Virtual Reality Simulator implementation in the Norwegian Coastal Administrations' Pilot Service

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Abstract

With millions of tons of cargo transported to and from Norwegian ports every year, the maritime waterways in Norway are heavily used. The high consequences of accidents and mishaps require well-trained seafarers and safe operating practices. The normal crews of vessels are supported by the Norwegian Coastal Administration (NCA) pilot service when operating vessels that do not meet specific regulations. Simulator training is used as part of the toolset designed to educate, train, and advance the knowledge of maritime pilots in order to improve their operability. The NCA is working on an internal project to distribute Virtual Reality (VR) simulators to selected pilot stations along the coast and train and familiarize maritime pilots with the tool. There has been a lack of research on virtual reality simulators and how they are implemented in maritime organizations. The goal of this research is to see if a VR-simulator can be used as a training tool within the Norwegian Coastal Administration's pilot service. Furthermore, the findings of this study contribute to the understanding of VR-simulators in the field of Maritime Education and Training (MET). This paper addresses two research questions:

1. Is virtual reality training useful in the competence development process of Norwegian maritime pilots?

2. How can virtual reality simulators improve the training outcomes of today's maritime pilot education?

The data gathered from the systematic literature review corresponds to the findings of the interviews. Considering the similarities with previous study findings from sectors such as healthcare, construction, and education, it is concluded that the results of the interviews can be generalized. For maritime pilots, the simulator offers recurrent scenario-based training and a high level of immersion. Pilots can learn at home, onboard a vessel, at the pilot station, and in group settings thanks to the system's mobility and user-friendliness. In terms of motivation and training effectiveness, the study finds that VR-simulators are effective and beneficial. The technology received positive reviews from the pilots. According to the findings of the research, the simulator can be used to teach both novice and experienced maritime pilots about new operations, larger tonnage, and new operational areas. After the NCA has utilized VR-simulators for some time, additional research may analyze the success of VR-simulators using a training evaluation study and investigate the impact of VR-training in the organization.

1. Introduction

With millions of tons of cargo transported to and from Norwegian ports every year, the maritime waterways in Norway are heavily used (SSB, 2021). The high consequences of accidents and mishaps require well trained seafarers and safe operating practices. The normal crews of vessels are supported by the Norwegian Coastal Administration (NCA) pilot service when operating vessels that do not meet specific regulations. With a wide range of different sorts of pilotage and challenges involved, and ships ranging in size from 70 meters to 400 meters, over 40 000 ships that visit Norway each year have a pilot onboard (kystdatahuset.no, 2022). The toolset utilized to educate, train, and expand the expertise of marine pilots in order to increase their operability includes simulator training.

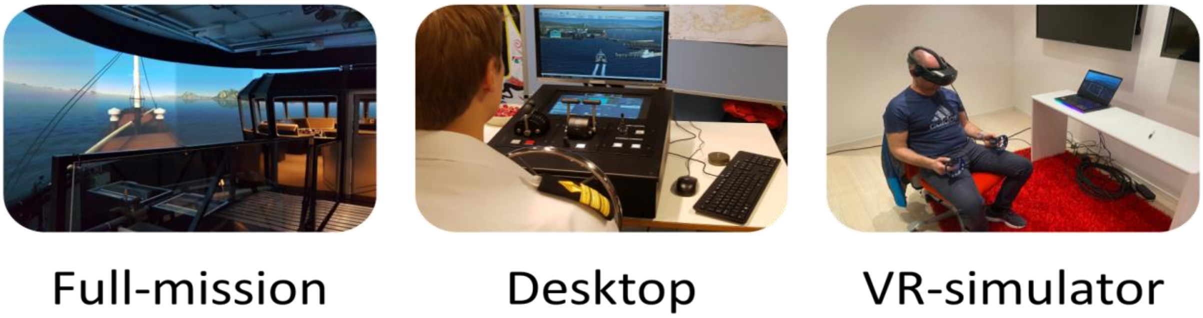

Figure 1: Different types of Maritime Simulators

Full-mission bridge simulators incorporate a real bridge atmosphere and screens or projectors. These simulators require a lot of room and are often custom-built sets. Full-mission advantages include a high level of immersion, and the ability to simulate complex scenarios. A desktop simulator is one that is designed to imitate a certain environment with ease of access. These simulators operate on machines with less processing capacity, resulting in a lower level of immersion. Here, one may provide input on or imitate a certain navigational instrument or other piece of equipment. These systems are often small and do not immerse the learner in the surroundings. In comparison to the full mission bridge simulator, it is incapable of immersing the learner in complicated scenarios using various instruments and physical control surfaces. They are often controlled by a keyboard and mouse, or by a reduced joystick and handle. Similar to desktop simulators, VR-simulators are easy to operate, and require low levels of resources and space; however, they maintain a full-mission immersion experience.

