Exploring the potential for augmented reality to assist dynamic positioning operators

What operations has potential and what information is needed.

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Abstract

Technology has quickly become a vital part of the everyday of a mariner on board a vessel. A major part of using the full potential of a vessel was the introduction of the dynamic positioning system (DP), a computer-based system that allows the mariner to keep the vessel in its exact position with high precision. The system requires a certified dynamic positioning operator (DPO) to monitor and interact with screens holding valuable information. This decreases the time they spend monitoring the surroundings', which could lead to reduced situational awareness. In the past decade the development of augmented reality/mixed reality glasses (AR/MR) has rapidly increased with industrial grade products entering the market, the glasses which allows the user to watch digital projected data as well as their surroundings could be a solution to reducing the time the DPO spends looking down at the screens. There is little to no research on when and how augmented reality/mixed reality glasses should be used in a maritime operation nonetheless DP operations. The purpose of this thesis is to add to the knowledge gap and hopefully contribute to further research by asking the following research questions, RQ1: What type of dynamic positioning operations could the operator benefit from augmented reality glasses? RQ2: What information is needed to be displayed in the augmented reality in order for the operator to safely perform their work?

To investigate where augmented reality/mixed reality glasses have potential to benefit in dynamic positioning operations a study was carried out interviewing a sample of eleven participants of which eight are active dynamic positioning operators and three are dynamic positioning instructors. The qualitative data collected in the semi-structured interviews suggests the following dynamic positioning operations with a potential use-case for augmented reality/mixed reality glasses: Complex operations where the vessel is operating nearby or close to a platform, installation, or windmill whether it be supply, construction, inspection, or maintenance. The common factor is that the user has a visual reference to orient themselves by. On the matter of how it should be used the results suggests that the data of highest importance is data on position keeping such like, position reference systems, thruster movement and force and relative vessel movement. The research has found fitting DP operations, uncovered what type of information is important for the DPO in today's system and gathered some suggestions on other potential information. The goal is that this research can be of help for further research and development of an AR/MR system that will improve safety at sea.

Acknowledgments

I would like to express my gratitude to my supervisor Dr. Steven Mallam for his patience, support, and guidance over the past year. Allowing for academic learning and growth and for inviting me to be part of the OpenAR research project giving me an introduction to research in practice. It has all been a pleasure learning from you.

The research in this thesis would not have existed had it not been for the participants volunteering their free time to take part in the study, your contribution is highly appreciated.

Finally, I would like to thank my family. To my parents and two sisters, thank you for your patience and support over the past two years.

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Abbreviations

AHTS – Anchor Handling Tug and Supply vessel

AMO – Advanced Maritime Operations

AR – Augmented Reality

BRM – Bridge Resource Management

DP – Dynamic Positioning

DOF – Degrees of Freedom

DPO – Dynamic Positioning Operator

ECDIS – Electronic Chart Display and Information System

GNSS – Global Navigation Satellite System

HDT – Head Down Time

HMD – Head Mounted Display

IMO – International Maritime Organization

MR – Mixed Reality

NI – Nautical Institute

NCS – Norwegian Continental Shelf

RADAR – Radio Detection and Ranging

ROV – Remotely Operated Vehicle

SA – Situational Awareness

SDPO – Senior Dynamic Positioning Operator

STCW – Standard for Training Certification and Watchkeeping

UI – User Interface

1 Introduction

1.1 Research background

Ship navigation and maneuvering has existed for thousands of years, with the first sea-going vessel dating back to approximately 1500 BC. For most of its existence the occupation of being a sailor has been done by paper and theoretical calculations but over the past several decades maritime navigation has evolved in a rapid pace with the introduction of RADAR, satellite navigation and electronic chart displays (ECDIS) allowing for higher accuracy in navigation and improved maneuverability (Kjerstad, 2015). Computer-based technology and automation did not initially have the effect that it was predicted to have, on Norwegian continental shelf (NCS) there was still 15 collisions between vessels and installations between the year 1999 and 2000 (Petroliumstilsynet, 2014, p. 70). After new requirements set by petroleum safety authority Norway there has been 30 accidents between installations and vessels from 2005 to 2021 on NSC, with a positive trend from 2013 with several years without a single collision (Petroliumstilsynet, 2021, p. 92). Then over the past three years there have been three accidents in total, all due to trouble with the dynamic positioning (DP) system for maneuverability (Petroliumstilsynet, 2021, p. 92).

