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Validation of virtual command bridge training environment

Comparing the VR-training with ship bridge simulation

Jenny Lauronen[1,2], Werner Ravyse[1], Mirva Salokorpi[2], Mika Luimula[1]

[1] Turku University of Applied Sciences, [2] Novia University of Applied Sciences

Abstract. In this validation exploration, we have studied a virtual reality ship command bridge against the standards and regulations that maritime training simulators must adhere to. We created a virtual reality replica of a command bridge with limited functionality that underwent user testing with 16 experienced ship officers. The results show that our training application did not meet all simulator criteria, but we point out that each of the shortcomings can be overcome with new generation hardware and expanded virtual reality programming. Our conclusion is that VR is a valid, affordable and efficient tool for command bridge simulator training.

Keywords: Virtual Reality · Maritime education · Ship Bridge Simulation

1 Introduction

Decision-making on ship bridges is a challenging professional skill. In many seafaring traffic situations, complex permutations affecting safe ship navigation can develop within minutes. Such challenging traffic situations, combined with fairway limitations, require a clear understanding of decision priorities. Simulated reality offers a realistic hands-on training environment for maritime students and professionals where they can practice situational decision-making in a protected environment [1]. Simulation training is also able to impart or improve application methods and motor skills [2] and although simulation training is a well-established educational method in seafaring, in its traditional form of room-scale simulators, it is expensive and significantly constrained for training officers at sea. The International Chamber of Shipping estimates that the maritime industry currently employs 1,7 million seafarers, of which 0,6 million are officers requiring simulator training. Excessive simulator costs are the leading cause that globally, many maritime officers are not able to benefit from traditional simulator training.

Virtual reality (VR) head-mounted display (HMD) training environments, on the other hand, present an affordable, measurable and repeatable training alternative in a variety of disciplines [3].The latest VR headsets no longer require beacons for player orientation within the virtual space, making them highly portable and suitable for delivering sea officer instruction anywhere. Other pertinent benefits include a high training immersion [4] and the possibility to include the attributes and behaviors of multiple ships on a single VR training scenario. The question is whether VR HMD training is able to meet the learning outcomes as expected from traditional simulators?

This paper presents a partial validation of a ship bridge VR HMD environment against a ship bridge simulator. The validation objective was to determine whether the further development of command bridge VR headset training is warranted. This paper also defines a set of validation criteria and indirectly establishes suitable verification guidelines for VR headset ship navigation scenario development. Our validation environment was designed to acquaint captains with ship bridge systems and train safety-critical decision-making for collision avoidance. We focused our validation efforts on the basic functional fidelity of steering and navigating a ship by measuring both usability and training relevance. This paper does not include technical verification, but rather emphasizes the system and content suitability for maritime training in comparison to known simulator training.[1]

2 Current simulator training practices

The International Maritime Organization (IMO) drives the obligation for continuous training and upkeep of seafaring skills and since practical skills can be learned and understood best through hands on practice, simulators are a focal training method in seafaring. Some of the core seafaring skill standards of competence to be learned by simulation training are prescribed by the Standards of Training, Certification and Watchkeeping for Seafarers (STCW). These standards form the basis of simulator validation and therefore, also the VR environment we set out to test.

The validation in this study is based on the STCW code for operational level requirements, explained in the DNVG-ST-0033 *Standard maritime simulator systems* by De Norske Veritas and the IMO Model Course 6.10 *Train the simulator trainer and assessor*. These references describe the training requirements for the four different simulator classes (A, B, C and S)[2]. Table 1 shows the competences for each of the simulator classes and indicates the competences used for our VR validation. The development of ship maneuverability (our primary case for validation) for VR caused incidental (but partial) development of: (a) planning and conducting a passage and determining position; and (b) maintaining a safe watch. Hence, limited aspects of these competences also cropped up in our validation testing.

Maritime training simulators consist of computer software systems that mimic the dynamics of a real-time environment and a physical simulator bridge comprising real consoles and instrumentation. Simulators are almost exclusively placed indoors with the simulated environment projected on several large monitors, affording trainees with a 120 to 180 degrees view of the scenery. The software realistically simulates physical ship behavior in response to navigational input from trainees and environmental factors such as weather conditions and water effects. Simulators additionally allow for the inclusion of system failures and other incidents.

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[1] For the further duration of this paper, VR will refer to VR HMD and the term simulator will reflect traditional (or current) simulators.

[2] Class A (Full mission); Class B (multi-task); Class C (limited task); Class S (special tasks, performance defined case by case)

Table 1. Simulator competences used for VR simulator validation (adapted from DNVG-ST-033).