Under the COVID-19 pandemic, traveling to and from simulator centers became increasingly difficult. In order to maintain knowledge and train on new scenarios, the NCA started an internal simulator project. The internal project aims to find a technology that facilitates mobile, on-demand training. Virtual Reality (VR) was identified as the most promising technology, and the NCA Pilot Service started to distribute VR-simulators to selected pilot stations along the coast to train and familiarize maritime pilots with the tool. There has been a lack of research on virtual reality simulators and how they are implemented in maritime organizations. The goal of this research is to see if a VR-simulator can be used as a training tool within the NCA pilot service. Furthermore, the findings of this study contribute to the understanding of VR-simulators in the field of Maritime Education and Training (MET). The research was part of a master’s thesis conducted at UiT The Arctic University of Norway in the spring of 2022 (Weissenberger, 2022).

2. Research method

Under the qualitative research methodology branch, a semi-structured interview and a systematic literature review were chosen as suitable methods. The different interview techniques, such as structured, semi-structured, and unstructured interviews, were studied to determine which method would suit the research questions best. The nature of semi-structured interviews allows for information gathering with a structured approach while being open to other inputs from interview subjects (Harrell & Bradley, 2009).

The systematic literature review provides qualitative data in the form of findings that previous research has concluded with. The systematic literature review allows for the collection of multiple points of research done in other industries, fields, and types of research. The result of conducting a systematic literature review is generally understood as setting the framework for research. However, it can also be used to establish state-of-the-art knowledge and be a collection of qualitative data. As Denyer & Tranfield (2009, p. 671) described:

"A systematic review should not be regarded as a literature review in the traditional sense, but as a self-contained research project in itself that explores a clearly specified question… ".

Both the systematic literature-review and the semi-structured interview are used to determine the VR-simulators' place in the pilot service of the NCA.

This study addresses two questions:

1. Is Virtual Reality training useful in the competence development process of Norwegian maritime pilots?
2. How can Virtual Reality simulators improve the training outcomes of today's maritime pilot education?

The literature used in the project has been sourced from multi-database search engines, such as Google Scholar, ScienceDirect, and PubMed. The literature study is based on inclusion and exclusion criteria. With VR and VR-training being very general terms used in many different approaches and areas, it is important to set specific search criteria to exclude fields of non interest. In order to filter the publications found in the different databases and identify their relevance to the thesis, some inclusion and exclusion criteria have been set. In the figure below, the inclusion and exclusion criteria are presented and listed. The criteria are selected to assure the relevancy and quality of publications used in the thesis.

Included

- Publications identified as relevant in citations
- lecture and staff recommended papers
- Publications with implementation studies, clinical trials, case studies and experiments

Excluded

- No full access
- only abstract published
- no citations
- no clinical trial, case or experiment.

Figure 2 Selection criterias publications

The literature search presented a total of 169 publications. After the first screening for inclusion and exclusion criteria, 152 publications remained. The first exclusion examined the publication's language, open-access status, and presence of a trial, case, or experiment. The second exclusion occurred after a content review of 152 articles. Some were rapidly rendered irrelevant, while others were difficult to classify. The inclusion and exclusion judgments followed the criteria. Following the reading and analysis of the abstracts and substance of the articles against the inclusion and exclusion criteria, a total of 76 publications remained for the literature study.

Search Engine	Search String	Results		Results		Total
PubMed	(("VR"[Title/Abstract] OR "virtual reality"[Title/Abstract]) AND "Education"[Title/Abstract]) AND ((ffrft[Filter]) AND (clinicaltrial[Filter] OR randomizedcontrolledtrial[Filter]))	48	First exclusion	45	Second exclusion	29
Google Scholar	allintitle: Virtual reality in education hmd OR VR OR training OR implementation "Virtual reality in education"	41		32		12
ScienceDirect	Education VR training Virtual Reality HMD Head mounted display Title, abstract, keywords: (Virtual Reality OR VR) AND Education	80		75		35
Total		169		152		**76**

Figure 3 Publication overview

3. The VR-simulator

The simulator consists of the Morild Bridge&Ship simulator software, laptop, a Head Mounted Device (HMD), and controllers. The requirements for the laptop are given by the developers, and a powerful Graphics Processing Unit (GPU) as well as a powerful Central Processing Unit (CPU) are needed. The quality of the experience is reliant on the HMD and controllers, which benefit from being state-of-the-art devices.