In regard to maneuvering the search for resources at sea has been the main contributor to the technological advancements made over the mast decades. Humans are today using vessels in ways we could not imagine five or six decades ago when companies and countries first started drilling for oil at sea. As the demand for resources grew in the late 1960s the production of oil and gas ramped up offshore. A need for better control over the vessel in order to perform the work at sea and more and more technology and automation were introduced to the ships bridge and for the mariners. Howard Shatto was responsible for the first know fully automated thruster control system, later know as dynamic positioning, placed on the drilling vessel *Eureka* in 1961, and by the 1980 the use of dynamic positioning was already an established technique (Bray et al., 2015, p. 1; Kjerstad, 2015, p. 3–74). The DP system introduced precision in ship maneuverability down to the centimeter and gave the operator the ability to hold the position even when the ship is exposed to outer forces like wind, sea and current. Today operations using DP in the field of offshore oil and gas are normal and an industry minimum requirement in any operations involving close quarters to live instalments (subsea wells, ground anchored platforms and floating production platforms). There are also applications for new ventures at sea such as offshore wind farms and offshore fish farms who are adapting to the use of the technology in order to ensure safe ship maneuvering. Operations involving DP today are often classified as advanced maritime operations (AMO).

Today the level of automation and technology at place on a ships bridge allows mariners more commonly known in these scenarios as Dynamic Positioning Operators or DPO's to obtain a more surveilling role. The vessels are then mainly controlled through the DP system with generally little inputs from the DPO. The DPO monitor data displayed to control that the vessel does not deviate from the position as well as watch over their surroundings. Bainbridge (1983) writes on the irony that automation systems automatically improves performance with little work by the human operator, but the reality of complexity in the system, navigating menus and submenus all to control the vessel and obtain data may lead to more mental workload and distractions for the DPO and reducing their situational awareness.

Mica Endsley describes situational awareness the following way "Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future." (M. Endsley, 1988, p. 97).

Historically there have been several events where either a DP system failure or more common, human error has created some dangerous situations. For example, the system failure on *Bibby Topaz* left a diver with a cut umbilical without oxygen for 40 minutes on 90-meter depth, or *PSV Sjøborg* hit *Statfjord A* oil platform after the operator ignored the alarms triggered by failure of forward tunnel thrusters and failed to manually maneuver the vessel away from the platform. And while automation might lead to an increase in performance in low stress situations, as soon as there are limited time humans becomes less effective problem solvers, "also the possibility that resolving them will require even greater technological ingenuity than does classic automation." (Bainbridge, 1983, p. 778).

To assist the DPO in keeping their SA the suggestion is to introduce head mounted displays (HMD) to the DPO. HMD are an emerging field of technology that is rapidly entering the market for industrial use but is still at a point that more research to better understand how it should be used to utilize its full potential. For this thesis the choice of HMD is a set of AR/MR glasses that allows the DPO to still see their surroundings as well as an additional digital layer.

The idea is that the DPO is able to keep and even enhance their SA by watching over surroundings as well as get the most critical data displayed in the general direction they are looking. In short, the AR/MR glasses will reduce head down time (HDT), which is the time the operator spends looking down at the screens instead of out the window.

