array of COTS input and output devices, with laptop computer as a platform that integrated the work of all components. No custom made technology was used in the process. The development heavily relied on commonly accessible resources, in particular Unity game engine and the family of Unity assets. A total price of all hardware components is calculated to be $3,300 for one system. This makes the system affordable for individual LSOs, which is an important step if its large-scale deployment across the fleet is a goal. The system also fully deserves a lightweight qualifier - it is portable and it does not require any prebuilt physical infrastructure beyond devices it already incorporates.
3. *Achieve high frame rate*: The final system performance proved that at minimum a framerate of 37 frames per second (case when most of geometry in user's field of view) was possible to achieve, allowing for effective and efficient human interaction in the system. Our informal system tests with a group of LSOs have shown that the LSOs tasks were

possible to be executed (system was effective), and that they were possible to be executed with expected performance (system was efficient). A formal usability user study would need to be executed to prove and solidify those initial findings.

4. *Support a range of input devices and interactive modalities*: Implemented prototype system integrated several input devices: Leap Motion Controller, Xbox Controller and keyboard (the latter one was predominantly used for testing and debugging purposes). Additionally, we identified a hand gesture supported by generic capabilities of Leap Motion Controller that allowed the system to recognize users' finger-pointing selection of virtual buttons with high precision (Figure 11). As a result the final system supported very efficient and intuitive interaction with the virtual buttons and dials on Landing Signal Officer Display System (LSODS).

The next stages of the work on this system include a development of features and capabilities that were initially listed as outside of the scope of proof-of-concept prototype training system (this includes development of a federation of applications to support team training), validation of all models and simulated processes that were incorporated in the system (examples: accuracy of aircraft behaviour, ocean movement and ship behaviour), formal usability study of all elements of graphical user interface (GUI), training effectiveness study, system re-design (addition of elements identified as deficient in model validation study and user studies), and transfer of training study. The series of efforts that have been planned illustrate the effort that is needed to bring a proof-of-concept prototype training system to fully-fledged training system that could be used to train current and future LSOs. The institutional support to start executing all those steps, has been secured.

9 Conclusion

The essence of LSOs job is to help the pilots land the aircraft safely. The team of LSOs has effectively 20 seconds to observe the environment, take into consideration all parameters that influence safe aircraft landing, interact with the pilot while giving corrections of his or her operation, and ultimately decide whether the pilot should attempt the landing or the plane should be waived off and requested to try again. In typical situations LSOs have a window of about 20 minutes during which they have to help 15 to 20 pilots land their aircraft. The stringent requirements imposed on this type of operations require that all individuals in the team are highly trained and fully confident in their decisions. The training they are provided with prior to executing this job will help them reach that point. Until now the only options they had available consisted of highly limited number hours in 2H111 simulator and on-the-job training. The creation of the lightweight immersive VR training system enables a paradigm shift in terms of the way in which LSOs could be trained in the future. Unlike 2H111 simulator that is tied to the physical space, the lightweight trainer can be carried anywhere and it can be launched any time, while still fulfilling the training objectives of 2H111 simulator that are deemed highly valuable. The LSO community expressed a great interest in this type of system, and they appear to be very receptive towards this novel training solution. It is now possible to say that the time for LSO training to make the leap to immersive VR has decidedly come.

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References

[1] N.B. Jones, Your Freedom of Information Act Case 2015-NSC-195; DON-NAVY-2015-007332. Norfolk, Virginia: Naval Safety Center, 2015, July 23.

[2] M. T. Schultheis, and A.A. Rizzo, "The application of virtual reality technology in rehabilitation," *Rehabilitation Psychology*, Vol 46(3), Aug 2001, pages 296-311.

[3] J.C. Silverstein, F. Dech, M. Edison, P. Jurek, W.S. Helton, and N.J. Espat, "Virtual reality: Immersive hepatic surgery educational environment,"*Surgery*, Vol. 132, No. 2, Aug. 2002, pages 274–277.

[4] I. Kruglikova, T.P. Grantcharov, A.M. Drewes, and P. Funch-Jensen, "The impact of constructive feedback on training in gastrointestinal endoscopy using high-fidelity virtual-reality simulation: a randomised controlled trial," *Gut*, Vol. 59, No. 2, Oct. 2009, pages 181–185.

[5] M.K. Annett, and W.F. Bischof, "Investigating the Application of Virtual Reality Systems to Psychology and Cognitive Neuroscience Research," *Presence: Teleoperators and Virtual Environments*. Vol. 19, No. 2, April 2010, pages 131-141.

[6] B. Bideau, R. Kulpa, N. Vignais, S. Brault, F. Multon, and C. Craig, "Using Virtual Reality to Analyze Sports Performance," *IEEE Computer Graphics and Applications*, Vol. 30, Issue: 2, 2010, pages: 14 - 21.

[7] N. Vignais, B. Bideau, C. Craig, S. Brault, F. Multon, and R. Kulpa, "Virtual Environments for Sport Analysis: Perception - Action Coupling in Handball Goalkeeping," *The International Journal of Virtual Reality*, Vol. 8, No. 4, 2009, pages 43-48.

[8] M. Cha, S. Han, J. Lee, and B. Choi, "A virtual reality based fire training simulator integrated with fire dynamics data," *Fire Safety Journal*, Vol. 50, May 2012, pages 12–24.

[9] D. L. Tate, "Virtual Environments for Shipboard Firefighting Training," Proceedings of the 1997 Virtual Reality Annual International Symposium (VRAIS '97).