The key difference between a traditional simulator setup, such as desktop or full-mission, and the Morild VR simulator is how the user interacts with the bridge operating equipment. Everything is virtual in the VR simulator, which opens new options for customizing bridge equipment and layouts for individual vessels and propulsion system combinations.

The “helmsman” function, which lets single-player and multiplayer players speak with an autonomous “helmsman” through voice commands, allows them to direct the course, steering input, and throttle control of their vessels. “Linesman” and “tugboat” are two more voice-activated functions that help to secure the vessel to quays and barges while also maneuvering the vessel with the use of tugboat orders. Helmsman, Linesman, and Tugboat are robots that use Natural Language Processing (NLP) in order to react to a voice command given by the person(s) who are using the VR-simulator. The voice commands are pre-defined, and for the Helmsman, the Standard Maritime Communication Protocol (SMCP) is used (IMO, 2002).

The simulator gives outstanding images that are based on data from publicly available terrain databases (GeoNorge.no, 2022) as well as infrastructure from OpenStreetMap and manual 3D modeling. Further navigational aids and maritime infrastructure are partly sourced from NCA’s databases. In addition, the user has the option of changing position to a predetermined position or moving freely over the bridge. Monitors like conning screens, ARPA radars, and fully updated ECDIS displays may all be utilized to keep a watch on the voyage. Panels may be made larger by selecting them and dragging them around. It is also feasible to communicate between boats in a functional manner using a simulated VHF radio.

Instructor control is either on the local host that portrays the VR or on a different computer that the users are connected to. The multiplayer functionality is run over the internet, so users can be connected from anywhere. The instructor may view a relay of the user's VR vision on the screen or observe the interaction on the ship’s bridge. The instructor may also alter meteorological elements such as the direction and strength of the wind and current.

The instructor's view has multiple functions ready for either an external instructor or the user themselves to modify the scenario in training situations. The different functions of the instructor’s view are shown and explained in Figure 8. The VR-simulator is still under development. Any functions shown in the figure may change in later versions. This is only shown as an introduction to the use of the simulator.

4. Simulator courses

The NCA Pilot Service provides several courses to complete the training to become a pilot. To be admitted as a pilot apprentice, the applicant must meet the qualifications specified by separate regulations (Forskrift om opplæring og sertifisering av loser, 2019). This includes a master's exam, a minimum master's certificate, at least three years of seagoing service as a responsible duty officer, and impeccable character. In addition, the pilot must maintain their knowledge of the waters (norwegian “loslekse”, english translation “pilot book”), stay current on laws and regulations pertaining to the service of pilotage, and meet minimum requirements for completing voyages in the fairways in the certificate area with an appropriate vessel, possibly with the use of a simulator. In general, a pilot apprentice is trained for 1,5 years before becoming a qualified pilot. The criteria for applying as a pilot apprentice is generalized to have about 5-15 years of experience sailing different types and sizes of ships, and most pilot apprentices have reached the position of captain before applying as pilot apprentices.

As a Pilot Apprentice, the main focus is on learning the methodology of the pilots (mentoring), but in addition, simulator scenarios are applied for specific training such as maneuvering and communication training. For qualified pilots, special simulator courses are set up on demand, such as learning how to use tug boats, conducting rig moves, or training on specific ports that are especially challenging.

The NCA Pilot Service would also like to have a simulation tool available, which makes it possible for the pilots to train on-premise (at the pilot station) and for the upcoming demand. With the VR-simulators, this can be facilitated by having a set of standard models and a database of the whole pilotage area (Norway) with harbors available for training purposes.

There has also been conducted trial testing of new fairways, in order to quality assure the planning process of new aids to navigations or extensions to specific fairways. The interaction between Subject Matter Experts (SMEs) such as pilots and maritime fairway planners in the NCA has shown good potential. When conducting 3D visualization of a specific project, the visualization has facilitated better understanding between different SMEs, such as pilots, tugboats and project planners.