1.2 Project background

The thesis scope and research goal are connected to the ongoing research project OpenAR. Together with a world-class consortium consisting of several Norwegian universities (USN, AHO, UIB) and major industry giants the goal of OpenAR is to improve safety at sea, by introducing augmented reality to improve the mariner's situational awareness by outfitting the mariner with an HMD. To do this, OpenAR is creating an open platform containing a user-interface architecture open to all interested parties. The goal is that by creating a standard framework for user-interface designed with the practice of user-centered design it should be impossible for the technology developing companies to make confusing and complex systems working against the goal of improving situational awareness. OpenAR's consist of four work packages where work package one is collecting data on what users, operations, contexts, and environmental knowledge are relevant and how should they be organized. The goal of the thesis is to research this on a smaller scale, but for it to still hold value to the OpenAR project and other future research.

1.3 Research questions

The goal of this thesis is to explore possible scenarios that will fit the AR technology. The main factor for possible scenarios will be if the DPO benefits from the technology or not. The second part of the thesis will explore what type of information is needed to be displayed in the different scenarios. What type of information benefits the DPO, and what is not necessary.

In order to address these goals on possible scenarios and information the following answers will be asked:

RQ1: What type of dynamic positioning operations could the operator benefit from augmented reality glasses?

RQ2: What information is needed to be displayed in the augmented reality in order for the operator to safely perform their work?

1.4 Thesis structure

The thesis is split in to six main chapters. These six chapters and their content is the following:

Chapter 1, Introduction: This chapter contains an introduction the research background, its project background, the research question's the thesis will try to answer and thesis structure.

Chapter 2, Literature review: This chapter contains the literature review and explains key concepts of the research, such as Standards for knowledge, training and certification, Augmented Reality, Dynamic positioning, and Situational Awareness.

Chapter 3, Method: This chapter contains the theory and methods of the thesis. The chapter will go into depts on what type of research data is collected, how it is structured, sample size and demographics, and data collection.

Chapter 4, Results: This chapter contains the results of the research and data collected.

Chapter 5, Discussion: This chapter contains a discussion of the data in an effort to answer the research questions presented in chapter one.

Chapter 6, Conclusion: This chapter concludes the data and research done in this thesis. It also holds recommendations and suggestions for further research.

Bibliography: Gathering of all references.

Appendix One: Interview guide
Appendix Two: NSD approval form.
Appendix Three: Interview information letter

2 Literature review

The goal of this chapter is to discover and present important information explaining the key concepts of the research. The literature review has been split into four main sections of subject related to the research, they are the following: Standards for knowledge, training and certification, Dynamic positioning, Augmented reality, and Situational awareness.

2.1 Standards for knowledge, training, and certification

One of the most defining factors of a maritime operation is the requirement towards the crew training and certification. All requirements for training can be found in the Standard for Training, Certification and Watchkeeping (STCW), which is a convention presented by the governing International Maritime Organization (IMO). The goal for the convention is to create a standard for training globally for all seafarers to ensure safe practice at sea. The convention presents minimum requirements for basic knowledge for officers attending to the bridge and keeping navigational watches stated in chapter two, *master and deck department* and chapter eight, *watchkeeping (International Maritime Organization, 2011, Chapter Two and Eight)*. For a bridge officer to obtain their certification they have to satisfy the requirements given by the convention and additional requirements set by the country the certificates are issued by.

Research on the matter of training on new technology concludes on how “the importance of training in relation to introduction of new technology cannot be overstated,” (Tang & Sampson, 2017, p. 2). A study performed by Tang and Sampson (2017) interview 43 mariners in order to learn what motivated them to learn new technology introduced to shipboard systems. The study shows that if there are personal gains like, more pay or promotion increased the motivation to learn. But having to pay for courses or training or being ordered to finish a course demotivates. At that point it is possible to experience that a participant of a course has finished it with very little learning, which can then create dangerous situations with certified operators without the proper knowledge. As the complexity of a maritime operation evolves and we demand more from the vessel as a working platform the knowledge and certification requirement for the bridge officer increases. As some vessels reach their area of work, they switch from transportation mode to operation mode, the work and/or area the vessels perform in require specialised training and certification of the crew.

