Mixed Reality Ship Handling Training Method

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November 16, 2016

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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.

1.1 Research Questions

Ship simulators are used extensively by ship crew for learning, certification and, upkeep of operational skills. Being simulations by nature, they are ap-

proximations of the process after all. Training on-board real ships is ideal from the perspective of learning vessel dynamics. It provides for hands-on experience of ship's movement behavior under various weather conditions. Besides, such a training should help get better acquainted with vessel-specific instrumentation. However, it is much more difficult, perhaps even infeasible to set up environments for training purposes on-board real vessels compared to the simulator. This is because training environments in this context involve large physical objects such as ports, natural landscapes, other vessels, etc. 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 description of the concept of augmented reality before describing the method of research used in this study.
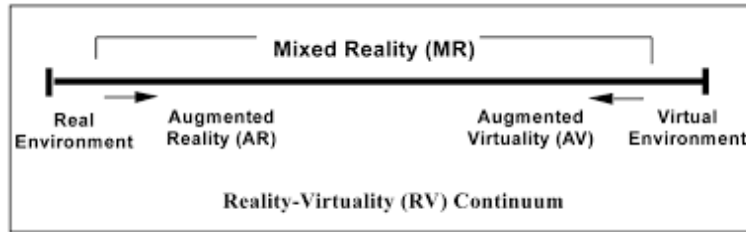
Figure 1.1: Mixed Reality Continuum (Source: Milgram et al. 1995)

1.2 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. Milgram et al. 1995 drew up a continuum (figure 1.1) characterising different mixed reality environments. 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

Figure 1.2: Conceptual depiction of augmented reality used in design

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 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).

1.3   Research Method

A research method devised by Neerincx and Lindenberg 2008 called situated cognitive engineering (SCE) was employed in this study. SCE 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 the method. 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.
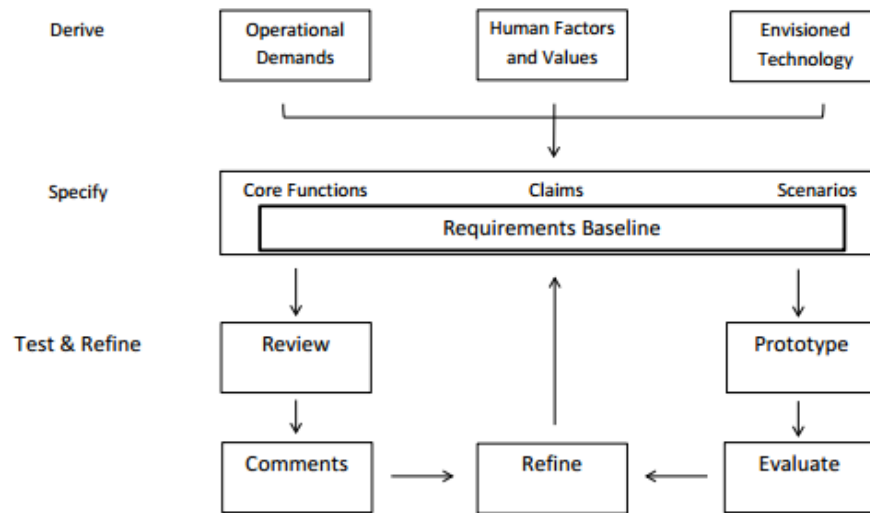
Figure 1.3: Situated Cognitive Engineering Method (Neerincx and Lindenberg 2008)

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 way-points, distance to next way-point, 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 members.

This chapter covers results of a domain analysis that was used to derive requirements for a scenario-based ship manoeuvring 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 specialized equipment for manoeuvring Section 2.3 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 2.4 titled human factors knowledge describes mode errors - a type of error arising from the operation of state-dependent systems out of state. Finally, section 2.5 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 to in open seas with vast empty space. Manoeuvring typically refers to ship handling in confined spaces, at low speeds; requiring accuracy and precision in movement. Navigation in contrast, takes place in open seas with more room for movement making it a relatively easy task compared to manoeuvring 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 manoeuvring 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. Manoeuvring 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 manoeuvring Besides being a skilled task, it also involves safety risks by nature of its activities. The next section describes challenges of manoeuvring 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 manoeuvring tasks and its riders that entail the presence of operators with manual handling skills.

2.1.1 Manoeuvring

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'. Manoeuvring a large vessel at low speeds is often a challenging operation even from the perspective of a human operator. Examples of difficult manoeuvring 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 manoeuvring 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 manoeuvring

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 manoeuvring Mistakes have high associated costs, possibly leading to lost lives and damage to expensive constructions.

2.2 Offshore Exploration and Supply

A special application of ship handling skills 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

Manoeuvring 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
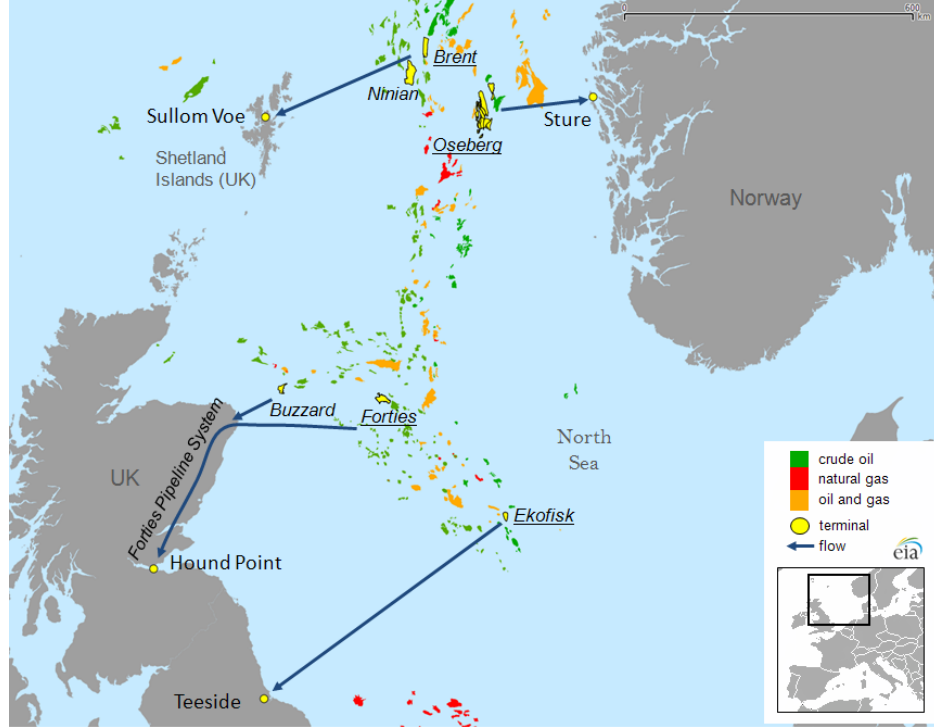
Source: refer footnote[1]