[10] G. Drettakis, M. Roussou, A. Reche, and N. Tsingos, "Design and Evaluation of a Real-World Virtual Environment for Architecture and Urban Planning," Presence: Teleoperators and Virtual Environments, Vol. 16, No. 3, June 2007, pages 318-332.

[11] H.C. Baxter, K.G. Ross, J. Phillips, J. Shafer, and J. Fowlkes, "Leveraging Commercial Video Game Technology to Improve Military Decision Skills," Inter-service/Industry Training, Simulation, and Education Conference (I/ITSEC), 2004.

[12] R.P. Darken, and W.P. Banker, "Navigating in Natural Environments: A Virtual Environment Training Transfer Study," *Virtual Reality Annual International Symposium*, 1998. Proceedings., IEEE 1998.

[13] N.E. Seymour, A. G. Gallagher, S.A. Roman, M.K. O'Brien, V.K. Bansal, D.K. Andersen, and R.M. Satava, "Virtual Reality Training Improves Operating Room Performance," *Annals of Surgery*, Vol. 236, No. 4, 2002 Oct, pages 458–464.

[14] J.M. Nolan, and J.M. Jones, "Games For Training: Leveraging Commercial Off The Shelf Multiplayer Gaming Software For Infantry Squad Collective Training," Master Thesis, Naval Postgraduate School, 2005.

[15] B. Brown, "A Training Transfer Study of Simulation Games," Master thesis, Naval Postgraduate School, 2010.

[16] P. Willemsen, M.B. Colton, S.H. Creem-Regehr, and W.B. Thompson, "The effects of head-mounted display mechanics on distance judgments in virtual environments," *APGV '04 Proceedings of the 1st Symposium on Applied perception in graphics and visualization*, 2004.

[17] W.B. Thompson, P. Willemsen, A.A. Gooch, S.H. Creem-Regehr, J.M. Loomis, and A.C. Beall, "Does the Quality of the Computer Graphics Matter when Judging Distances in Visually Immersive Environments?" *Journal Presence: Teleoperators and Virtual Environments*, Vol. 13, No. 5, Oct. 2004, pages 560 - 571.

[18] J.M. Knapp, and J.M. Loomis, "Limited Field of View of Head-Mounted Displays Is Not the Cause of Distance Underestimation in Virtual Environments," *Journal Presence: Teleoperators and Virtual Environments*, Vol. 13, No. 5, Oct. 2004, pages 572-577.

[19] I.V. Piryankova, S. de la Rosa, U. Kloos, H.H. Bülthoff, and B.J. Mohler, "Egocentric Distance Perception in Large Screen Immersive Displays," *Journal Displays*, Vol. 34, No. 2, 2013, pages 153-164.
[20] K.M. Stanney, and R.S. Kennedy, "The Psychometrics of Cybersickness," *Communications of the ACM*, Vol. 40, No. 8, Aug. 1997, pages 66-68.
[21] K.M. Stanney, R.S. Kennedy, and J.M. Drexler, "Cybersickness Is Not Simulator Sickness," *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, l997.
[22] R. Patterson, M. Winterbottom, and B. Pierce, "Perceptual Issues in the Use of Head-mounted Visual Displays," *Human Factors: Journal of Human Factors and Ergonomics Society*, Vol. 48, No. 3, 2006, pages 555–573.
[23] J. J. LaViola Jr., "A Discussion of Cybersickness in Virtual Environments," *ACM SIGCHI Bulletin*, Vol. 32, No. 1, 2000, pages 47–56.
[24] S. Sharples, S. Cobb, A. Moody, and J.R. Wilson, "Virtual Reality Induced Symptoms and Effects (VRISE): Comparison of Head Mounted Display (HMD), Desktop and Projection Display Systems," *Displays*, Vol. 29, No. 2, 2008, pages 58–69.
[25] B. Geoghegan, "Navigational Heads-Up Display: Will a Shipboard Augmented Electronic Navigation System Sink or Swim?" Master Thesis, Naval Postgraduate School, 2015.
[26] G. Salvendy, “Task Analysis,” Handbook of Human Factors and Ergonomics, John Wiley & Sons, Second Edition, pp 340-416, 1997
[27] Naval Air Systems Command. Landing Signal Officer NATOPS Manual (NAVAIR 00–80T-104). (15 September 2013). Paxtuxent River, MD: COMNAVAIRSYSCOM.
[28] L. Greunke, "“Charlie,” Development of a Light-weight, Virtual Reality Trainer for the LSO Community: Time to Make the Leap Toward Immersive VR," Master Thesis, Naval Postgraduate School, 2015.
[29] J. L. Gabbard, D. Hix, and J. E. Swan, “User-centered Design and Evaluation of Virtual Environments,” Computer Graphics and Applications, IEEE, 19(6), pp 51-59, 1999.
[30] D. A. Bowman, J. L. Gabbard, and D. Hix, “A Survey of Usability Evaluation in Virtual Environments: Classification and Comparison of Methods,” Presence: Teleoperators and Virtual Environments, 11(4), 404-424, 2002.
[31] D. A. Bowman, E. Kruijff, J. J. LaViola Jr., and I. Poupyrev, *3D User Interfaces: Theory and Practice*, Addison-Wesley Professional, 2004
[32] DoDI 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A), 2009.
[33] A. Sadagic, “Validating Visual Simulation of Small Unit Behavior,” *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC 2010),* Orlando, FL.
[34] A. Sadagic, and F. Yates, "Large Scale Adoption of Training Simulations: Are We There Yet?" Interservice/Industry Training, Simulation, and Education Conference (*I/ITSEC 2015)*, Orlando, FL.