For officers keeping watch on vessels like these, there are specific requirements to documented knowledge, training, and certification of an advanced skill trough an own chapter in the STCW convention. Chapter five, *Guidance regarding special training requirements for personnel on certain types on ships*, in the convention mentions requirements of knowledge on specific operations/vessels such as oil tankers, passenger ships and vessels operating in polar waters (International Maritime Organization, 2011, Chapter Five)

When a vessel enters into this type of operation the complexity reaches a point where there is usually more than one officer on the bridge, they are usually in active communication to other departments or teams on board or on other installations and/or vessels nearby. For operations demanding the vessel to hold one position or maneuverer with high precision the manoeuvring is often done through a computer system most commonly known as dynamic positioning (DP) allowing the vessel to keep its position even in heavy sea and strong winds. Operating a vessel through the DP system requires training and certification according to the requirements mentioned in STCW Part A Section A-I/14 (International Maritime Organization, 2011, A-I/14). As the vessel and its crew enters these types of operations, they have taken a step into advanced maritime operations (AMO). In order to some extent limit the thesis the definition of AMO is set as any operation involving manoeuvring of a vessel in any operation demanding that the vessel stays in one position or precise manoeuvring with the assistance of a dynamic positioning system by personnel satisfying the requirements in STCW chapter five and section A-I/14.

2.2 Dynamic positioning

Meaning and History

"Dynamic positioning is not a piece of equipment. It is a vessel capability provided through the integration of a variety of individual systems and functions" (Bray et al., 2015, p. 3). In short, the system that is not a system but a gathering of several systems working together to keeps the vessel in one position and orientated in one direction by controlling and adjusting the force provided by the thrusters to adjust for all outer forces acting on the vessel.

After the first system was placed on board the American drillship Eureka in 1961, Honeywell started their production of a complete package which would give a vessel DP capability, some Norwegian ship owners was early with implementing the system on their ships, one of them was the Tromsø based Odd Berg ship owning company (Kjerstad, 2015, p. 3–74). As Norway discovered oil in 1969 the motivation grew to build a Norwegian system for dynamic positioning. Kongsberg Våpenfabrikk together with local universities and researchers began the adventure that created Kongsberg Albatross a modern DP system that was later known as Kongsberg DP. The Kongsberg Albatross system was well engineered and quickly grew world-wide. By the mid 1980 the Kongsberg DP was the majority DP system used and sold globally (Breivik et al., 2015, p. 1). Today the modern version of Albatross is known as Kongsberg K-Pos is still holds the market majority, other developers later join the market, most known are Thrustmasters (former Rolls-Royce), Marine Technologies and L-3.

How a DP system works

The system is controlled through the control station. Through this the DPO can define movement in three out of the six degrees of freedom (DOF) a vessel can move in. The different directions the DPO can control are: sideways known as sway, forward and aft known as surge and rotation known as yaw all seen in orange in figure one. Each of these three can be individually engaged, usually with an individual button. This means that the DPO can individually lock each degree of freedom. In K-Pos the buttons are marked as *Auto Surge, Auto Sway, and Auto Heading.* By activating auto modus on all three DOF the system will keep its position (Kjerstad, 2015, p. 3–76). Figure two show a typical combination of two control station that can usually be found on the bridge. Each station holds its own screen and are independent of each other for redundancy purposes, but since they both collect data from the same sensors, they can display different data to the operator for them to observe more information at once or have faster access to adjustment parameters during an operation.