automated systems that help with station keeping and other manoeuvring 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 manoeuvring operators.

2.2.1   Dynamic Positioning System

Dynamic positioning (DP) is an automated system that helps human operators with manoeuvring operations. It began to be developed as a system that maintains position and heading of a vessel automatically by using its

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

propellers and thrusters. The use of DP systems has been increasing over 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 manoeuvring in shallow water and harbour 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 by the systems. It is supplied as input to a program that calculates changes in position and heading required to bring the vessel to a pre-set 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 station it in a pre-set location.

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,

Figure 2.2: Forces acting on a ship and its possible movements
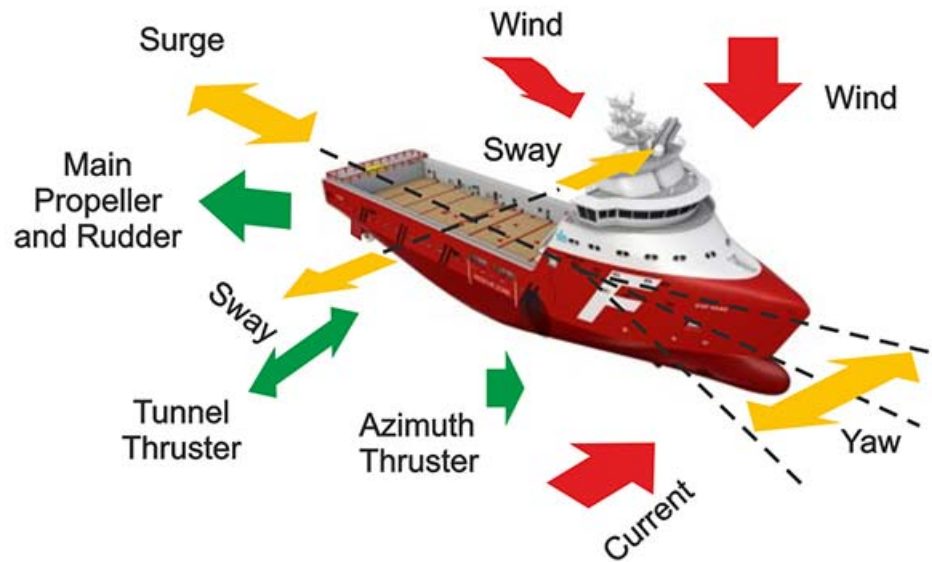
Source: kongsberg.com

it is 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 $\pm$ 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.
2. **Auto heading**: In this mode, the vessel automatically maintains a pre-set heading.

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

2.2.2   Manual Handling

Going by number of total losses occurring 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 7, 2004 are mentioned as cases of shipping incidents that
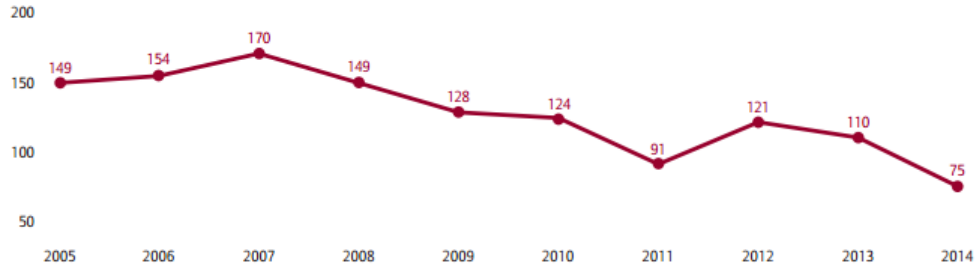
Figure 2.3: Yearly vessel loss since 2005

showcase the lack of preparedness among crew members to handle with emergency situations (Vinnem 2013).

2.3 Operational Demands

An analysis of the task domain was conducted in order to better understand the actions performed by human operators while manoeuvring a vessel and the conditions under which they are performed. This section describes results of the analysis which in turn drove the specification of a system that can be used to learn ship manoeuvring

A key outcome of the task domain analysis was that an intuitive understanding of vessel handling is required to manually manoeuvre a vessel. Different vessels exhibit different handling behaviour 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 behaviour of the vessel - 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. It follows then that a training system for manoeuvring should enable manoeuvring practice on real vessels in real operational conditions.

A clear view of the target object around which the vessel is being manoeuvred 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 progress of the manoeuvring operation. Using this information, the operator can make adjustments to the vessel's movement as required. When manoeuvring 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 watch-keeping experience on-board real vessels with DP. This watch-keeping exercise takes place for a relatively short period of time where the trainee is familiarised with DP equipments on-board the vessel and gets to witness operations. This is followed by a simulator-based course where the trainee gets practical experience operating DP systems at shore-based simulation centres

Comparison of training methods Table 2.1 presents a comparison of simulator-based training, mixed reality on-board training and practice-based or on-the-job learning.

