Mixed Reality Ship Handling Training Method

Mahesh Nayak

November 9, 2016

Contents

1 Introduction **1**

1.0.1 Research Questions 2

1.1 Augmented Reality 4

1.2 Research Method 5

2 Foundation **7**

2.1 Ship Handling 8

2.1.1 Maneuvering 9

2.1.2 Offshore Supply Operations 10

2.2 Operational Demands 15

2.3 Human Factors Knowledge 16

2.3.1 Mode Errors 16

2.4 Envisioned Technology 18

2.4.1 Augmented Reality Display 19

2.4.2 Comparison of Head-Mounted Displays 25

2.4.3 Ship Instrument Augmentation 27

3 Specification **31**

3.1 On-board Training Possibilities 31

Chapter 1

Introduction

Ship handling is the task of precisely controlling a seafaring vessel's movement using its propulsion and navigation systems. Ships move in a variety of marine environments. From shallow waters of a harbour, a vessel may navigate vast seas to a port across the ocean. They also navigate inland waterways such as rivers, canals, backwaters and creeks. Handling a ship in such varied environments is the task of a skilled seafarer who controls it's movement precisely with a consideration of environmental forces such as wind, waves and current acting on the ship (Seamanship 2016). More recently, developments in offshore wind farming, the oil and gas industry have necessitated regular visits to offshore structures located on continental shelves for construction and maintenance activities.

Navigation in marine environments just as in aviation requires the navigator to assimilate information of environmental forces at play. In 1955, the US Navy began researching head-up displays (HUD) to reduce complexity of aircraft instrumentation. HUDs were found helpful for piloting and by 1970s, the use of HUDs expanded beyond military aircraft into commercial aviation.

In ships, navigational-aid information has been traditionally presented in display panels placed around the navigator in the ship's bridge. Although aviation and maritime navigation present similar challenges for a navigator, the use of head-up displays is not yet commonplace in the latter. It could be attributable to the maritime industry being a niche sector with a segmented market-space (many small and medium-sized companies), low R&D intensity and, a conservative attitude towards innovation (Lukas, Vahl, and Mesing 2014). Nevertheless, research studies can be found on maritime applications of augmented reality (Hugues, Cieutat, and Guitton 2010, Vasiljević, Borović, and Vukić 2011 and, Lukas, Vahl, and Mesing 2014). There has been a focus on augmenting vision with real-time information of the environment; potentially helping navigators perform the job more efficiently. For example, overlaying the bridge-view of a ship with route waypoints, distance to next waypoint, local hazards, and navigational aids such as buoys, lighthouses.

Further, developments in ship instrumentation design over the recent years with newer bridges tending to feature relatively minimal, less-cluttered designs. This design change is also a reflection of increasing automation seeping into industrial processes. The dynamic positioning system for example can be used to automatically position a vessel at a specific location.

With increasing automation, the need for human-operation will reduce and so will the need to learn to do them manually. Ship simulations systems are currently the *de facto* method of learning ship navigation. Various schools around the world setup simulation centers where generic principles of seafaring can be learned and practiced. However, there has been little research on the use of mixed reality technologies to create simulation environments for training purposes. This research studies the feasibility of a training method to learn ship navigation in mixed reality environments on-board ships.

1.0.1 Research Questions

Ship simulators are used extensively by ship crew for learning, certification and, upkeep of operational skills. But being simulations by nature, they are approximations of the process after all. Training on-board real ships is ideal from the perspective of learning dynamics under various weather conditions. Besides, such a training should help getting better acquainted with vessel-specific instrumentation. However, it is much more difficult, infeasible even to set up environments for training purposes on-board real vessels compared to the simulator, as it involves setting up large physical objects for training. For example, an offshore oil platform in the case of dynamic positioning training.

A system of generating visual perception of a training environment is then desirable. It can be a solution to the non-trivial problem of setting up training environments. If such a system were capable of producing a convincing feeling of the presence of physical objects in the surrounding, it would enable on-board training in real environments enhanced by visuals of virtual objects.

The following research questions were proposed, with the intention of learning feasibility of using mixed reality technology for training purposes in the maritime sector.

1. **What are the operational scenarios in which mixed reality training would be useful?**

2. **How is the experience of navigating vessels in mixed reality environment using state-of-the-art see-through display technology?**

3. **How effective a tool can mixed reality be for learning ship maneuvering?**

The remainder of this chapter provides a brief overview of the concept augmented reality before describing the method of research used in this study.

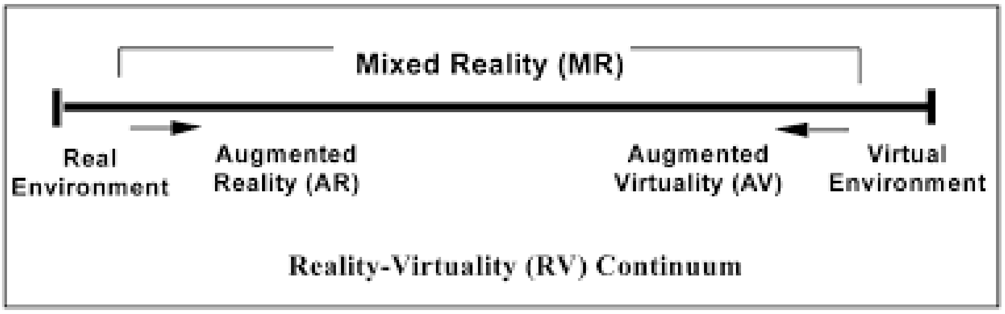


Figure 1.1: Mixed Reality Continuum (Source: Milgram et al. 1995)

1.1 Augmented Reality

Augmented reality refers to the merging of virtual and real worlds in which physical and digital objects co-exist and interact in real time. In this realm, distinctions have been made between various types of applications based on the amount of virtual content in the mix. As figure 1.1 shows, a continuum has been drawn characterising different mixed reality environments Milgram et al. 1995. Completely real and completely virtual environments bring up far ends of the continuum with different levels of virtuality in between.

Virtual reality lies in the extreme right of this spectrum. Here, user's perception of reality is influenced to create the feeling of immersion in a completely virtual world. It is a specific type of mixed reality featuring entirely digital visuals and virtual environments. Driven by the gaming industry, this type of mixed reality is more technologically advanced as of this writing.

Augmented reality on the other hand refers to systems that feature predominantly real environments whose perception may be augmented with information not readily available to the user. It is also used in context of 3D visualizations of designs in real world spaces. In a definitive paper on augmented reality, Azuma (1997) identified the technology to have the following three characteristics:

1. It combines real and virtual

2. Is interactive in real time
3. Is registered in three dimensions

In general terms, mixed reality is an emerging technology which can be used to display virtual objects merged with real world views. It has been found to be useful in job scenarios that require execution of complex tasks. One use case that has been explored in the real-world is the assembly and maintenance of equipment. During an operation, overlaying 3-D virtual job-support guides on see-through images of actual equipment obviates the need to look away in order to refer to a manual. A study on the application of augmented reality found that 3-D virtual guides help users perform ship building and maintenance tasks in almost half the usual time (Henderson and Feiner 2011).