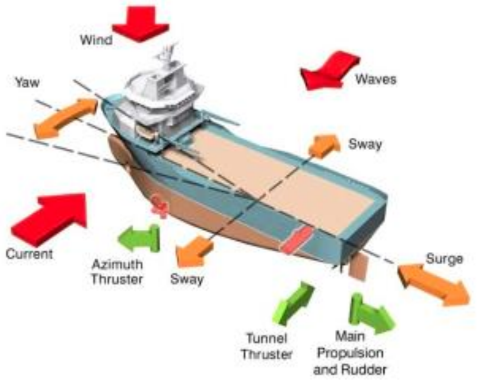

Figure 1. Shows forces acting on the vessel in red, vessel movement in orange and thruster forces to be applied in green (Breivik et al., 2015, p. 2).

Figure 2. Dual K-Pos Control Station (Kongsberg Maritime, 2022).

All consoles are outfitted with some hotkeys for functions of high importance, but most of the systems functions and adjustments are done through the user interface and found in submenus. There are also more modern options where the DP control station is more built in and around the system operator with joysticks and thruster controls built into the operator's chair, as well as touch interfaces and several dedicated small screens.

The system keeps the vessel in position by watching over data from a large array of sensors, and usually several of the same type of sensor. To take account for outer forces acting on the vessel usually two or more wind sensors are used together with and motion reference unit measuring the vessels movement in the waves. Heading is usually given by highly precise gyro compasses; position is taken from very precise satellite position systems more known as GNSS systems. In addition to GNSS there are often position reference systems, these support the position signal in order to more precise tell the system the exact position of the vessel. Some systems, laser, hydroacoustic and microwave gives a position relative to a known fixture (platform or seabed installments) other uses a differential signal to the GNSS system that corrects for errors (Kjerstad, 2015, pp. 3-89-3–95). All of these sensors combined with data from thrusters is a lot to process and in order to avoid for false or incorrect signals taking command of the vessel Kongsberg launched its Albatross DP with the revolutionizing Kalman filter. The Kalman filter allowed the DPO's to operate the vessel with a new precision. The filter uses linear mathematics with a pre-set estimation on vessel movement together with live data from sensors on thruster force, winds, current and vessel movement calculated through the filter to determine thruster direction and force use. By doing this the system removes noise and other errors in the signals entering the system making for more exact positioning. Today Kalman filter is a standard in any DP system.

As seen in figure three, the signal travels through the filter before it reaches the control station, this also updates the pre-set estimations each time to give smoother calculations. Due to the Kalman filter the system will in the beginning use a lot of thruster force and may have reduced accuracy before it has updated the pre-set estimate model. Usually this can take 15-30 minutes. Due to this there are often a requirement for the safety

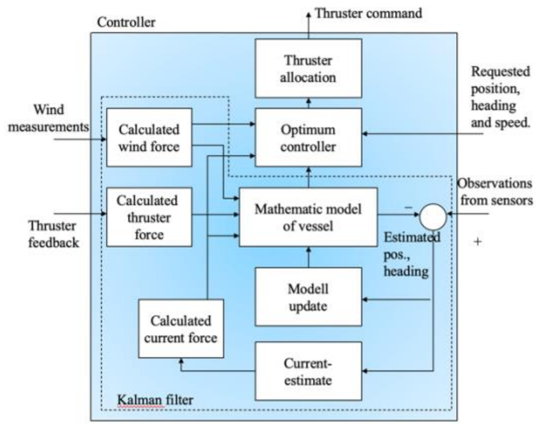

Figure 3. The path of signals from sensors to control station and thrusters (Kjerstad, 2015, p. 3-77).

requirement that the DP system is to be activated 30 minutes before the system is to be used so that the estimate model within the filter is based on information of the current environment (Kjerstad, 2015, pp. 3–77). See figure four for a complete understanding of how sensors tie together with the DP control station, how the control station signals to the thrusters input/output controller that transforms the signal to a command to the thruster which in return sends a signal on current status through the thruster controller and back up to the DP control station.

