Mixed Reality Ship Handling Training Method

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Contents

Chapter 1

Introduction

Chapter 2

Foundation

This chapter covers results of the domain analysis that was used to derive requirements for the scenario based training being developed in this project. The first section is an introduction that describes ship handling in general before delving into details of a specific case - the offshore energy industry where special requirements led to the development of increased automation and specialized equipment. The following three sections conform to the sce method. Section 2.2 titled operational demands describe the skills/knowledge required for safe execution of ship handling operations. According to the sce method, the design of a technological solution takes into account human factors that affect the interaction between users and the system. In keeping with the method, section 2.3 titled human factors knowledge describes mode errors - a type of error arising from operation of state-dependent systems out of state. Finally, section 2.4 describes technological possibilities and options available to implement the augmented training method envisioned here.

2.1 Ship Handling

Ship handling is the task of controlling a vessel's movement with accuracy and precision using its propulsion and navigation systems while also taking into account environmental forces such as wind, waves and current acting on the vessel (Seamanship 2016). Vessels move in a variety of marine environments. Starting from shallow waters of harbour ports a vessel might navigate vast oceans to a port in another harbour across the ocean. Vessels also navigate inland waterways such as rivers, canals, backwaters and creeks. More recently, developments in offshore wind farming and the oil and gas industry have necessitated regular and frequent visits to offshore structures located on continental shelves for construction and maintenance activities.

Given the different situations in which a ship is handled, a distinction is made between vessel handling in restricted spaces as opposed to navigating the open seas. Maneuvering typically refers to the handling of ships in confined spaces and at low speeds; requiring accuracy and precision. Navigation occurs in open waters where there is more room for movement, making it a comparatively easier task. Over the years, some amount of automation has seeped into marine technology that enable these tasks such as autopilot for navigation and dynamic positioning for maneuvering. The training method developed here is aimed at learning maneuvering, a skilled task that involves safety risks by nature of its activities. The following sections describe the challenges of maneuvering and its high relevance in the offshore oil industry.

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 speed is often a challenging operation even from the perspective of a human operator. Many factors affect the precise handling of a given vessel such as it's size, power, thruster configuration, onboard bridge equipment, etc. Further, the vessel's handling characteristics are subject to environmental conditions such as wind, current, 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.

A method for objective evaluation of ship handling difficulties in restricted maneuvering area, in areas of traffic congestion is presented in (Inoue 2000). 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 port-bound vessel heading to its berthing location in the 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. Safety risks involved in such tasks make it a stressful operation. Mistakes have high associated costs, possibly leading to lost lives and damage to expensive constructions.