2.4 Human Factors Knowledge

2.4.1 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
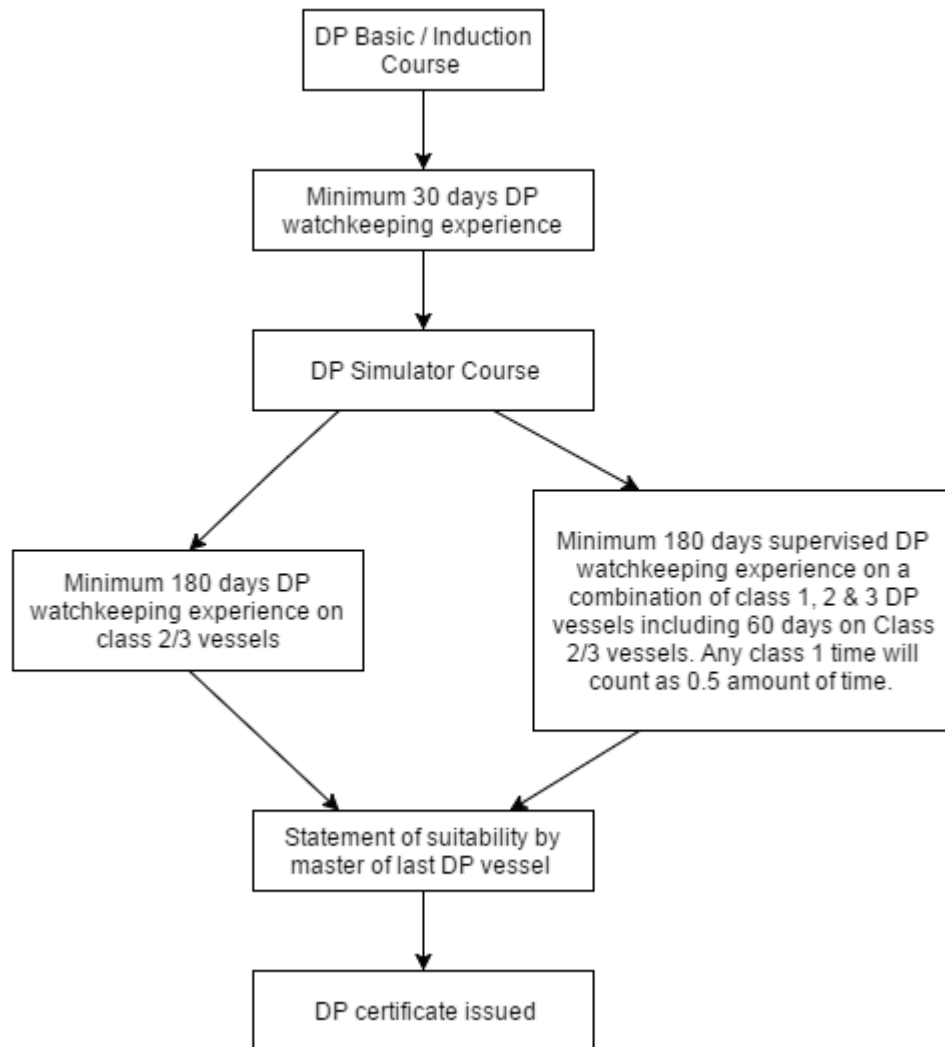
Figure 2.4: Flowchart of nautical institute Dynamic positioning certification scheme

Table 2.1: 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

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 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 immersion of the experience.
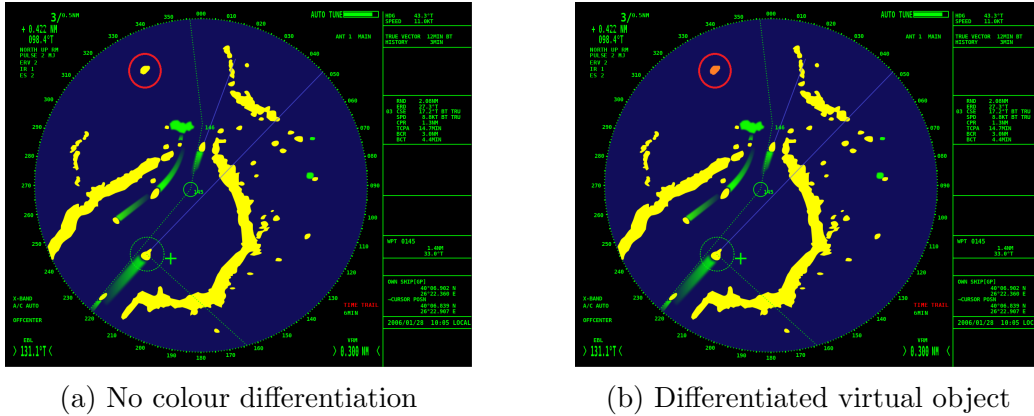

(a) No colour differentiation   (b) Differentiated virtual object

Figure 2.5: Display of virtual objects on radar

2.5   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. The evolution of computing technology from large machines driven by punch cards and that filled up entire large rooms to the personal computer form goes hand in hand 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 set-ups involve actual bridge equipment to input commands to the program, making the experience more realistic. 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 set-up of a typical dynamic positioning simulator.

2.5.1 Augmented Reality Display

This section is about display technology needed to create augmented reality applications. It briefly describes different display technology options for creating the visual perception that is part of augmented reality. Three types 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, in military, and medical visualization context,

Figure 2.6: Set-up of a dynamic positioning simulator by VSTEP B.V.

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 for ship
handling training is considered in this research. Optical see-through displays
allow an unhindered view of the outside world in theory, whereas in video
see-through display the user's view is camera-mediated. Optical see-through
HMDs appear to be the most logical choice for AR. It is ideologically consis-
tent 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 the 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.

2.5.1.1 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-through 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 a more popular use. 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 digital content. Optical combiners usually reduce the amount of light from the 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 an undistorted view of the real world (apart from slight obstructions caused by the glasses' frame itself). As a downside, it also affects the display of digital content adversely, making virtual objects appear semi-transparent and 'ghostlike'.