1.2 Research Method

Situated cognitive engineering (Neerincx and Lindenberg 2008) was the research method used in this study. This method separates a human-computer interaction research into three different phases namely derive, specify and evaluate. Accordingly, this report has been structured to describe the three phases of this research outlined by sCE. Chapter 2 named Foundation first describes so-called operational demands that define requirements of the problem at an abstract level. It goes on to describe existing knowledge of human anatomical factors that can be leveraged in designing a solution to the problem. The chapter ends with a survey of possible technological solutions, stating also their strengths and weaknesses. Chapter 3 named Specification sketches a real-life scenario in which the artifact could possibly be used. It lists formal requirements for the software system and makes claims about consequences of its use. Chapter 4 named Evaluation describes the artifact that was developed, an experiment designed to test the claims and, discusses result and conclusion of the experiment.

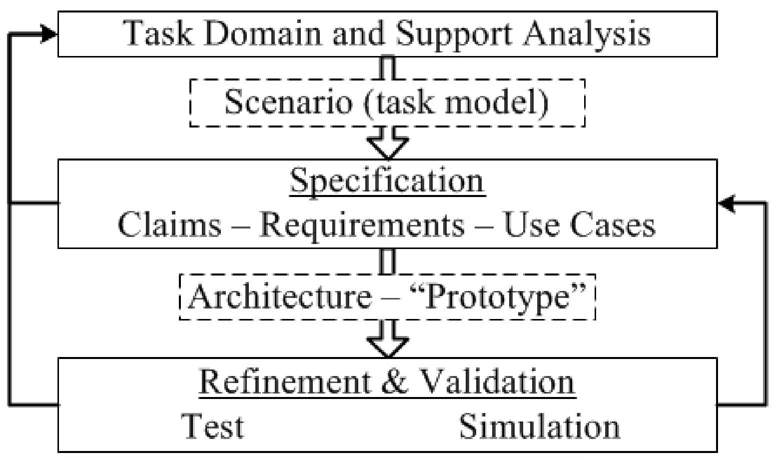


Figure 1.2: Situated Cognitive Engineering Method (Neerincx and Lindenberg 2008)

Chapter 2

Foundation

A literature survey on the topic of augmented reality in maritime context brings up studies of applications that aid job performance by providing helpful contextual information on top of real-world views. Overlaying route waypoints, distance to next waypoint, local hazards and other navigational aids allows the integration of various information that is used by the officer of the watch into one single augmented display. In poor visibility conditions, virtual rails on both sides of the ship help with steering. Buoys, fog signals, day beacons and other navigational aids can also be visually overlaid in low-visibility conditions to help with navigation. These applications show the use of augmented reality as aids for task execution. But little research can be found on use in training ship crew.

This chapter covers results of a domain analysis that was used to derive requirements for a scenario-based ship maneuvering training method. The content explored in this chapter are relevant to answering the research question - what are the operational scenarios in which mixed reality training could be useful. In keeping with the sCE method, it covers operational demands, human factors and, technological options available for the design of this human-computer interface for maritime training.

The first section is an introduction to ship handling in general, including a specific case - the offshore energy industry where unique requirements led to the development of increased automation and specialised equipment for manoeuvring. Section 2.2 titled operational demands describe from an operator point-of-view, requirements for safe execution of ship handling operations. In designing a technological solution, the SCE method takes into account human factors that could affect interactions between users and the system being developed. Section 2.3 titled human factors knowledge describes mode errors - a type of error arising from the operation of state-dependent systems out of state. Finally, section 2.4 describes technological options available to implement the mixed reality training method that is envisioned along with their pros and cons.

2.1 Ship Handling

Given the varied environments in which ships are handled, a distinction is made between vessel handling in restricted spaces as opposed the same in open seas with vast empty space. Manoeuvring typically refers to handling of ships in confined spaces and at low speeds; requiring accuracy and precision in movement. In contrast, navigation occurs in open seas with more room for movement which makes it a comparatively easy task over maneuvering. Besides, a ship usually moves in straight lines while navigating the open seas with the objective to reach destination in the most efficient manner. Fewer changes in direction occur over time, there is lesser need to steer in comparison with manoeuvring scenarios.

Automation has been seeping into the marine industry over the years. It assists human operators to accomplish vessel handling tasks with functions such as autopilot for navigation and dynamic positioning for maneuvering. The underlying idea is to counter water resistance to movement using the ship's propellers and thrusters, while also accounting for environmental forces such as wind, waves and current measured using sensors on board. Current generation autopilots do a satisfactory job of navigating ships in open seas. Maneuvering on the other hand continues to be a specialized human job even though a good degree of automation support exists.

The training method developed here is aimed at learning maneuvering. Besides being a skilled task, it also involves safety risks by nature of its activities. The next section describes challenges of maneuvering and its relevance in the offshore oil industry. It is followed by a brief description of Dynamic Positioning Systems, the automation technology that assists with ship maneuvering tasks and its riders that entail the presence of operators with manual handling skills.

2.1.1 Maneuvering

Vessel handling at low speeds has been difficult on marine vessels historically (Ship 2016). From a technical point of view, the working mechanism of past rudder systems made it difficult to turn vessels 'in place'. Maneuvering a large vessel at low speeds is often a challenging operation even from the perspective of a human operator. Examples of difficult maneuvering operations include approaching a harbour, berthing in a port, sailing side-by-side another vessel, approaching and stationing close to an oil platform, etc. An often recurring sequence is that of a port-bound vessel heading to its berthing location in harbour. Having entered pilot waters from seaward, a vessel's course needs to be controlled accurately to ensure safe passage through channels, bridges, and locks; avoiding collisions with other vessels at the same time. A method for objective evaluation of ship handling difficulties in restricted maneuvering area, areas of traffic congestion is presented in (Inoue 2000).

Many factors affect the precise handling of a given vessel - it's size, power, thruster configuration, on-board bridge equipment, etc. Further, the vessel's handling characteristics are subject to environmental conditions (the combined effect of current, wind and, waves). Besides, low speed maneuvering often occurs in close proximity to man-made constructions such as docks, offshore structures and other ships. The potentially destructive consequences of collision risks in such scenarios makes it a stressful operation, further amplifying the challenge of maneuvering. Safety risks involved in these tasks make it a stressful operation. Mistakes have high associated costs, possibly leading to lost lives and damage to expensive constructions.