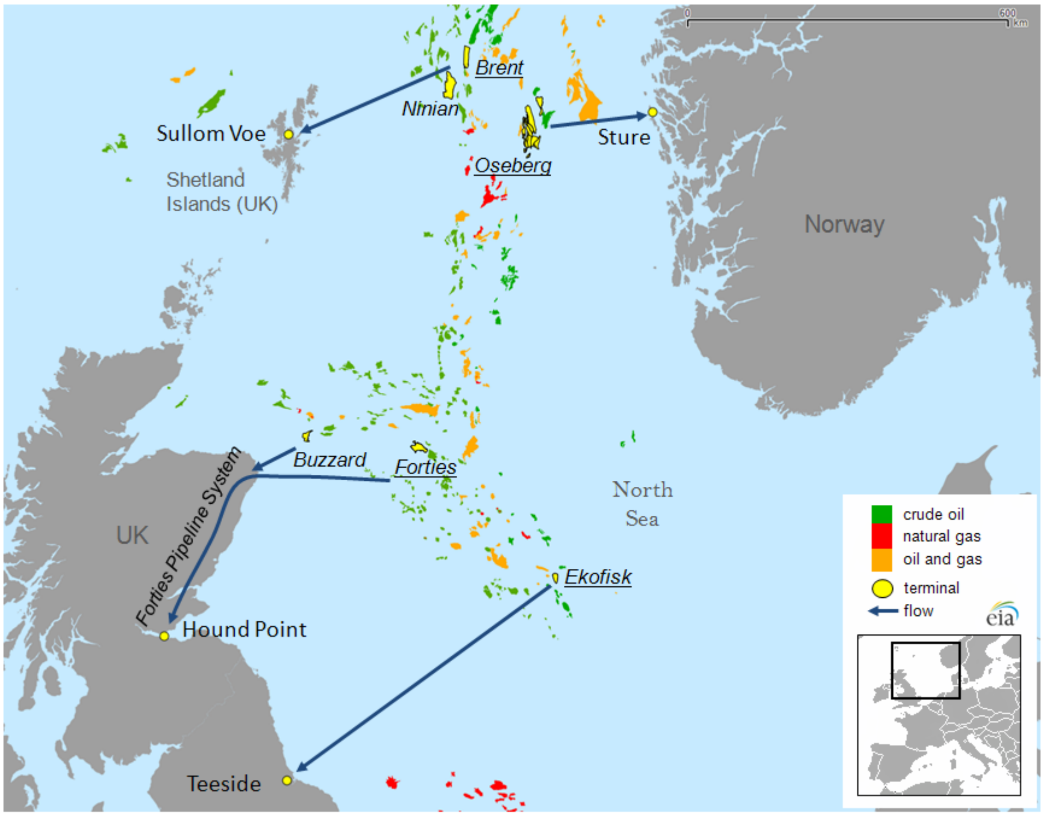
2.1.2 Offshore Supply Operations

A special application of ship handling skill is on-board offshore supply vessels. These are vessels that are used in support of exploration and production of offshore mineral or energy resources located in continental shelves around the world. For example, figure 2.1 shows some prominent oil fields in the North sea. 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

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

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



Source: refer footnote[1]

- 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 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.

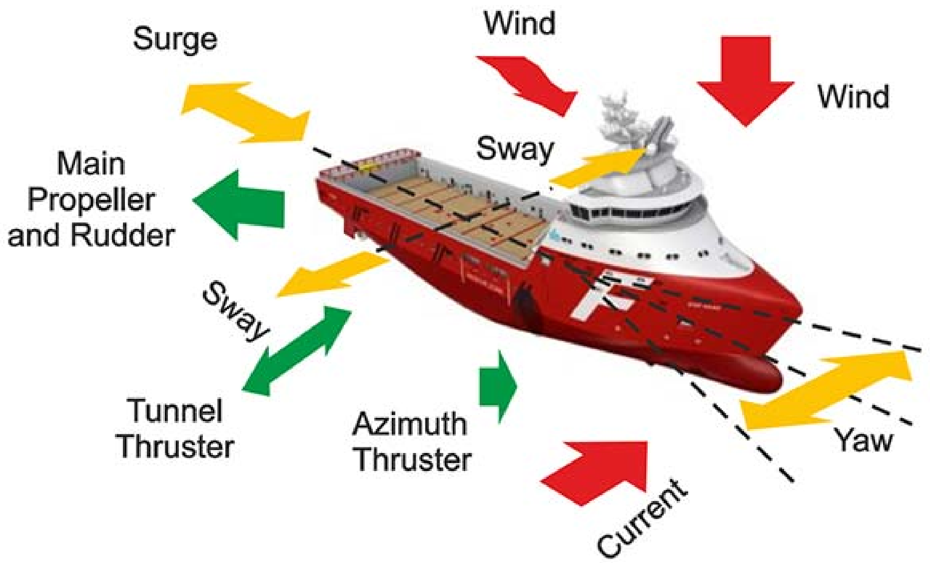
2.1.2.1 Dynamic Positioning System

Dynamic positioning (DP) is a computer-controlled system that maintains position and heading of a vessel automatically by using its propellers and thrusters. 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 by the system. The information is supplied as input to a program that calculates the changes in position/heading required to bring the vessel a preset location and, activates the vessel's thrusters as necessary.