2.5.1.2 Video See-Through Head-Mounted Display

Video see-through HMDs are similar to optical see-through HMDs in that they allow the combining of real world views with digital content. Differences between them stem from their source of real world view. As opposed to OST
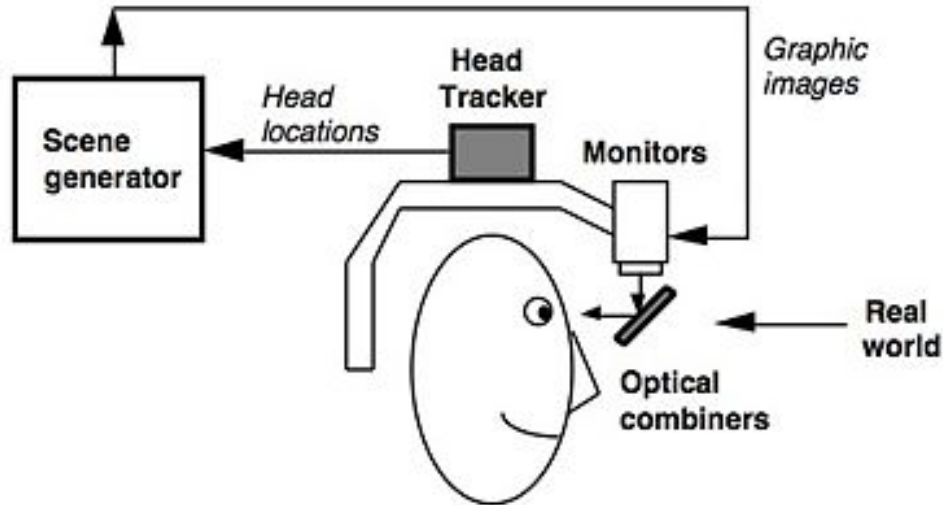
Figure 2.7: Schematic diagram of optical see through display (Source: Azuma 1997)

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, VST HMDs require a camera appendage in the setup (see figure 2.8). The video camera mounted on the exterior of such an HMD incorporates external view back into the content. This type of HMDs obscures the wearer's external view in favor of better immersion into the stereoscopic view provided by the system.

Driven by interest from the gaming community, and virtual reality applications in general, closed-view HMDs have seen more development as of this writing compared to optical see-through displays. 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.
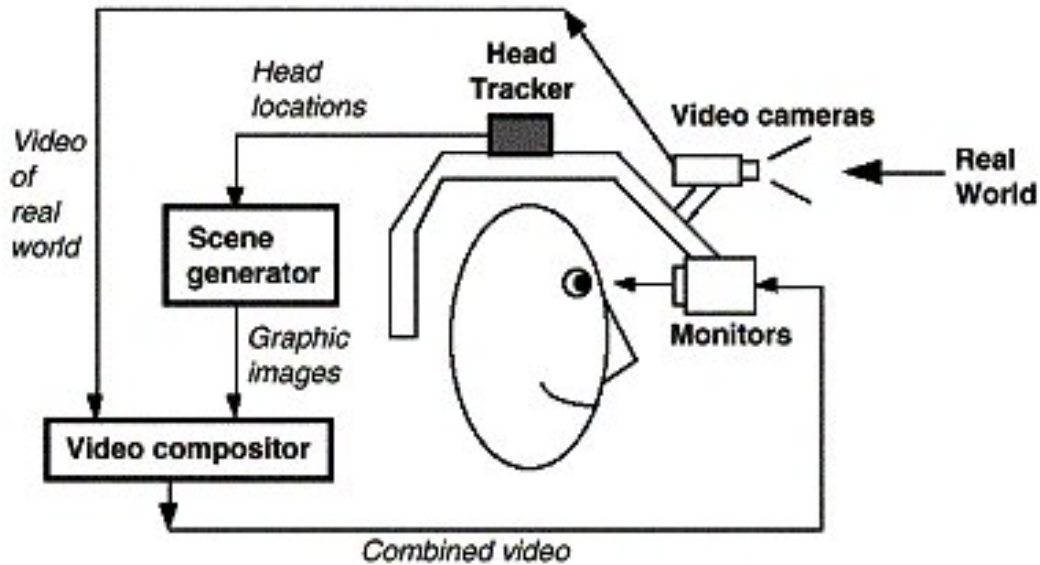
Figure 2.8: Schematic diagram of video see through display (Source: Azuma 1997)

2.5.1.3   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. Being an AR technology, implementations of SAR must adhere to the basic requirements of augmented reality listed in earlier section 1.2. Alongside HMDs, it forms another paradigm for the creation of mixed reality content. SAR offers unique benefits over HMDs such as obviating the need for users 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 requiring setting up of expensive custom-made display configurations that require more space and hardware

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[2]refer to section 3.1.3.1 for a discussion on photorealism

than standardized HMDs. The lack of standardized solutions and the need to set up special hardware tailored to individual ships makes SAR an impractical solution for the creation of AR on-board ships for manoeuvring training purposes. A portable technological solution that enables mobility between vessels is desired. This allows for training to be conducted on various different vessels with minimal time and effort involved in setting up the augmented environment. Using mobile AR devices such as HMDs enables trainees to bring their own AR devices on-board 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 set-up, the user experiences mixed reality through one or more monitors placed in front, displaying 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 three 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.
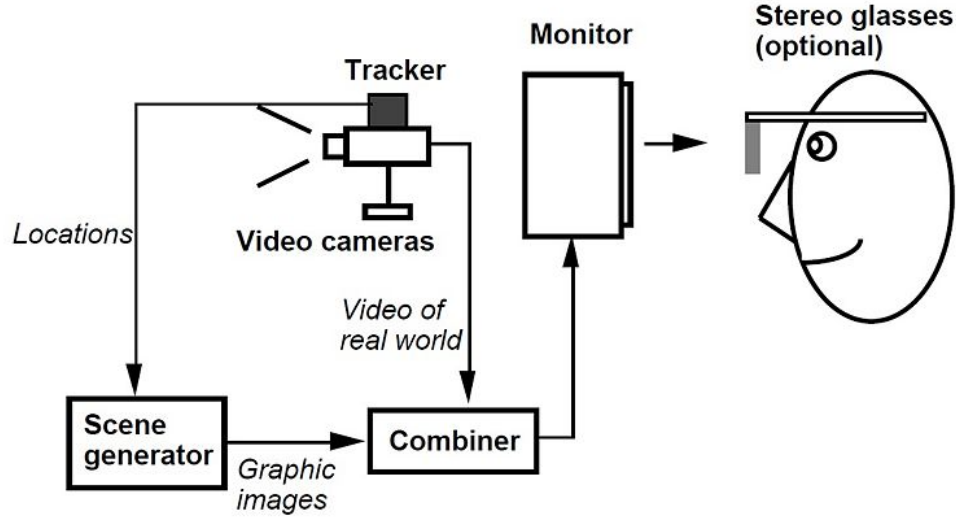
Figure 2.9: Schematic diagram of monitor see through display (Source: Azuma 1997)