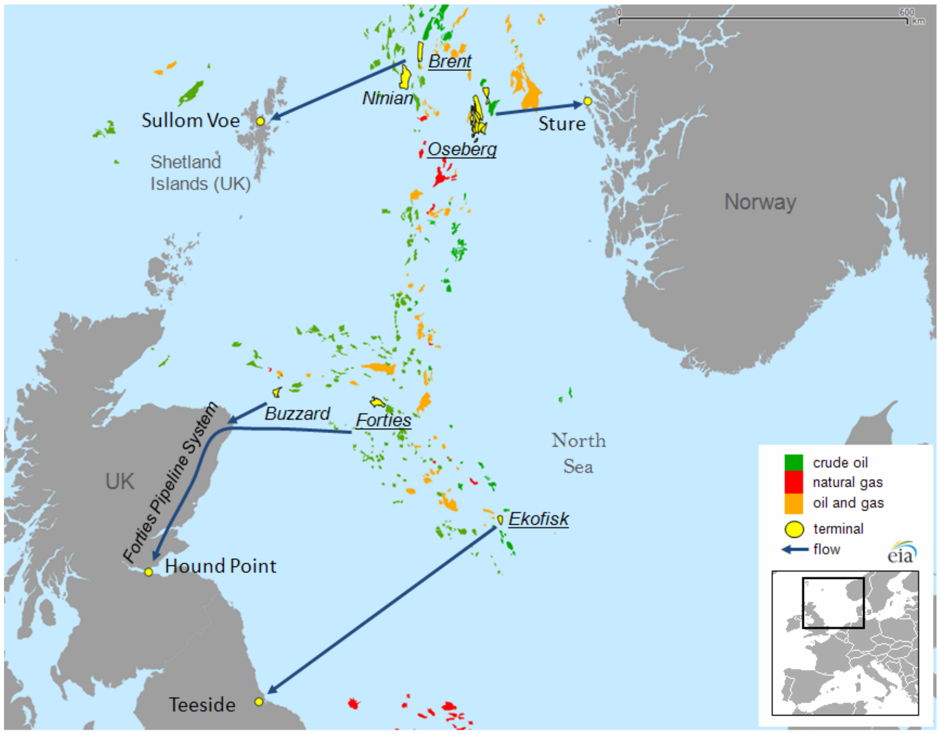
2.1.2 Offshore Supply Operations

A special application of ship handling skill is on offshore supply vessels. These are vessels used to support exploration and production of offshore mineral or energy resources located in continental shelves around the world. Specific missions of offshore supply vessels include

- seismic survey to locate potential oil and gas fields
- towing of rigs to their location, positioning them and laying anchoring and mooring equipment
- supplying equipment, personnel, provisions, other necessary goods to rigs
- subsea operations such as ROV operation, diving support, inspection and maintenance
- safety standby for emergency response and rescue operations

Maneuvering plays an important role in platform supply vessels. They transport supplies such as fuel, water and chemicals to the offshore facilities and bring back disposables for proper recycling. Hence, these vessels need to approach and be stationed close to platforms on a regular basis. Loading and unloading operations happen at the stern of a vessel and requires station keeping till the operation is complete. This requirement led to the development and subsequent popularity of dynamic positioning systems. These are

Figure 2.1: Prominent oil and gas fields in the North sea



Source: refer footnote[1]

automated systems that help with station keeping and other maneuvering operations. The following sections describe the dynamic positioning system, their conceptual working mechanism and modes of operation before making a case about the need for skilled manual maneuvering operators.

2.1.2.1 Dynamic Positioning System

Dynamic positioning (DP) is an automated system that helps human operators with maneuvering operations. It began to be developed as a system that maintains position and heading of a vessel automatically by using its propellers and thrusters. The use of DP systems has been increasing over

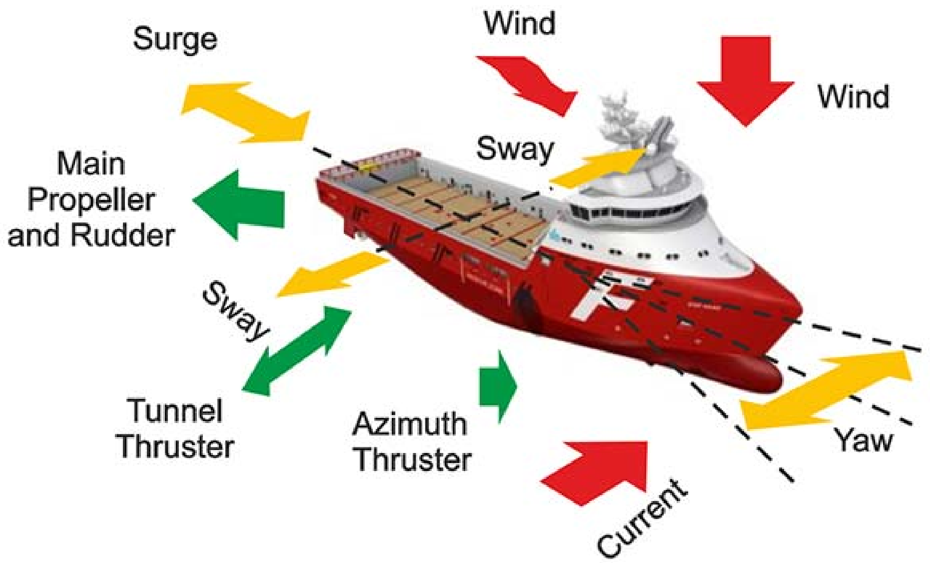
[1] U.S. Energy Information Administration, United Kingdom Department of Energy and Climate Change, Norwegian Petroleum Directorate

the years since its inception in 1960s. There are well over 2000 DP vessels in operation today (Sørensen 2011). From early days of the technology where main focus areas of research were accurate position measurement and control system technologies used, research has now moved on to more specialized problems such as optimizing them for energy efficiency. With increasing popularity of DP systems and increased use of sophisticated technology on-board ships, the marine industry can expect more advanced automation in vessel control over the years. Future systems could be enabled with features such as automatic maneuvering in shallow water and harbor areas, formation sailing, and automatic collision avoidance.

Position reference systems are vital to the operation of dynamic positioning systems. Information from position reference sensors that provide the vessel's position and heading, along with information from wind sensors, motion sensors and gyrocompasses on the vessel are used. The information is supplied as input to a program that calculates changes in position and heading required to bring the vessel to a preset location by activating the vessel's thrusters when necessary. Using a mathematical model of the ship and, the forces acting on it, DP system can control the vessel's thrusters to position it in a preset destination.

The system needs to compensate for unpredictable environmental forces as it decides on power allocations for individual thrusters. While the system takes into account wind forces acting on the vessel measured using wind sensors, as shown in 2.2, a vessel's position is also affected by ocean currents and waves. Kalman filter is generally used to model the environmental forces. It is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables by using Bayesian inference and estimating a joint probability distribution over the variables for each timeframe. While it tends to be more precise than algorithms based on a single measurement alone, it is nevertheless a probability based system that produces estimate predic-

Figure 2.2: Forces acting on a ship and its possible movements



Source: kongsberg.com

tions of changes in environmental forces over time and some uncertainty in predictions can be expected. Although there do not exist rules specifying acceptance criteria for the positioning performance of DP systems, DNVGL guidelines state that "in moderate weather conditions and with a fully operational DP-system the vessel should generally be able to demonstrate position keeping accuracy with a 3 meter radius and $\pm$ 1°of heading." (Veritas 2011)

Dynamic Positioning Modes Most DP systems are offered with several modes of operation. They differ in the type of operation and amount of automation involved. Following are a few common modes of operation.