The data collected for this study was based on a special operation course, which implied training with a large cruise vessel (344 meters long, 42 meters wide, 11 meters draft) on the challenging entrance of the port of Haugesund (Figure 5). 46 pilots from the respective pilotage area conducted the simulator course with the VR-simulator for the port of Haugesund, and a total of 16 participated in the data collection for this project.

In addition, the data collection includes a special operation course for entrance to the port of Narvik (Figure 4) with large bulk vessels using tug boats with six pilots from the respective pilotage area (Loedingen). The ore carrier is 292 meters long, 48 meters wide, and has a draught around 8 meters. A total of four participants took part in the data collection in Loedingen.

Figure 4 Port of Narvik

Figure 5: Port of Haugesund

5. Results and discussion

The systematic literature review identified that in the field of education, the use of VR-simulation resulted in higher training motivation, effectiveness, and knowledge retention (Fischer et al., 2021; Shibata, 2019; Wong et al., 2020). This is further supported by the interview conducted with maritime pilots. Firstly, most of the pilots participating in the study had never used any type of VR-simulator. Some mentioned the fact that they had never used any type of gamified computer hardware or software and were relatively skeptical of the system. However, after using the VR-simulator for some time (approximately 15 minutes), the participants were impressed by the performance, especially the visuals the simulator provided. However, the task of controlling the simulator was a more diverse result, where there was some mixed feedback in the interviews. This is also mentioned in multiple studies regarding education with VR-simulators (Hatchard et al., 2019; Kariapper et al., 2021; Makransky et al., 2019; Smutny et al., 2019). To be able to control the simulator effectively, a familiarization period was needed. The interviewees were clear on how a familiarization period before entering a real scenario helped them perform better. When comparing VR-simulators and conventional simulators, some advantages were identified.

The interview subjects highlighted the usability and ease of the simulator as one of its major advantages. For maritime pilots to train in conventional simulators, they would have to travel to a location with an existing simulator and consume financial and time resources to train. They argued that the mobility, cost, and low-effort nature of the simulator provided good training opportunities in the area they were located. This key advantage is identified and further supported by previous research conducted on VR-simulator training (Young et al., 2020).

Some literature showed increased knowledge retention if students have text annotations displayed in the virtual world (Albus et al., 2021; Baceviciute et al., 2021). On this point many of the maritime pilots pointed out how the simulator can be used in the education of new pilot cadets. Where mountains, landmarks, navigational marks, etc. could be annotated or highlighted to show the simulated location and teach the student the "loslekse" (pilot book) as a supplement. On the other side, this may increase the cognitive load of the users in the scenario. However, one study argued that the learning was more effective but came at the cost of an increase in training time and cognitive engagement (Baceviciute et al., 2021).

With the maritime pilots being able to recognize the area, their situational awareness increased, and they performed better in the scenarios, multiple participants reported. This is further supported in the literature review, where it is found that VR-simulators are especially useful for training for operations where spatial and environmental awareness are important (Eiris et al., 2021).

Debriefing students after performing a VR-simulator task resulted in increased knowledge acquisition (Luo et al., 2021). This is supported by feedback from some of the pilots, where they mention how the cooperative nature of the simulator, as well as being able to overview the scenario from the instructor screen, made it possible to catch details in how more experienced pilots operated the vessel. This was especially introduced as an effective means of learning about larger tonnage vessels for pilots who did not have the large tonnage certificates required for these areas.

The literature also found that if the digital environment simulated is as close to real life as possible, the training output can even be increased in comparison to more traditional teaching methods such as classroom lectures, informative videos, and object analysis (Calvert & Abadia, 2020; Carrion et al., 2021; Hallberg et al., 2020; Krüger et al., 2022; Meyer et al., 2019). Likewise, the maritime pilots reported high learning efficiency due to the visual quality of the image and its resemblance to the real world. All the pilots reported on being familiar with areas, and recognizing local landmarks, buildings, mountains, and other reference points they had acquired over the years.