The use of dp systems has been increasing over the years since its first inception in 1960s. There are well over 2000 DP vessels in operation today Sørensen 2011. From the 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 dp systems for energy efficiency. With increasing popularity of DP systems and increased use of sophisticated technology onboard 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.

Dynamic positioning is an automated system that helps human operators with maneuvering operations. It offloads part of the human operator's decision making overhead in real-time. Using a mathematical model of the ship and, the forces acting on it, the DP system can control the vessel's thrusters

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



Source: kongsberg.com

to position it in a preset destination. Figure 2.3 is a model of the functional components of a dynamic positioning system.

The system contains a *controller* module that influences vessel movements by taking decisions on power allocation for individual vessel thrusters. It takes as input, weather information from wind sensors and current position information from position reference systems. Expected output is to position the vessel at a position and heading preset by the operator. After being initiated, the system determines the difference between current position and desired position. It then attempts to minimize this difference over time. This is done by firing appropriate thrusters into action, producing vessel movements in different directions.

Environmental forces acting on the vessel during the time though add to the complexity of this operation. The controller then needs to compensate for unpredictable environmental forces as it decides on allocations for individual thrusters. While the system takes into account wind forces acting on the

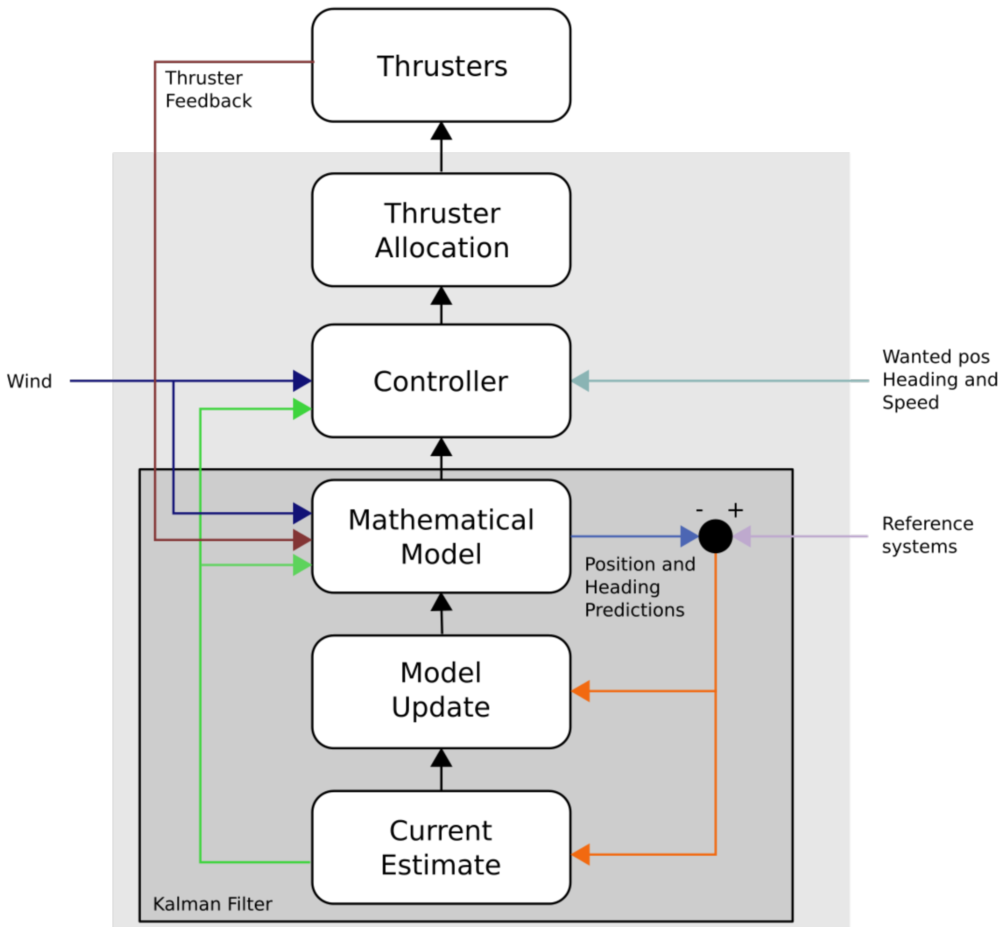


Figure 2.3: Model architecture of Dynamic Positioning systems

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 a nevertheless a probability based system that produces estimate predictions 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 ± 1°of heading." Veritas 2011