1. **Joystick**: Operator can control vessel position and heading manually using a joystick in this mode of operation.

2. **Auto heading**: In this mode, the vessel automatically maintains a preset heading.

3. **Auto position**: Maintain both the vessel's position and heading automatically.

4. **Follow target**: Enables the vessel to follow a moving target.

5. **Autopilot**: In this mode, the vessel steers automatically to follow a predefined course of movement.

It can be observed that besides functionality, the modes listed above differ by the level of automation involved in the functionality. Joystick mode offers the least amount of automation. In this mode, a single lever can be used to control all of the vessel's thrusters at the same time. A large vessel such as a platform supply vessel typically has two azimuth thrusters at the stern-end of the vessel and one at the bow-end. In addition, they also typically have tunnel bow thrusters that can be used to turn the vessel in place. While it is possible to control each of the thrusters individually from the bridge of the vessel for fine-grained control; the joystick mode encapsulates all the thrusters into one control. This allows control of forward, reverse, steering and even sideways motion using just one lever.

2.1.2.2 Manual Handling

Going by number of total losses occuring per year (refer figure 2.3), the safety of vessels world-wide can be said to have improved over the years, particularly in the last decade, despite the ever increasing number of sea-faring vessels. Nevertheless, there is a growing concern in the industry regarding over-reliance on electronic navigation aids. Studies have found human error to be the dominant factor in a significant percentage of the accidents (Baker and McCafferty 2005; Hauff 2014). Incidents such as the Norne shuttle tanker's collision with an FPSO on March 5, 2000, Big Orange XVIII's collision with the water injection facility Ekofisk 2/4-W on June 8, 2009 and standby vessel Far Symphony's impact with the mobile installation West Venture on March

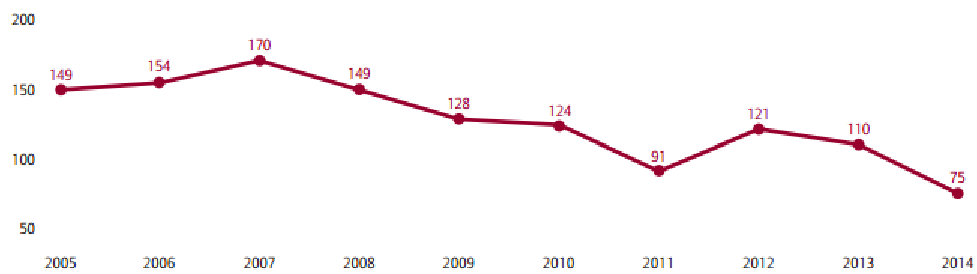


Figure 2.3: Yearly vessel loss since 2005

7, 2004 are mentioned as cases of shipping incidents that showcase the lack of preparedness among crew members to handle with emergency situations (Vinnem 2013).

2.2 Operational Demands

An intuitive understanding of the vessel's handling is required to manually manoeuvre the vessel. Different vessels exhibit different handling behavior depending on their propulsion technology, steering controls, and, dynamics of the particular vessel, owing to its design. These factors have a combined effect on the handling behavior of the vessel which is unique to that vessel-type. Besides, vessels also differ in their response to various weather conditions. Gaining a high level of intuitive understanding of the vessel's motion dynamics comes with extensive practice. A manoeuvre training system should then enable maneuvering practice on the real vessel in real situations.

A clear view of the target object around which the vessel is being maneuvered provides direct visual feedback of the target's position relative to the vessel. By looking out the bridge windows, the operator can immediately learn about the progress of the maneuvering operation. Using this information, the operator can make adjustments to the vessel's movement as required. When maneuvering large vessels, besides the person at the helm, another person usually aids the operation. Standing outside the bridge of the vessel, this person keeps a lookout for the position of the ship, and conveys it to bridge personnel. He also keeps a lookout for traffic and other objects in the vicinity such as navigational aids.

Figure 2.4 shows the certification process required to be a qualified dynamic positioning operator. One starts with a classroom-based induction course that provides basic knowledge of the principles and practical use of DP. After such a course, the trainee is expected to be familiar with the components of a DP system, concept of redundancy that separate different classes of DP systems, its modes of operation and limitations. Thereafter the trainee goes on to acquire watchkeeping experience onboard real vessels with DP. This watchkeeping exercise takes place for a relatively short period of time where the trainee is familiarised with DP equipments onboard the vessel and gets to witness operations. This is followed by a simulator-based course where the trainee gets practical experience operating DP systems in onshore simulation centers.

2.3 Human Factors Knowledge

2.3.1 Mode Errors

Mode errors are the errors that occur when a user operates an interface in a manner that is appropriate to a different state of the system than the one it actually is in. When the user forgets the actual state and performs an action appropriate to a different state, the system response is unexpected and usually undesired. A common example of mode errors is the undesired input of capitalised letters on a computer due to caps lock, or the inability to enter numbers using the number pad due to numlock.

The design of a ship operation training method set in augmented reality needs to take into account the possibility of mode errors resulting from the two realities that are simultaneously at play. A trainee moving a real ship in augmented reality is also moving it in reality. Take the example of a training