The field where VR-simulators are most researched and implemented is healthcare. These studies also conclude with increased training motivation, excitement, and training output (Botha et al., 2021; Bracq et al., 2021; Breitkreuz et al., 2021; Kaphingst et al., 2009; Lesch et al., 2020). However, one is not able to necessarily generalize these findings and project them onto MET. Moreover, the VR-simulators used in healthcare are often very task-specific, where training on one special procedure is simulated. Students in these healthcare simulators have to encounter unforeseen changes in the virtual patient's condition and adequately react. This can be generalized and compared to the operation of ships. Whereas a surgeon is continuously watching and monitoring the vital parameters of a patient, this also applies for maritime pilots, where monitoring the position, navigation, and operation of the vessel while anticipating the coming maneuvers is a key factor in their work. The effectiveness of the VR-simulator shown in the healthcare fields, may provide an argument for why VR-simulation can be useful for the pilots. Since controlled, specific scenarios are best trained with the VR-simulator, this also fits into how maritime pilots can design their scenarios. Shorter scenarios through narrow passages, docking operations, or maneuvering are all suitable for the VR-simulator.

Other scenarios may be specialized situations such as oil rig moves or other operations maritime pilots seldomly perform. This was brought up by numerous pilots in the interviews, as they found the potential for the simulator to be highlighted most with being able to simulate special operations before they do the mission.

On VR-simulation induced symptoms and VR-sickness, there were some astounding findings. While previous research (Harrington et al., 2018; Servotte et al., 2020; Sharples et al., 2008) mostly recommends limiting the symptoms of VR-sickness, by having scenarios limited to 20 minutes, this was consequently different in the VR-simulation course run in Haugesund and Loedingen. While some participants reported minor cases of headache, dizziness, or fatigue, the majority felt fine after being in the simulator. The special thing about these courses was the duration of the scenarios, where participants were immersed in the VR-simulator for one to two hours at a time. In the most extreme cases, the participants were in the environment for more than three hours. Surprisingly, no major sickness was reported, except for some tiredness in the eyes from wearing the HMD. A suspected cause for this severe lack of VR-sickness is the quality of the technology. In studies conducted on the causes of VR-sickness, it is determined how latency, visual quality, framerate, and other technical factors all contribute to VR-sickness (Porcino et al., 2022). With the simulator being as optimized as it is, running on last-generation HMDs with high resolution and powerful laptops, the movements of the participants did cohere with the view and control of the simulator. Some participants even reported the feeling of being so immersed that they wanted to lean on walls present in the virtual environment but not in the physical environment they sat in. Another argument for why they were able to operate the simulators with few symptoms of VR-sickness is thought to be the fact that most of the time they sat still on a chair. Some of the participants stood up in order to get a better view of the maneuvering operation and mentioned how they became more unstable and dizzier. However, this was only reported by a few participants. The theory of participants not experiencing symptoms while being stationary in a chair is further supported by studies identified in the literature review (Porcino et al., 2022; Sharples et al., 2008).

The advantages the simulator provides for maritime pilots enables repetitive multi-scenario training. The mobility and ease of use of the system can also allow for pilots to train at home, take it with them on a vessel, at the pilot station, as well as in group settings to discuss different solutions and options. From the interview results, the simulator can provide a tool for both new and experienced maritime pilots, to train for further upgrades of their certificate. Especially the new maritime pilots, who are experienced mariners and must learn the “loslekse” (pilot book), are able to familiarize themselves with the area using the VR-simulator. As the education to become a certified maritime pilot is busy, time-consuming, and strict, newly educated participants emphasized the importance of not removing any of the education but using it as a supplement to the existing training. More specifically, the introduction phase of the training was argued to be well suited for familiarization of the area in VR-training. Further, more experienced maritime pilots can get familiar with large tonnage vessels, or special purpose vessels, in scenarios seldom conducted. The possibility for further usage is also available.

The pilotage regulations mention familiarization, and a minimum number of voyages may be done in simulators. If the simulator is classified correctly, the familiarization of areas can even be accepted as a certified training option. However, the maritime pilots argued strongly against substituting any real-world experience gathering in favor of simulator usage of any kind. They were adamant about keeping the simulator as a supplement to the existing training and not introducing it as a replacement.

Using the four training assessment levels of Kirkpatrick (Kirkpatrick & Kirkpatrick, 2016; Smidt et al., 2009), one might claim that the VR-simulator implementation is in its early phases. The levels indicate the success of training within the organization, and while the VR-simulator is only beginning to be used by the NCA, it has been accepted. The "response" level of Kirkpatrick's model for evaluating training provides distinct answers. With the good responses from marine pilots, the first level 1 assessment is positive. The potential of the technology is elucidated, and marine pilots responded favorably to inquiries about the simulator's future in their training.

Level 2 of Kirkpatrick's training model examines whether or not the pilots have acquired adequate knowledge and skills via training. Efficiency in time utilization and training output were highlighted as significant elements in the interview replies on the training output.