write about accidents that occured. ekofisk etc

Figure 2.4 shows the interface of a typical DP system. A display monitor is used to show various information regarding the vessel and its control systems. Apart from the display, there exists input interface in the form of buttons. They are used to provide information to the system such as desired location and the mode in which it will be used.

Dynamic Positioning Modes Dynamic positioning systems can be commonly operated in different modes. Modes define the type of automatic vessel operation, some of which differ in the amount of automation involved. Following are some common modes of dynamic positioning systems.

1. **Joystick**: In this mode, the operator can control the vessel position and heading manually using a joystick.
2. **Auto heading**: In this mode, the vessel automatically maintains a preset heading.

Figure 2.4: Typical dynamic positioning console

3. **Auto position**: This mode automatically maintains the vessel's position and heading.

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

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

This is by no means an exhaustive list of DP modes. It can be observed that besides functionality, the modes listed above differ by the level of automation involved in the functionality. The 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 (refer figure 2.5). 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

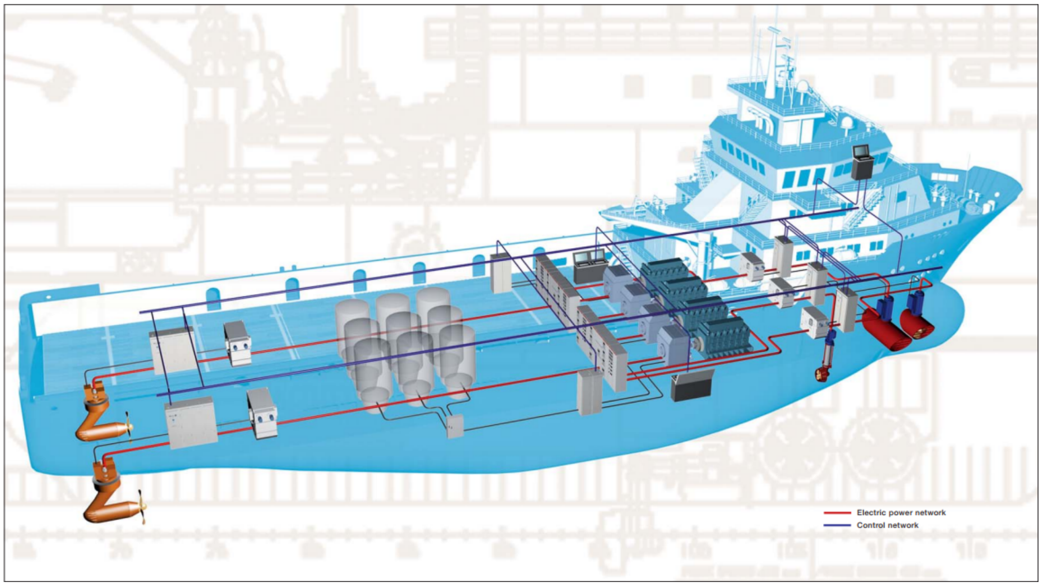


Figure 2.5: Schematic diagram of the power and control network of a typical offshore supply vessel

all the thrusters into one control. This allows control of forward, reverse, steering and even sideways motion using just one lever.

w

rite about other modes of operation, how they differ from joystick mode in terms of automation.