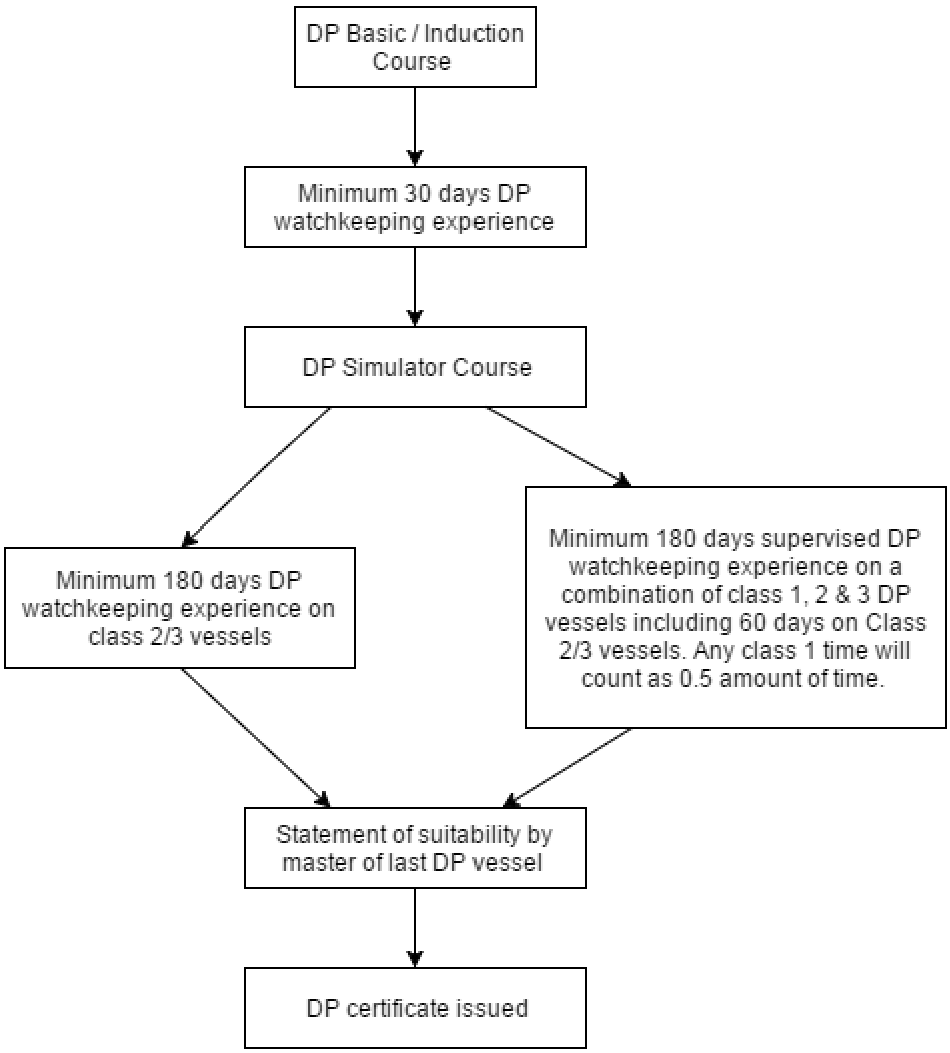
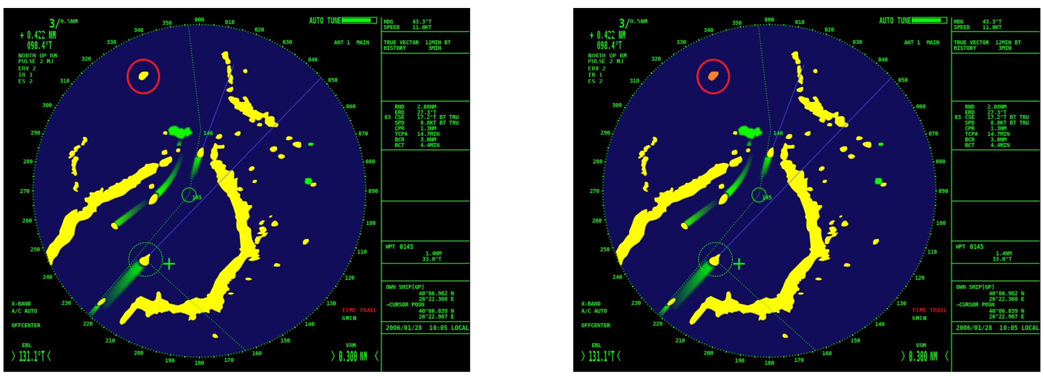


Figure 2.4: Flowchart of nautical institute Dynamic positioning certification scheme

exercise to approach a virtual object out in the open sea. In the course of the exercise, the trainee moves the vessel towards the virtual object in the augmented reality. At the same time, the real vessel is actually moving somewhere out in the open sea. If the bridge equipment is also augmented, the radar would be expected to display an indication of the virtual oil platform. Adding a virtual object to a radar display that already contains information regarding other real objects can be confounding to users. A way to distinctly identify virtual objects should help reduce mode errors but it also hampers immersion of the experience. It is advised to avoid the possibility of mode errors when possible (citation needed).



(a) No colour differentiation (b) Differentiated virtual object

Figure 2.5: Display of virtual objects on radar

2.4 Envisioned Technology

An important choice in the design of a new human-computer interface is the technology used to build prototypes, and eventually the end product. For example, devices like keyboard, mouse and trackpad have acted as the standard input interface for personal computers for over 2 decades now, while computer monitors in the form of CRT, LCD and TFT displays have formed the output interface. Not unlike television monitors, computer monitors were initially used for purposes of data processing before being used for entertainment purposes such as gaming and media streaming. With the evolution of computing technology from large machines driven by punch cards and that filled up entire rooms to the personal computer form has coincided with their ubiquitous use in the modern world influencing the manner in which most office jobs are carried out today.

Computers had a significant impact on the maritime industry. Where naval architecture was traditionally a craft with little scientific information to back designs, modern computers enabled computing power to be leveraged to predict performance. Modern ship designs make use of tools that have been developed to assess static and dynamic stability, water resistance, for hull development and structural analysis. Among other uses, maritime industry found use for computers as devices that could be used for the simulation of movements of vessels on sea. In a gaming-like use case, computers are used to run ship simulation software for educational purposes. These programs can be used to control virtual ships in virtual marine environments. Some setups involve actual bridge equipment to input commands to the program, making the experience more real-like. An array of monitors are used for display. Backed by computer graphics and models of sea, vessel and other objects, the simulation software is supposed to create the perception of being inside a real vessel. It is now standard practice to undergo training using simulators in the maritime industry. Figure 2.6 shows the setup of a typical dynamic positioning simulator.

2.4.1 Augmented Reality Display

state conclusion here (going to use optical see through

This section talks about display technology that is needed to create augmented reality applications.It briefly describes technological options available for augmented reality applications from the point-of-view of creating the visual perception that is part of augmented reality. Three ideas of mixed reality displays are considered, namely, optical see-through, video see-through head-

Figure 2.6: Setup of a dynamic positioning simulator by VSTEP

mounted displays and, spatial augmented reality. Having been conceived in the 1980s, military and medical visualization contexts, these options for mixed reality displays were first catalogued in a landmark survey paper on augmented reality by Ronald Azuma (Azuma 1997).

The utility of different categories of augmented reality displays in the ship handling training context is considered in this research. Optical see-through displays theoretically allow an unhindered view of the outside world, whereas in video see-through display it is camera-mediated. Optical see-through HMDs appear to be the most logical choice for AR intuitively. It is ideologically consistent with AR in that most of the visual reality is left untouched, only to add bits of information (real/virtual) as necessary. Spatial augmented reality is another option for AR, but lack of mobility makes it infeasible in this scenario. It is nevertheless described in brief here for posterity. The following sections describe each of the display technologies in turn before comparing optical and video see-through HMDs.

2.4.1.1 Optical See-Through Head-Mounted Display

Optical see-through head-mounted displays are one of the two basic choices available for mixed reality content display along with video see-though head-mounted displays. In general, see-through displays allow the user to see the real world through a display system while also being able to seamlessly display digital content on it. These were first developed for military aircraft for applications such as fixing the target of ammunition on locations that could be seen through the aircraft. The concept of see-through display is also making way into consumer markets, with head up displays used in cars being one of the more popular uses. Such display systems can also be mobile with users wearing them on the head so as to directly influence their view of the outside world. These are called as head-mounted displays. The following sections describe optical and video see-through displays in turn. A comparison of the two technologies on various parameters is presented thereafter.