STCW Reference	Competence	Class A	Class B	Class C	Class S	VR sim
Table A-II/1.1	Plan and conduct a passage and determine position	Yes	Yes		Yes	Limited
Table A-II/1.2	Maintain a safe navigational watch	Yes	Yes		Yes	Limited
Table A-II/1.3	Use of radar and ARPA to maintain safety of navigation	Yes	Yes	Yes	Yes	
Table A-II/1.4	Respond to emergencies	Yes	Yes	Yes	Yes	
Table A-II/1.5	Respond to distress signal at sea	Yes	Yes	Yes	Yes	
Table A-II/1.8	Maneuver the ship	Yes	Yes	Yes	Yes	Yes

The IMO describes simulator training sessions as a four-step process that begins with an instructor briefing where officers are introduced to the scenario surrounding their navigational challenge. After the brief, officers must plan the ship's course before moving to the command bridge simulator where the scenario unfolds on the screens and instrument panels. The instructor, who is in a different room, now manipulates the various inputs that influence the scenario while maintaining continuous communication with the officer. Upon completion of the session, officers once more meet with the instructor for an in-depth debriefing.

The trainer's role in simulation training is formidable because the laws and regulations of seafaring are largely subjective. This implies that the instructor must be able to interpret all trainee decisions and actions within the context of the scenario. The result is that trainers must be skillful enough to convey complete understanding of the scenario outcome to the officer [5]. A second major challenge trainers face is to scaffold the scenario appropriately. That is, in order to eliminate much of the subjectivity, trainers can simplify the scenario by removing variables or reducing their effect on the navigation task. This would prohibit officers from potentially learning incorrect responses but runs the risk of over-simplification that could result in a false sense of know-how. Trainers must be conscious of this scaffolding balance throughout the training session.

3 Experiment design

The VR ship bridge for validation is a general model of a 170-meter containership. The bridge facilities include steering, speed control and typical ship bridge equipment, such as Electronic Chart Display and Information System (ECDIS), radar and control screens. The VR environment (Figure 1) was created using the Unity game engine and utilizes HTC Vive as the VR hardware.

The VR task was to safely maneuver the containership through a section of the strait of Denmark and avoid grounding or colliding with another vessel. This other vessel (a fishing boat) in the scenario was not visible from the electronic charts because the automatic identification system (AIS) was not connected. Participants could only see the fishing boat by using radar or looking out the window. However, the radar was set for rainy weather, which hides fairway signs and small objects and participants were expected to adjust the radar settings at the start of their session.

Fig. 1. Command bridge in VR scenario.

To understand the VR bridge maturity, user testing was conducted with 16 sea officers. They were master students, teachers or the trainees of Aboa Mare maritime academy with at least four years of officer experience.

Since 13 participants were completely new to VR, the exercise started with a short familiarization whereby all VR functionalities and the controllers were tested—this lasted about 90 seconds. Soon the users felt comfortable and the exercise could start. Navigating the vessel to clear waters took between 9-13 minutes, depending the speed used. The users were not advised about the speed range they should maintain, but they knew the normal speed in such traffic situations would be 12-18 knots. Our VR headset scenario hydro-dynamic model has a limited water-to-vessel interaction speed range of 5-20 knots.

The validation results were obtained through observation, questionnaires and interviews. The observation phase resulted in a set of notes from the research team and the session trainer. The researchers and trainers analyzed and discussed the notes and the key observations served as input for the free-form interviews that concluded the experiment. The participants filled system usability scale (SUS) questionnaires immediately after their VR session. This was done to verify the extent that usability concerns may have influenced the validation results. The researchers summarized the interview notes and wrote the conclusion in collaboration with the trainers.

4 Findings and results

Observation showed that as long as the participants were uncertain about the VR technology, their gaze locked onto the control panels, but as soon they became familiar with the VR equipment, they started to behave as in real life by looking around and maneuvering as required. The VR controllers appeared to be ungainly and participants struggled to use all the command bridge instruments. Levers and large wheels were easy to handle, but dials with small turning angles and sensitive feedback systems posed problems for the controllers, as did closely spaced buttons. Also, participants were forced to look at the virtual equipment in order to align them with the controllers, hampering habitual hand movements that would normally be able to blindly find ship controls. When turning the ship, five of the participants reached for a support in the virtual world to prepare them for the tilt of the vessel. Since this support was not physically present, these participants slightly lost their balance infringing upon their scenario immersion. No-one claimed cyber sickness during or after the exercise.

The interviews were open discussions with the objective of forming an opinion on the validity of using VR as collision avoidance training to be used in off times during an actual sea voyage. Eleven participants claimed that it was a positively interesting experiment and that they would be willing to test it again after the next development stage. The other five participants found it strange or uncomfortable and did not believe it could be useful for training as it is. There was consensus among the participants that this VR training would be most suited for basic education, rather than advanced scenarios. All participants were delighted with the VR solution's high visual fidelity. The problems they pointed out were centered around the controllers and how this would affect user and training experience.