2.1.2.2 Manual Handling

Going by number of total losses occuring per year (refer figure 2.6), the safety of vessels world-wide can be said to have improved over the years, particularly the last decade, despite the ever increasing number of sea-faring vessels. Nevertheless, there is a growing concern in the industry regarding overreliance on electronic navigation aids. Studies have found human error to be 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 5 March 2000, Big Orange XVIII's collision with

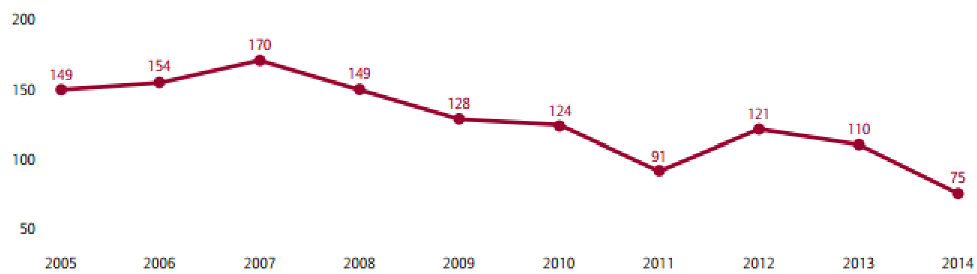


Figure 2.6: Schematic diagram of the power and control network of a typical offshore supply vessel

the water injection facility Ekofisk 2/4-W on 8 June 2009 and standby vessel Far Symphony's impact with the mobile installation West Venture on 7 March 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, that is unique to the vessel, or the vessel type in general. Besides, vessels also differ in the way they respond 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 2.7 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

In context of interface design, 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

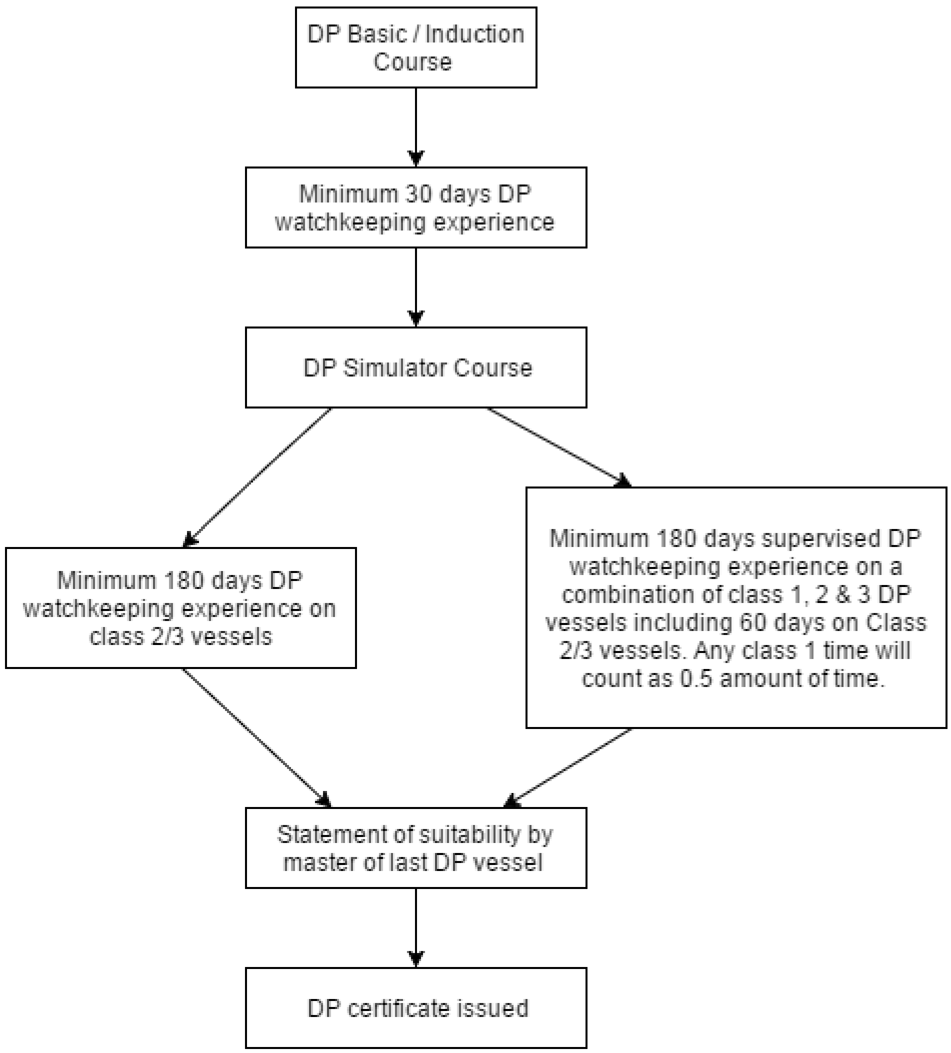
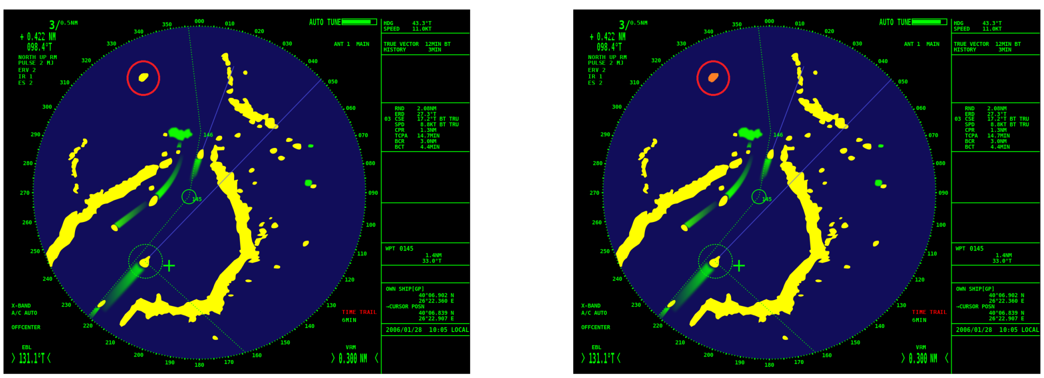