Optical see-through head-mounted displays (OST) are display systems that exploit the transparency of glass material to provide unobstructed views of the outside world. By definition, they can also digital content on the same surface simultaneously. As figure 2.7 shows, OST displays use optical combiners to combine light from the real world with that of the digital content. Optical combiners usually reduce the amount of light from real world. Combiners act like half-silvered mirrors to be able to reflect light from monitors into user's eyes. Theoretically, this display system can provide undistorted view of the real world (apart from slight obstructions caused by the frame itself). As a downside, it also affects the display of digital content adversely, making virtual objects appear semi-transparent and 'ghostlike'.

2.4.1.2 Video See-Through Head-Mounted Display

Video see-through HMDs are similar to optical see-through HMDs in that they allow the combination of real world views with digital content. Differences between them stem from their source of real world view. As opposed

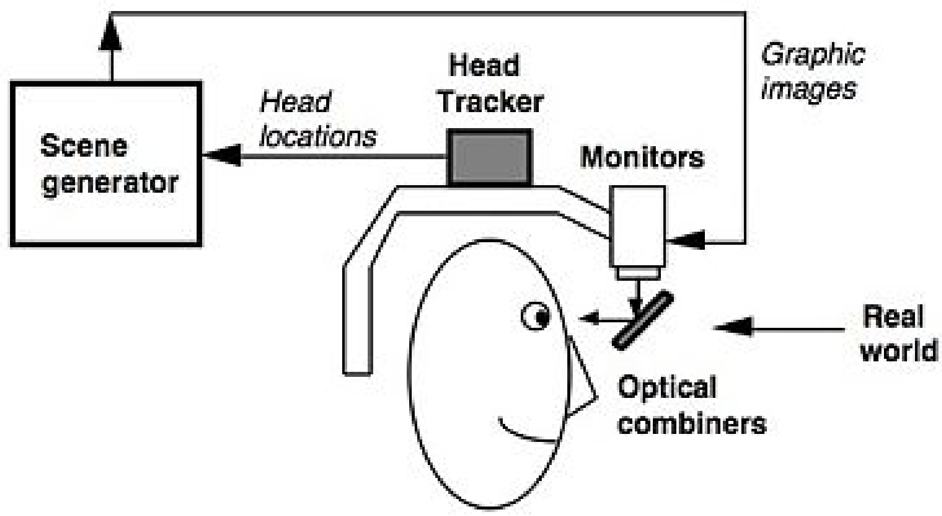


Figure 2.7: Schematic diagram of optical see through display (Source: Azuma 1997)

to OST which provides a direct view of the environment, VST uses video feed from a camera in the HMD system to provide real world views. So, in addition to the head trackers and viewing monitors as in OST HMDs, VST HMDs require a camera appendage in the setup (see figure 2.8). This type of HMDs block the wearer's external view in favor of better immersion into the stereoscopic view provided by the system. A video camera can be mounted on the exterior of such an HMD to incorporate external view back into the content.

Driven by interest from the gaming community, and virtual reality applications in general, closed-view HMDs have seen more development as of this writing. Low cost HMDs are available in the consumer market, and can be used for 3D games and entertainment applications. With the addition of one or two cameras, these can be leveraged for mixed reality applications. Consequently, calibration of the camera's view to that of the user's eye position will have to be made.

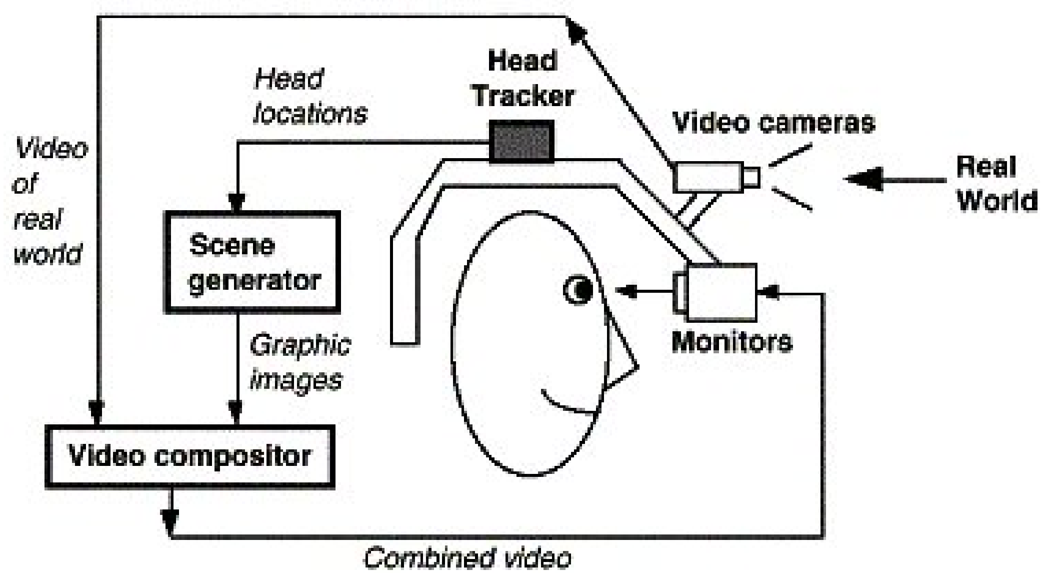


Figure 2.8: Schematic diagram of video see through display (Source: Azuma 1997)

2.4.1.3 Spatial Augmented Reality

Spatial augmented reality (SAR) refers to the concept of augmenting real-world spaces (with digital media) without the use of special devices such head-mounted display. As an AR technology, implementations of SAR must adhere to the basic requirements of augmented reality listed in section 1.1. Along with HMDs, it forms another paradigm for the creation of mixed reality content. SAR offers unique benefits over HMDs such as obviating the need to wear special devices and possibly high resolution, wide field of view displays integrated into natural environments. Large field of view and higher resolution provides a stronger feeling of presence (Lantz 1996), allowing for better immersion and easier eye accommodation[2]. On the downside, it suffers from setbacks such as having to set up expensive custom-made display configurations that require more space and hardware than standardized HMDS.

[2]refer to section 2.4.2.1 for a discussion on photorealism

The lack of standardized solutions and the need to setup special hardware tailored to individual ships makes SAR an impractical solution for creation of AR onboard ships for maneuvering training purposes. A portable technological solution that enables mobility between vessels is desired. This allows for trainings to be conducted on various different vessels with minimal time and effort involved in setting up the augmented environment. Instead, the use of mobile AR devices such as HMDs means that trainees can carry individual AR devices onboard and vessels do not need to be docked for purposes of setting up the AR environment. Nevertheless, the concept is described in brief here for completeness. A detailed treatment of the topic of spatial augmented reality can be found in Bimber and Raskar 2005.