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 on-board difference vessels would involve considerable effort to tailor the display system for individual ships. Besides, some modification of the ship's bridge room is involved such as placing of projectors at appropriate locations and turning bridge windows into projection screens onto which virtual objects can be projected.

2.5.2 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 addition to virtual images, there is a need to view the external world in mixed reality applications. Optical see-through systems meet this requirement naturally by employing transparent displays which do not interfere with the outside view. Video see-through systems on the other hand, obscure the outside view and need to use a camera that is looking outwards to compensate. 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 and when it is to be displayed indeed. Finally, there will be a small delay in rendering images on the display system.

   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

Table 2.2: Comparison of see-through head-mounted displays

	Optical	**Video**
Peripheral FOV (horizontal)	180 degrees	110 degrees
Time lag - real world view	0ms	>16ms
Digital display FOV (horizontal)	20-40 degrees	>90 degrees
Real world view	Largely undistorted	Camera and display dependent
Simplicity	Process one stream (virtual images)	Process two streams (camera feed & virtual)
Resolution	Partially display dependent	Fully Camera and display dependent
Focus and contrast	Hard to blend virtual object into real scene	Lesser contrast issues (limited by camera's dynamic response)
Occlusion	Challenging to achieve full occlusion	Occlusion is possible due to full control over displayed content

millimeter of error.

One 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.

2.5.3   Ship Instrument Augmentation

Mixed reality displays described in the previous section form a part of enabling technologies for the mixed reality ship manoeuvring 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 artefacts 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 bridge room to accurately correspond with the reality that is being visually perceived.

2.5.4   Tracking Requirements

Tracking is a vital requirement for augmented reality as already stated in section 1.2. An AR system needs vision capability in order to track viewer's position and register objects in his field of view. Specifically, it is of interest to track user's head position and gaze direction so that virtual objects can be registered in the appropriate location. Tracking systems usually comprise of camera/s that are used to sense real-world space. Cameras produce the raw data necessary for computer vision systems.

It is common for tracking systems to work on the infra-red light spectrum even though the concept is also viable on the visible spectrum. Two main options are available for construction of tracking systems. They differ based on the positioning of the camera relative to the viewer. In broad terms, inside-out tracking systems are designed such that camera is placed on the

viewer and it tracks the environment as a viewer moves around in it. Whereas in outside-in tracking, a stationary camera that is placed away from the viewer (but in sight and, without occlusion) tracks the viewer's movement using markers placed on the viewer themselves.

The two types are described below along with their implications for the on-board training scenario. For a detailed discussion of tracking methods, readers are referred to Zhou, Duh, and Billinghurst 2008. According to Zhou, Duh, and Billinghurst 2008, tracking, being a core enabling technology for AR, is an unsolved problem with many "fertile" areas of research.

2.5.4.1   Inside-out Tracking

Inside-out tracking refers to systems in which the camera that tracks positions is located in the same physical location as the device/viewer being tracked (head mounted display for example) so the camera moves along with the tracked object. With the camera mounted on the object that is being tracked, the system tracks the world around it from the vantage point of the tracked object. Changes in location/orientation of the tracked object can be detected from the camera's changing perspective of the outside world.

Fiducial Markers   A straightforward implementation of this idea would process images from video stream captured by the camera to locate objects in the world space and register virtual objects among them. However, interpreting live camera feed is a computationally expensive operation due to the difficult computations involved in processing images on the fly. A popular refinement of this solution is to place so called fiducial markers in the environment being tracked. Figure 4.2 shows a typical marker that can be used for marker-based tracking. With visible markers (to the camera) in the tracked space, the complexity of image processing computations is reduced. The tracking system is then aware of the type of images to look for and make decisions accordingly. Moreover, marker images are usually black-and-white

so that the camera input can be converted to B&W, significantly simplifying image processing computations.

Figure 2.10

2.5.4.2 Outside-in Tracking

Outside-in tracking systems are those in which a stationary camera placed away from the viewer in the tracking environment tracks the viewer. Changes in viewers position are tracked using markers placed on them. Unlike inside-out tracking systems, tracking range with this method of tracking is not limited by fiducial markers in the environment. Outside-in tracking is considered to be more accurate at tracking position than inside-out tracking systems (Klein 2006).

A disadvantage with this system is that since the camera is at a different physical location than the system that generates the virtual images, tracking

data is not directly available on the AR system itself. Then data has to be sent to the system from a separate device that does the tracking. Data can be sent by a wireless or wired connection. A wired connection impedes free movement in the environment but it is also the faster and more reliable method of data transfer. Data might also be sent wireless which allows for ease of movement. But it comes at the cost of latency and reliability issues in data transfer.

Besides latency in obtaining tracking information on the AR headset, another disadvantage of this tracking system is that it is susceptible to noise in the form of ambient infra-red light. This is a constraint on the system with the implication being that lighting in the tracked space will have to be carefully controlled to prevent the system from being affected by noise.