Figure 2.7: Flowchart of nautical institute Dynamic positioning certification scheme

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 actual reality. Take the example of a training 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 immersiveness 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 2.8: 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 2.9 shows the setup of a typical dynamic positioning simulator.

Figure 2.9: Setup of a dynamic positioning simulator by VSTEP

2.4.1 Augmented Reality Display

state conclusion here (going to use optical see through)

This section talks about display technology that can be used 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 the augmented reality. Three abstract ideas of mixed reality displays are considered, namely, optical see-through, video see-through head-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. This paper weighs the utility of these displays in the ship handling training context.

2.4.1.1 Augmented Reality

Mixed reality refers to the merging of virtual and real worlds in which physical and digital objects co-exist and interact in real time. In the field of mixed

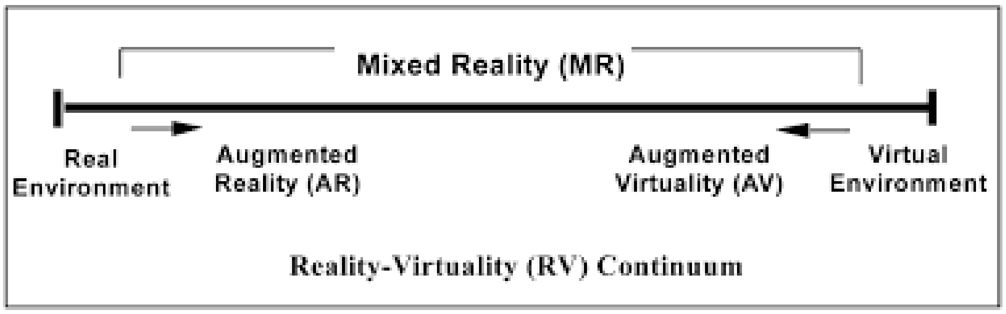


Figure 2.10: Mixed Reality Continuum (Source: Milgram et al. 1995)

reality, some distinctions have been made between various applications based on the amount of virtual content in the mix. A continuum has been drawn characterising different mixed reality environments as shown in figure 2.10. Completely real and completely virtual environments bring up extreme ends of the continuum, with different levels of virtuality in between.