Figure 2.9 shows a concept of monitor-based spatial augmented reality. In this setup, the user views the mixed reality on one or more monitors in front of the user which display a combination of virtual and real world images captured by video camera. This is similar to the CAVE (Cruz-Neira, Sandin, and DeFanti 1993) concept for virtual reality. CAVE (CAVE automatic virtual environment) seeks to immerse the user in a 3D virtual environment created using rear/front facing projectors lighting up projection screens in 3 dimensions. Although originally designed for virtual reality experience, the concept can be adapted for augmented reality. Advances in projection technology make it possible to have projections on transparent screens (Peterson and Pinska 2006).

A discussion of display options for AR would be incomplete without spatial augmented reality. As opposed to head-mounted displays, SAR relies on projectors to create the views necessary for the perception of mixed reality. SAR may be just as effective as head-mounted displays in being able to create immersive mixed environments. A study on the use of large projection screen as an alternative to HMDs for virtual environment found no significant difference between the two for spatial cognition tasks (Patrick et al. 2000). But projector-based display systems are custom solutions that need

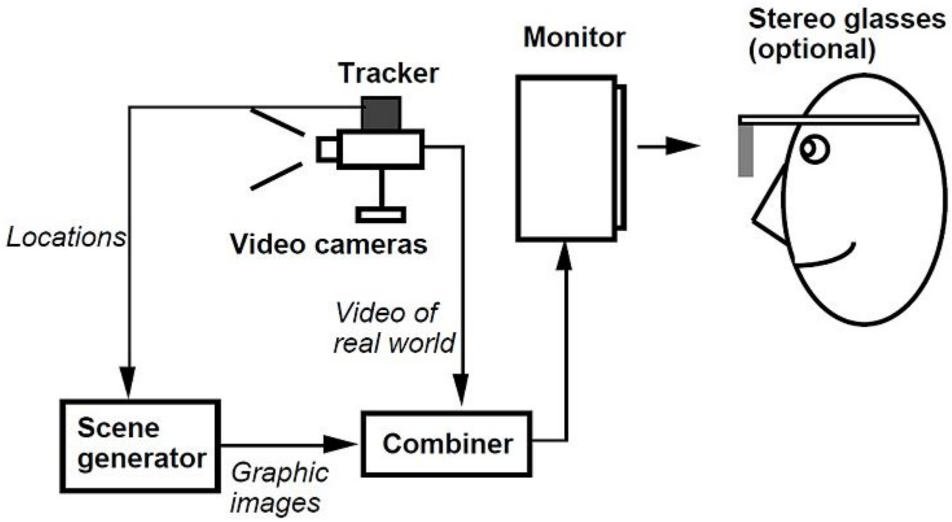


Figure 2.9: Schematic diagram of monitor see through display (Source: Azuma 1997)

to be designed for the specific environment in consideration. Ships come in a variety of shapes and sizes, so do their bridge rooms. Setting up MR environments onboard different supply vessels would then involve considerable effort to tailor the display system for individual ships. Besides, some modification of the ship bridge room is involved such as placing projectors at the appropriate locations and turning bridge windows in to projection screens onto which virtual objects can be projected.

2.4.2 Comparison of Head-Mounted Displays

This section provides a comparison of optical and video see-through HMDs based on parameters thought to be relevant to this study. For an in-depth review and comparison between these two display types, readers can refer to Rolland, Holloway, and Fuchs 1995.

1. *Simplicity*: In mixed reality applications, there is a need to see the

external world besides virtual images being displayed in the HMDs. Optical see-through systems meet this requirement naturally from employing transparent displays which do not interfere with the external view. Video see-through systems on the other hand, use a camera to capture the external view. The camera then seeks to perform the role of human vision, one of the most complicated sensory systems in the universe, the various functions of which are either not built into or not yet achievable using consumer grade cameras. For example, the resolution of the entire view (real + virtual) is limited to that of the display device in case of VST. This constraint is also present in optical see-through devices, with a crucial difference that it is only applicable to virtual parts of the scene.

2. *Lag*: A persistent problem with interactive computer graphics is that of time delay (lag) between expectation of the appearance of a scene and it's actual appearance. For example, in an OST system, there will be near zero lag in viewing real scene as it is viewed directly by the user. Whereas, the display of any virtual objects can be a source of lag. The system first needs to decide whether to display virtual objects based on viewing direction and orientation and, also calculate appropriate projection of the virtual object if it needs to be displayed indeed. Finally, there will be a small delay in rendering the images itself.

   In case of video see-through systems, additional lag is present from having to digitize video stream of the real world. In a display that refreshes at 60Hz, the time that elapses between display of one frame and another is 16.67ms. Hence there will be a minimum of 16.67ms delay in displaying the external view recorded by a camera, discounting the time taken to digitize the camera view. According to (Ellis et al. 1997), for close range tasks, one millisecond of delay causes one millimeter of error

> An advantage of VST over OST is that the higher degree of control over display streams (real and virtual) in video see-through makes it possible to avoid the problem of temporal mismatch due to delay in virtual images by delaying real view as well.

The display technologies considered so far have been applicable for creation of mixed reality for individual users. These systems do not scale easily to groups of users needing to experience the same mixed reality. For example, in the mixed reality ship handling training method that is being conceived in this project, it is required that at least two people experience the same scenario, i.e. the trainee and a trainer (experience ship handler). Apart from the trainee who needs to view the virtual object/s for training purposes, the trainer also needs to see the same in order to evaluate trainee performance. Collaborative design such as for architecture and modeling is another use case multiple users needing to experience the same mixed reality.

2.4.2.1 Photorealism

2.4.3 Ship Instrument Augmentation

Mixed reality displays described in the previous section form a part of enabling technologies for the mixed reality ship maneuvering training conceptualized in this research. HMDs for instance can help create visual perception of an offshore oil platform standing on the open sea. In other training scenarios they may be used to display tracks/lanes for navigational tracking or virtual ships on collision course/sailing side-by-side etc. Different artifacts may be displayed depending on training objectives and the perceptions that need to be created. Ships over the years though have evolved to be technically complex machines. The bridge room of a modern age vessel houses multiple instruments tracking different aspects of its reality. Therefore, the design of a mixed reality environment on-board a modern seafaring vessel should consider how virtual objects interact with various instruments in the

Table 2.1: Comparison of see-through head-mounted displays

	Optical see-through	**Video see-through**
Simplicity	Only one stream to process (virtual images)	Two streams to process (camera feed + virtual images)
Quality of real world view	Largely undistorted	Camera and display dependent
Time lag of real world view	0ms	>16ms
Resolution	Partially display dependent	Fully Camera and display dependent
Peripheral field of view (horizontal)	180 degrees	110 degrees
Digital display field of view (horizontal)	20-40 degrees	>90 degrees
Focus and contrast	Hard to blend virtual object into real scene	Less severe contrast issues due to limited dynamic response of cameras
Occlusion	Challenging to achieve full occlusion	Occlusion is possible due to full control over displayed content

bridge room to accurately correspond with the reality that is being visually perceived.