Chapter 3

Design Specification

This research is a study of the viability of leveraging augmented reality technology for simulation-based training purposes in the maritime sector. A working prototype was envisaged in order to access the user experience of such a system. This chapter consists of the design solution that was devised to the ship handling training problem outlined in the previous chapter.

Development of the actual prototype was based on a few functional requirements thought to be essential to the system (section 3.3). SCE method prescribes that functional requirements be linked to objectives of the system. An evaluation of the prototype is then conducted to test it's ability to meet desired objectives. Evaluation hinges on claims that are made regarding the system. Claims in this context are the hypothesis that are tested during system evaluation(section 3.4). First, section 3.1 makes a comparison of three types of on-board training differing in their expected outcomes in terms of learning. A basic use-case flow is outlined along with alternate steps of system use in section 3.5.

3.0.5   Design Challenge

Systems that involve human-computer interaction(HCI) are intended to be aids of human activity. However, system designs are as much constraints on

the solution space as they are solutions themselves to the problem at hand (Carroll 2000). In other words, a proposal for a certain way of tackling a problem ties further reflections of it's effectiveness to specifics of the design. How then does a research in HCI deal with this unavoidable conflict?

Further, it is often advised that designs must be open-for-change. A popular saying in software design practice is *requirements always change.* But, changing requirements are not conducive to testing.

One way to counter this problem is to list a few different desirable objectives for the system in question. A broader look into the problem space allows for insight on requirements of a minimum viable product. It can be posited that such an insight enables the design of a system that is more accommodating of changes in requirement. By exploring many different objectives and designing to meet their basic underlying functional requirements, the chances that future requirement changes are related to those already explored is increased and so is the validity of evaluations.

3.1 On-board Training Possibilities

An analysis of various scenarios for simulation-based on-board training resulted in three areas of training - manoeuvre training, navigation training and, emergency response training. They are characterised by their different learning objectives. These categories were conceived after a research of ship crew training options using augmented reality. The analysis was conducted by surveying research papers in this context and interviewing industry experts on the subject.

As mentioned previously, a prototype was envisaged to evaluate the feasibility of the training method explored in this study. Prototype artefacts inevitably embody a particular design choice; a choice rife with challenges that are faced by systems design described earlier in section 3.0.5. This study deals with the challenge by explicitly outlining available design choices. Con-

sequently, one is chosen for prototyping and evaluation. Results can then be viewed in light of the general context. Following is an overview of each of the training options. Table 3.2 presents a comparison of the three categories.

3.1.1   Manoeuvre Training

Ship manoeuvring and its growing importance in the maritime industry has been elucidated in section 2.1. To reinstate, manoeuvring is the skilled task of handling a vessel with precise control in navigationally challenging scenarios, for example in close quarters of large man-made artefacts. The skill involved is noteworthy as the operator faces two-fold demands of timely accurate assessment of evolving weather conditions, their effect on the vessel as well as effecting its movement using ship controls. Currently, experienced seafarers are entrusted with manoeuvring responsibility. It is a reflection the importance of practice-based learning where ship handling skill is concerned.

It is expected that this type of training would require a high degree of photorealism [1]. Manoeuvring typically occurs in physical proximity of large man-made or natural objects. At close range, the human eye sees objects in greater detail than when they're farther away. One implication then is that the device used for augmented reality display would have to render virtual images at a high resolution. Another implication is that these scenarios will place high demand on registration accuracy since inconsistencies in positioning of virtual objects' will be more noticeable at close range owing to the nature of human vision.

A manoeuvre training scenario was chosen for prototyping and evaluation despite the relatively high level of photorealism thought to be required for the concept to be workable. Reasoning for this choice two-fold. Firstly, an evaluation (user-testing a prototype) in this scenario would bring to light shortcomings, if any, of state-of-the-art consumer grade AR devices for their ability to render high quality 3D graphics necessary to create believable aug-

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[1]refer page 39 for categorization of photorealism

mented reality training scenarios. Secondly, manoeuvring scenarios in off-shore supply context do not require a large number of virtual objects in the scene. Position keeping for example, is an exercise where the vessel is to be kept stationary with reference to a particular offshore construction. Position keeping training scenario then allowed for rapid prototyping with low time-investment on developing the virtual aspect of the augmented reality.

3.1.2 Navigation Training

Scenarios involving activities aimed to learn the tasks of navigation are described in this section. Navigation here refers to ship handling from the time it is unberthed and, along the journey to the destination. This includes path planning, following the plan to avoid collision in adherence to COLREGS [2], maintaining watch along the path, etc.

There is scope for augmented reality to be used as a training aid in these scenarios. Buoy for instance is a floating device that serves as a navigational aid, and can form part/s of a virtual environment set up for training purposes. More elaborate scenarios maybe envisioned such as visualization of landscape in the vicinity and harbour ports with in and outbound traffic. Simulated scenarios of this nature should also be visualised on ship bridge instruments. In order to be consistent with the augmented reality of sailing by an island for example, the radar should reflect said island in its display system.

3.1.3 Emergency Response Training

Emergency response training in general aims to arm trainees with the knowledge and alertness required to encounter hazardous situations in real life. This type of training has potential for use of augmented reality to create the illusion of dangerous situations. Examples of it on ships can be fire in the engine room or water flooding in the ship's deck. It is posited that these are

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[2]The International Regulations for Preventing Collisions at Sea

Table 3.1: Comparison of on-board training options

	Manoeuvre Training	Navigation Training	Emergency Response
Learning Objectives	Vessel handling in navigationally challenging situations	Long-distance maritime navigation	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 Gained	■ 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.
Crew Requirement	■ Trainee ■ Instructor ■ Officer of the watch	■ Trainee ■ Instructor ■ Officer of the watch	■ Full crew / part of crew located at emergency site
Photorealism required	High	Medium	Medium

situations that lend themselves well to simulation-based training. Further, interviews with industry experts revealed that emergency response training on-board could be improved by simulations. During training exercises, visual evidence of a hazard can be a more powerful motivator compared to vocal signals to the same effect. The idiom *seeing is believing* perhaps then applies.