Augmented reality has been defined by Azuma (1997) as having the following three characteristics:

1. Combines real and virtual
2. Is interactive in real time
3. Is registered in three dimensions

Virtual reality has been gaining popularity in the consumer market in recent years. It is a specific type of mixed reality featuring entirely digital visuals and virtual environments. No clear distinctions are made between points in the continuum. One particular construct, augmented reality, has been gaining popularity over the years. Augmented reality refers to systems that feature predominantly real environments whose perception maybe augmented with information not readily available to the user (figure 2.11 for example, shows a map overlay on top of the camera view of a street). Further, some factors have been identified that help distinguish between different

Figure 2.11: View of a street 'augmented' with information on places of interest

mixed reality systems: extent of world knowledge (whether the augmentation takes place in a modeled world or not), reproduction fidelity (quality of display of the real/virtual objects) and extent of presence metaphor (extent to which user feels they are present in the displayed scene themselves). A detailed description of mixed reality displays and differences in their characteristics can be found in Milgram et al. 1995.

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 Display

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 2.12 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'.

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 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 2.13). This is because this type of HMDs block the wearer's external view in favor of bet-

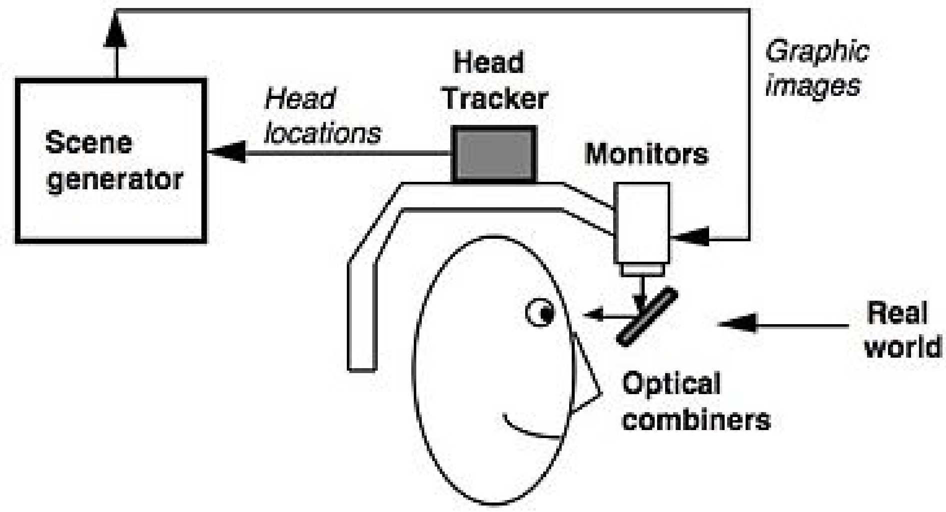


Figure 2.12: Schematic diagram of optical see through display (Source: Azuma 1997)

ter immersion into the stereoscopic view provided by the system. A video camera mounted on the exterior of such an HMD then enables the outside view to be incorporated back into the content being displayed

consider revision

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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