2.4.3.1 Bridge Instrumentation

2.4.3.2 Tracking Requirements

In-out vs out-in tracking

Fiducial Markers

Table 2.2: Levels of photorealism

Classification	**Reasoning**
High	1. Presentation of occlusion, a basic depth cue, is necessary to induce sense of depth in the augmented scene 2. Wide field of view is required to create illusion of large object being nearby. 3. Virtual object is the main focus in the scene and, inconsistency in 3D view of augmented reality can hamper task performance from visual fatigue due to accomodation-vergence conflict.
Medium	1. Occlusion is useful to induce depth in the scene, but some amount transparency can be tolerated. 2. Lack of wide field of view does not affect task performance. 3. Inconsistency in 3D view does not easily amount to visual fatigue as virtual object is not the user's main object of focus in the augmented scene.
Low	1. Depth cues in the scene are not necessary for purposes of the training. 2. Wide field of view is not required for effective task performance. 3. Inconsistency in 3D view does not easily amount to visual fatigue as virtual object is not the user's main object of focus in the augmented scene

Chapter 3

Specification

3.1 On-board Training Possibilities

Comparison of training methods

Table 3.1: Comparison of on-board training options

	Manoeuvre Training	**Navigation Training**	**Emergency Response**
Aim	Learn vessel steering in navigationally challenging situations	Learn long distance maritime navigation	Learn emergency response procedures and teamwork skills
Scenarios	▪ Position keeping ▪ In-place turning ▪ Berthing	▪ Path planning ▪ Navigate port entrances	▪ Fire in engine room ▪ Water flooding in lower deck ▪ Man over-board
Competences	▪ Bridge equipment operation ▪ Vessel movement intuition ▪ Depth estimation	▪ Route planning ▪ Identify, use maritime navigation aids	▪ Emergency severity assessment ▪ Teamwork, communication
Equipments Required	Radar, ARPA, ECDIS, Fiducial markers in bridge	Radar, ECDIS, ARPA, AIS, Markers in bridge	Fiducial markers in engine room, deck, etc.
Onboard crew Requirements	▪ Trainee ▪ Instructor ▪ Officer of the watch	▪ Trainee ▪ Instructor ▪ Officer of the watch	▪ Full crew / part of crew located at emergency site
Photorealism required	High	Low	Medium

Table 3.2: Comparison of training methods

	Simulator training	**MR on-board training**	**On-the-job training**
Practice on real vessel	✗	✓	✓
Practice in various real weather conditions	✗	✓	✓
Perform training repetitions in same conditions	✓	✗	✗
Scope for standardized competency assessment	✓	✓	✗
Scope for gradation of learning outcomes	✓	✓	✗
Close range ship handling training	✓	✓	✗
Scope for introduction of learning framework	✓	✓	✗
Risk of collision with other vessels	✗	✓	✓
Suitable for learning level	All	All	Advanced

Bibliography

Azuma, Ronald T (1997). “A survey of augmented reality”. In: *Presence: Teleoperators and virtual environments* 6.4, pp. 355–385.

Baker, CC and DB McCafferty (2005). “Accident database review of human element concerns: What do the results mean for classification?” In: *Proc. Int Conf.'Human Factors in Ship Design and Operation, RINA Feb.* Citeseer.

Bimber, Oliver and Ramesh Raskar (2005). *Spatial augmented reality: merging real and virtual worlds*. CRC Press.

Cruz-Neira, Carolina, Daniel J Sandin, and Thomas A DeFanti (1993). “Surround-screen projection-based virtual reality: the design and implementation of the CAVE”. In: *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*. ACM, pp. 135–142.

Ellis, Stephen R et al. (1997). “Factors influencing operator interaction with virtual objects viewed via head-mounted see-through displays: viewing conditions and rendering latency”. In: *Virtual Reality Annual International Symposium, 1997., IEEE 1997*. IEEE, pp. 138–145.

Hauff, Kristian Stenvågnes (2014). “Analysis of Loss of Position Incidents for Dynamically Operated Vessels”. In:

Henderson, Steven and Steven Feiner (2011). “Exploring the benefits of augmented reality documentation for maintenance and repair”. In: *Visualization and Computer Graphics, IEEE Transactions on* 17.10, pp. 1355–1368.

Hugues, Olivier, Jean-Marc Cieutat, and Pascal Guitton (2010). “An experimental augmented reality platform for assisted maritime navigation”. In: *Proceedings of the 1st Augmented Human International Conference*. ACM, p. 12.

Inoue, Kinzo (2000). “Evaluation method of ship-handling difficulty for navigation in restricted and congested waterways”. In: *Journal of Navigation* 53.01, pp. 167–180.

Lantz, Ed (1996). “The future of virtual reality: head mounted displays versus spatially immersive displays (panel)”. In: *Proceedings of the 23rd annual conference on Computer graphics and interactive techniques*. ACM, pp. 485–486.

Lukas, Uwe von, Matthias Vahl, and Benjamin Mesing (2014). “Maritime Applications of Augmented Reality–Experiences and Challenges”. In: *Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality*. Springer, pp. 465–475.

Milgram, Paul et al. (1995). “Augmented reality: A class of displays on the reality-virtuality continuum”. In: *Photonics for industrial applications*. International Society for Optics and Photonics, pp. 282–292.

Neerincx, Mark A and Jasper Lindenberg (2008). *Situated cognitive engineering for complex task environments*. Ashgate Publishing Limited.

Patrick, Emilee et al. (2000). “Using a large projection screen as an alternative to head-mounted displays for virtual environments”. In: *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, pp. 478–485.

Peterson, Stephen and Ella Pinska (2006). “Human Performance with simulated Collimation in Transparent Projection Screens”. In: *Proceedings of the Second International Conference on Research in Air Transportation (ICRAT)*, pp. 231–237.

Rolland, Jannick P, Richard L Holloway, and Henry Fuchs (1995). “Comparison of optical and video see-through, head-mounted displays”. In: *Pho-*

tonics for Industrial Applications. International Society for Optics and Photonics, pp. 293–307.

Seamanship (2016). *Seamanship — Wikipedia, The Free Encyclopedia*. [Online; accessed 16-May-2016]. URL: `\url{https://en.wikipedia.org/w/index.php?title=Seamanship&oldid=714898900}`.

Ship (2016). *Ship — Encyclopædia Britannica. Encyclopædia Britannica Online*. [Online; accessed 17-May-2016]. URL: `\url{http://www.britannica.com/technology/ship}`.

Sørensen, Asgeir J (2011). "A survey of dynamic positioning control systems". In: *Annual reviews in control* 35.1, pp. 123–136.

Vasiljević, Antonio, Bruno Borović, and Zoran Vukić (2011). "Augmented reality in marine applications". In: *Brodogradnja* 62.2, pp. 136–142.

Veritas, Det Norske (2011). "Dynamic Positioning System–Enhanced Reliability DYNPOS-ER". In: *DNV Guidance*.

Vinnem, J.E. (2013). *Offshore Risk Assessment vol 1.: Principles, Modelling and Applications of QRA Studies*. Springer Series in Reliability Engineering. Springer London. ISBN: 9781447152071. URL: `https://books.google.nl/books?id=zzO3BAAAQBAJ`.