The SUS is a barometer indicating how much work is left before the system in question could be considered usable—a score of 68/100 is viewed as sufficiently usable with some work to be done [6]. Our VR command bridge scored 66/100. The areas where participants were most satisfied included the system consistency (73/100), the low level of complexity (78/100), onboarding (81/100) and learnability (72/100). On the other hand, the system integration was considered weak (52/100) and many participants felt they would need technical assistance at some point (56/100).

5 Discussion: VR simulation validation and verification criteria

Simulation pedagogy highlights that physical fidelity, behavioral fidelity and the operating environment are influential in VR solutions [7].

We addressed the physical fidelity by creating a virtual space that accurately follows a real ship bridge and further strengthened the onboard experience by including vessel traffic service radio. Our efforts were well-received and evidenced in the direct participant comments indicating appreciation for the physical realism of our VR setting.

Although our system's behavioral fidelity was not faulted in the direct maneuvering of the ship, it is compromised through a limited hydro-dynamic model. This is highlighted in a general sentiment that VR would only be useful in basic training. Such remarks were not unexpected since the VR scenario for this study was only a partial representation of the current simulator capabilities and the simple scenario was not aligned with the participant level of skill and experience. Nevertheless, to rectify the current misgivings in the target use of VR in ship navigation training: (a) the vessel response to various weather conditions must be refined; (b) the speed range where the ship behavior is natural should be increased; (c) fully functional ECDIS and automatic radar positioning aid systems must be present; and (d) autopilot must be available.

The challenges in the operating environment are somewhat more complex to overcome, as they are related to hardware (rather than programming) limitations. The control system restricts training potential through unwieldy controllers that are unable to adjust finer dials or press closely spaced buttons. Moreover, the controllers obstruct the training by disqualifying habitual movement, which can potentially lead to facilitating bad habits during training that will manifest in unsafe ship navigation. An additional operating environment stumbling block that our VR training scenario revealed, was the HMD's low resolution. Low resolution made it difficult for our participants to observe finer details, such as gauge readings and ECDIS communication. During the course of this validation test, a new generation of high-resolution VR headsets that include finger tracking were released. These headsets could potentially address both crucial operating environment limitations our VR scenario exhibits.

Current practices highlight that a primary strength of simulator training lies in the close instructor-learner collaboration to mimic the teamwork essential in successful ship navigation. The fidelity of an embedded teacher avatar, as a scenario character, is a proven learning facilitator in serious games [8], leading us to conjecture that either asymmetric or conventional multi-player VR scenarios could address teamwork aspects.

Debriefing sessions, known to be a crucial component of the learning process [5], are well-integrated into simulator training and usually happen on the basis of trainee actions recorded during a scenario and discussed post-exercise. VR scenarios should therefore ensure that a there exists a sub-system that collects, stores and reproduces the learning analytics required for meaningful debriefing sessions.

Simple scenarios work well in familiarization and part-task learning. Simulator training sessions are hallmarked by dynamic scaffolding to maintain optimal learning opportunities. By gradually increasing the fidelity and realistic complexity of the tasks, the simulation training goes to higher levels of learning [2]. Research and development of dynamic manipulation of variables in VR scenarios is in its infancy, but given the potential of VR in maritime and other fields utilizing dynamic simulation training, this is certainly worth investigating.

VR's propensity for high immersion also reaches beyond the test scenario, as demonstrated by our participant response of reaching for a stabilizing table in the virtual world. This places trainees in situations where the physical environment could be hazardous and should therefore, be addressed when considering VR simulation training.

6 Conclusion

In this paper we set out to validate whether VR would be a suitable alternative for traditional simulator training. We did this by developing a VR experience that focuses on the ship maneuvering competency from the STCW. User testing with 16 experienced sea captains led us to uncover various shortcomings in our VR training environment.

These include unnatural controllers, low HMD resolution, limitations in ship behavior, a lack of interaction with the trainer, missing documentation for meaningful debriefing sessions, omitted possibility to dynamically change environment variables and jeopardized physical safety of the trainees. However, we point out that these drawbacks do not invalidate VR as a simulator training opportunity as each of the challenges can be resolved, be it with next-generation headsets or more elaborate software engineering. The listed shortcomings should be viewed as a verification checklist for VR command bridge simulator development.

We have found the VR simulation environment immersive, interactive and useable, making it a valid tool for command bridge simulation training. VR offers, over traditional simulators, an affordable and efficient training tool that allows officers to practice critical decision-making across a full range of variables and situations. User experience and usability testing among highly experienced seafarers are essential for determining an authentic training interface and in collaboration with maritime education specialists and VR software engineers, VR has the potential to provide much sought-after simulator training to a considerably larger ship officer audience than at current.

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