citation needed

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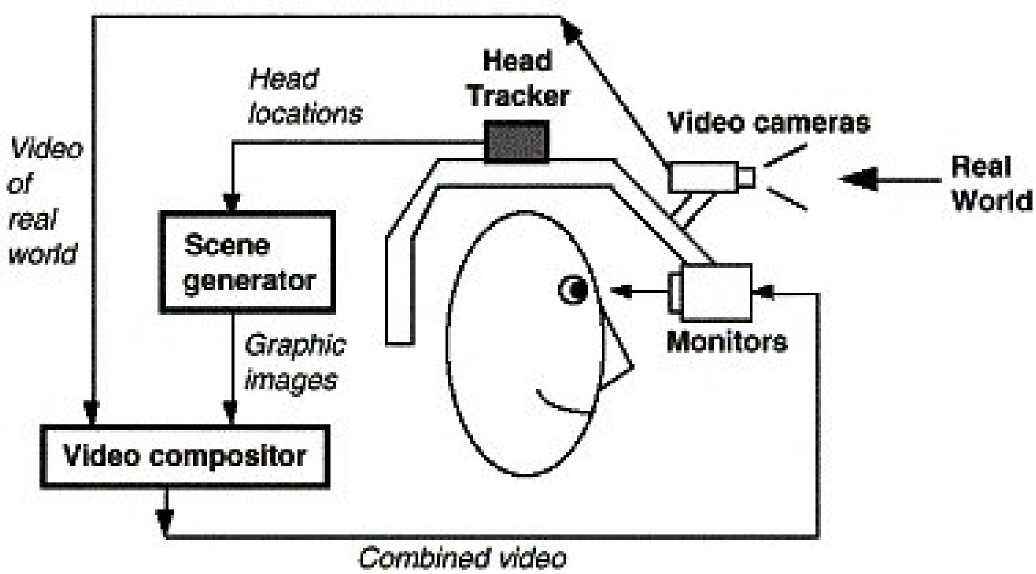

Figure 2.13: Schematic diagram of video see through display (Source: Azuma 1997)

2.4.1.2 Head-Mounted Displays

This section provides a comparison of optical and video see-through HMDs based on parameters thought by this author to be relevant in this context. For a thorough review and comparison between these two, check out..

citation needed

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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 otherhand, 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

   what do you mean by digitize??

   . 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.

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

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.

2.4.1.3 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 2.4.1.1. 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.

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

[2] refer to section 2.4.1.4 for a discussion on photorealism

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 2.14 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 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

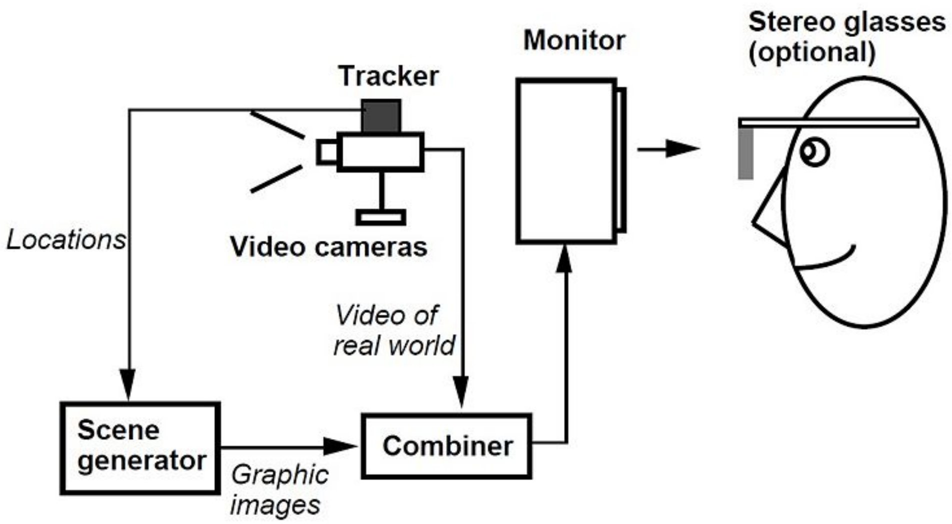

Figure 2.14: Schematic diagram of monitor see through display (Source: Azuma 1997)

appropriate locations and turning bridge windows in to projection screens onto which virtual objects can be projected.

2.4.1.4 Photorealism

2.4.2 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 onboard a modern seafaring vessel should consider how virtual objects interact with various instruments in the bridge room so as to accurately correspond with the reality that is being visually perceived.

2.4.2.1 Bridge Instrumentation

2.4.2.2 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

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