Compared to manoeuvre training, emergency response places looser demands on the augmented reality system. Fires and floods for instance are shapeless and for training purposes their exact form is of less importance than their very existence. Also in such situations, attention of rescue workers is not always entirely on the cause of hazard itself. There is a focus on rescuing crew members and emerging from the situation safely.

3.1.3.1   Photorealism

Photorealism in this context refers to the quality of visualisation of objects in the simulation. At high levels of photorealism, virtual objects are visible with a high level of detail, blend seamlessly into the surroundings - appropriately occluding objects behind it and, are of proper focus and contrast, with the end result being a realistic visualisation whose virtual aspects are hard to distinguish from the real.

Stereoscopic displays are plagued by problems from accomodation-vergence conflict (Hoffman et al. 2008). For purposes of this study, levels of photorealism are grouped into three distinct categories. The extent to which accommodation-vergence conflict affects a scenario is one of the attributes on which the classification has been made. Another attribute is occlusion, an essential depth cue that can be important in manoeuvring scenarios for instance. Table 3.2 is a listing of the three categories.

Table 3.2: 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. 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

3.2   Design Scenario

"AugMan helps Michiel practice ship maneuvering and, improve depth perception."

Michiel, 25 years old, received the dynamic positioning (DP) certificate a short time ago. He has just taken up his first job as a dynamic positioning operator (DPO) on-board VOS BASE - a medium-size platform supply vessel. Fitted with Class 1 DP system, the vessel has been rented by Royal Dutch Shell to supply cargo to offshore oil platforms off the Dutch coast. Michiel is joined on the deck by captain Willem and chief mate Steve, both experienced seafarers capable of handling the ship as well as its DP equipment.

He lacks manual vessel manoeuvring skills. Though familiar with bridge equipment, he has little experience using it on an actual vessel. Manoeuvring a large vessel in close range of offshore platforms causes him anxiety. He feels unprepared for an emergency such as failure of one of the DP system's components effectively rendering it unusable. Should this situation arise during a load/unload operation, an operator needs to maintain the vessel's position and heading manually - at least until it is safe to stop the operation. Following this, the vessel will be steered away outside the 500m safety zone of the oil rig. With a dysfunctional DP system, either joystick manoeuvring or manual vessel handling will have to be engaged; both of which he is not adequately trained for.

3.3   Functional Requirements

This section lists the functional requirements that were drawn for a prototype application. Requirements were based primarily on specifications of augmented reality put forward by Azuma 1997. They are tailored to suit the operational demands of ship manoeuvring training. Accordingly, functional requirements of the prototype are listed below.

The system shall be able to:

1. **Present 3D images** of objects such as ships, oil platforms, buoys and landscape features to create the augmented environment.

2. **Register virtual objects** in user's physical space.

3. **Generate projections** of virtual object to be consistent with user position.

4. Provide exercises to **accommodate various learning goals**.

5. **Provide manoeuvring instructions** adapted to user's manoeuvring proficiency.

3.4   Claims

1. Presenting user with 3D images helps create a convincing feeling of presence of an object in user's reality.

2. Registering the virtual object in a fixed space creates a convincing feeling of presence.

3. Generating view-specific projections of virtual object based on user position is essential to leverage parallax effect which provides depth cues.

4. Maneuvering instructions, help automate the task of coaching.

5. Different types of maneuvering exercises makes the system useful to a wide range of users of varying levels of maneuvering skills.

3.5 Use Case

3.5.1 Manoeuvre Training

Actors:	DP Operator, AugMan, Captain/Instructor.
Circumstance:	DP operator is idle on an offshore supply vessel.
Precondition:	Vessel is not undertaking any operation.
Post condition:	DP operator has improved maneuvering skills.
Method:	Practice maneuvering in augmented reality.

3.5.2 Basic Flow

1. Operator wears AR device and starts the application.

2. AugMan presents a list maneuvering exercises and asks user to choose.

3. Operator chooses an exercise and orients himself (including head position) in the direction in which the virtual object/augmented environment should appear.

4. Operator indicates he is ready to start the exercise.

5. AugMan brings up the augmented reality environment and asks the operator to set vessel controls to neutral position before starting the exercise.

6. After making sure that the vessel controls are in neutral position, operator starts the exercise.

7. AugMan receives position changes from the vessel and renders visuals of the virtual environment accordingly.

8. Operator practices maneuvering the vessel in the virtual environment using visuals from the AR device as reference.

9. AugMan provides a review and feedback of the maneuvering performance.

3.5.2.1 Alternative steps (Beginner Level)

Application provides direction and maneuvering hints throughout the exercise.

1. Operator wears Ar device and starts the application.
2. AugMan presents a list of **low-difficulty maneuvering exercises** available and asks user to choose.
3. Operator chooses an exercise and orients himself (including head position) in the direction in which the virtual object/augmented environment should appear.
4. Operator indicates he is ready to start the exercise.
5. AugMan brings up the augmented reality environment and asks the operator to set vessel controls to neutral position before starting the exercise.
6. After ensuring that the vessel controls are in neutral position, operator starts the exercise.
7. AugMan receives position changes from the vessel and renders visuals of the virtual environment accordingly.
8. Operator practices maneuvering the vessel in the virtual environment using visuals from the AR device as reference.
9. Application provides **helpful hints** for maneuvering such as the directional pointers and controls to be engaged **throughout the exercise**.
10. AugMan provides a review and feedback of the maneuvering performance.

3.5.2.2 Alternative steps (Intermediate Level)

Application provides maneuvering hints during the exercise on request by user.