Levels 3 and 4 of Kirkpatrick's evaluation of training cannot be addressed in this thesis. Due to the research's constraints about the early adoption of the technology, it is currently not possible to quantify the impact on the organization. However, some pilots said that the information gained in the training prompted them to consider future decisions. This suggests that Kirkpatrick's training assessment for level 3 might be tested relatively soon. With level 4 evaluating direct training results, this would be an excellent topic for future research. Future research on the effect of introducing the VR-simulator into an organization such as the NCA Pilot Service would be advantageous for MET, despite the fact that evaluating the benefit of VR-training versus traditional simulator training may present some challenges.

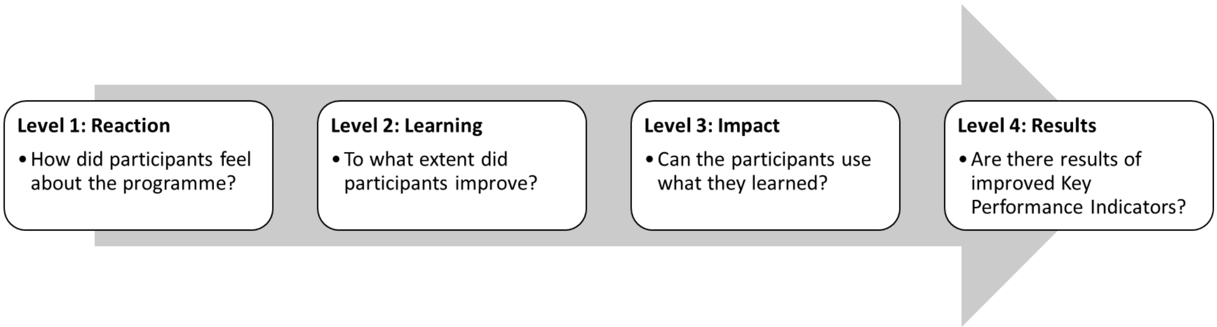

Figure 6 Kirckpatrick`s four levels of training assessment

6. Conclusion

This study used qualitative methods to determine how the VR-simulator can be used in maritime pilot training. The systematic literature review analyzed 76 publications from multiple fields. To generalize and contribute to the field, it's important to find common findings across industries and research fields. Previous research on VR-simulators focused on non-maritime industries. This thesis contributes to maritime education and training and VR simulation research.

The simulator helps maritime pilots train in multiple scenarios. The system's portability and user-friendliness allow pilots to train at home, aboard a vessel, at the pilot station, and in groups to discuss different options. The simulator can train new and experienced maritime pilots on new operations, larger tonnage, and new areas based on interview results. The simulator was a groundbreaking technology that provided excellent training. Most respondents supported VR-simulators in the Norwegian maritime pilot organization. The VR-simulator shouldn't replace existential training but rather supplement it. The findings on the benefits of training with the VR-simulator match the findings from the systematic literature review and NCA survey.

Is Virtual Reality training useful in the competence development process of Norwegian maritime pilots?

The maritime pilots who participated in the VR-simulator courses were pleased with the training output and cited its efficiency, usability, portability, and immersion as key success factors. This is supported by previous research on training in VR-simulators conducted in other fields. The simulator was regarded as an excellent training tool for both novice pilots seeking familiarization experience and seasoned pilots desiring to train. It can be concluded that the VR-simulator is useful in the competence development of maritime pilots. Per the maritime pilots' opinions, the simulator is not considered a replacement for other simulator training or real-life training onboard operational vessels.

How can the Virtual Reality simulators improve the training outcomes of today's maritime pilot education?

The VR-simulator can make simulator training less resource-intensive. It can provide simple, quick, mobile, and efficient training for maritime pilots. The high level of fidelity and immersion, both in operation with voice commands and visual input, provide a high level of realism for pilots going through the educational course. It can further be used as a training tool prior to advanced, unusual, or difficult missions. The ability for pilots to share their experiences with one another via the visualization of group choices may also enhance training results. The simple functionality of the simulator allows users to practice in their chosen settings. Due to the specialized nature of their vocation and the intense nature of the training period, it is evident that maritime pilots do not want the simulator to supplant or replace any real-world scenario training onboard vessels. The simulator may preferably be used in the introduction and familiarization to the maritime pilot role, with maneuvering with voice commands, as well as getting to know the operational area.

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