1. Operator wears AR device and starts the application.
2. AugMan presents a list of **medium-difficulty maneuvering exercises** available and asks user to choose.
3. Operator chooses an exercise and orients himself (including head position) in the direction in which the virtual object/augmented environment should appear.
4. Operator indicates he is ready to start the exercise.
5. AugMan brings up the augmented reality environment and asks the operator to set vessel controls to neutral position before starting the exercise.
6. Having ensured that the vessel controls are in neutral position, operator starts the exercise.
7. AugMan receives position changes from the vessel and renders visuals of the virtual environment accordingly.
8. Operator practices maneuvering the vessel in the virtual environment using visuals from the AR device as reference.
9. Application provides **helpful hints** for maneuvering such as the controls to be engaged during the exercise **on need basis**.
10. AugMan provides a review and feedback of the maneuvering performance.

3.5.2.3 Alternative steps (Expert Level)

Application does not provide maneuvering hints during the exercise.

1. Operator wears AR device and starts the application.
2. AugMan presents a list of **high-difficulty maneuvering exercises** available and asks user to choose.

3. Operator chooses an exercise and orients himself (including head position) in the direction in which the virtual object/augmented environment should appear.

4. Operator indicates he is ready to start the exercise.

5. AugMan brings up the augmented reality environment and asks the operator to set vessel controls to neutral position before starting the exercise.

6. Having ensured that the vessel controls are in neutral position, operator starts the exercise.

7. AugMan receives position changes from the vessel and renders visuals of the virtual environment accordingly.

8. Operator practices maneuvering the vessel in the virtual environment using visuals from the AR device as reference.

9. Application provides **no maneuvering hints** during the exercise.

10. AugMan provides a review and feedback of the maneuvering performance.

3.5.3   Ontology

Augman - augmented reality prototype consisting of see-through glasses and a head tracking system capable of registering objects a predetermined location in space

See-through glasses - Wearable see-through glasses that are capable of rendering 3D graphics making it possible to create augmented reality environments which leaves the wearer's view of the outside world intact while rendering virtual objects in the same visual field.

DP Operation trainee - Dynamic positioning operator with limited manual vessel handling experience.

DP Vessel - A vessel with dynamic positioning system installed on it that can

also be operated in manual mode wherein the automatic vessel position control systems can be disabled for training purposes.

Training supervisor - A qualified and experienced officer-of-the-watch who is capable of manual vessel control that instructs trainees on learning goals, provides feedback on performance and can take control of the vessel if necessary.

Chapter 4

Evaluation

4.1 Artefact

A prototype was developed to evaluate the effectiveness of augmented reality as a ship maneuvering training aid. It is composed of various hardware devices which work together to meet one of the three defining aspects of augmented reality listed in section 1.2. The prototype was composed of the following hardware components: Epson Moverio BT-200 Augmented Reality Smart Glasses TrackIR 5 Motion Tracking Input Device Desktop PC with WiFi capability

Outside-in tracking was chosen as the method of tracking for this scenario. This method of tracking allows for the creation of a tracking system with minimal changes to the environment in which the tracking takes place as there is no need to place fiducial markers. It is required to have a clear view from the bridge of the vessel for safety reasons. Markers obscure external view since they will have to be placed on the window of the bridge in order register a virtual object in that region of space.
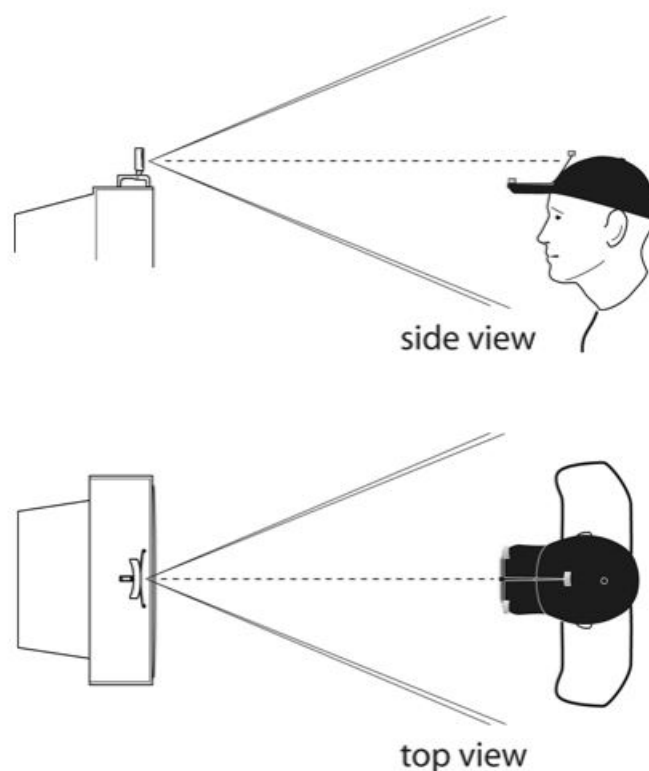
Figure 4.1

4.1.1   Evaluation Method

It is assumed that the skill of depth perception and judging relative motion of one object with respect to another can be trained for and, improved. Such a training then requires visual targets whose distance/depth can be perceived accurately by the human eye. This experiment is set in the marine environment. In the absence of working motion reference units, maneuvering a vessel manually requires accurate perception of distance in order to effect necessary adjustments to position over time.

Position keeping is chosen as the exercise against which maneuvering performance is measured in this experiment. The task of the subject in this manoeuvre is to keep a vessel stationary for a certain period of time. It is
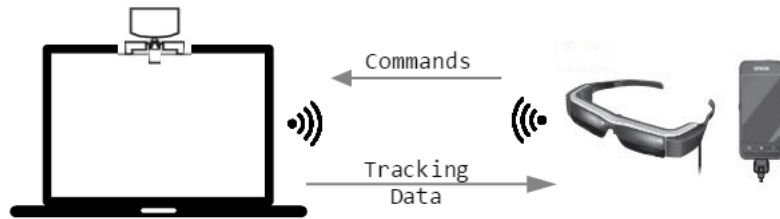
49

Figure 4.2

to be performed in the absence of aid from motion reference units, so that no automated computer assistance is available in performing the exercise. This will ensure that subject has to rely on their depth perception skills and ability to finely control vessel movements to keep in stationary in the face of wind and current that continuously affect the position of the vessel.

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