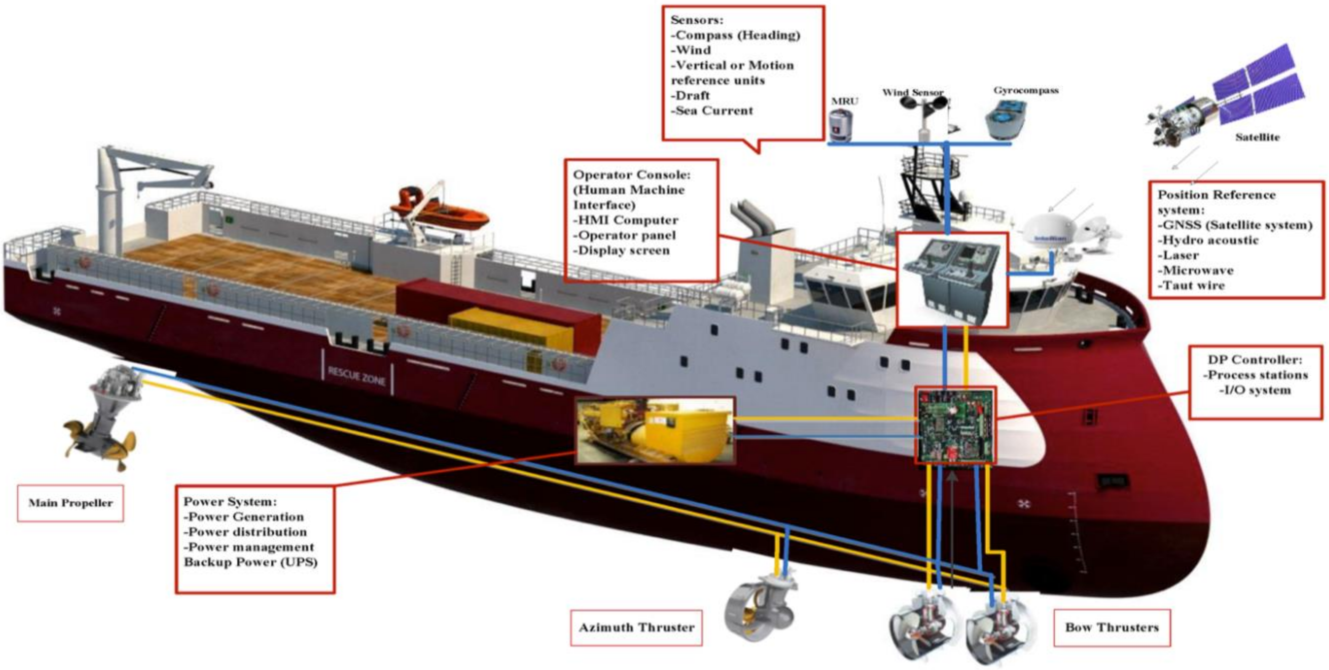

Figure 4. Complete overview of signal path in a DP system (Mehrzadi et al., 2020).

A vessel's DP capability is set by a classification society based on the vessels DP configuration and especially the redundancy within the systems. The classification classes are set by the International Maritime Organization (IMO) but ruled by classification societies around the world. There are four levels of DP capabilities, from zero to three, where a vessel with level three DP is the most capable (Bray et al., 2015, pp. 21–23). The different class societies have different acronyms for each level, see table one to get a complete overview of the different class notations. As mentioned, the DP capability of the vessel is given from the redundancy of the DP system installed on board. See table two for the complete overview of the minimum requirement put in place by IMO for redundancy within each class of DP. Depending on what the operation demands, a client will book a vessel that has a class notation that matches or surpasses this demand. Often the countries regulating the oilfields have requirements for the vessel that will engage in operations within their continental shelf. Redundancy is a very important aspect to ensure safety at oil and gas fields.

IMO Equipment class	Class 0	Class 1	Class 2	Class 3
Lloyds Register of shipping (LR)	DP (CM)	DP (AM)	DP (AA)	DP (AAA)
Bureau Veritas (BV)	DYNAPOS SAM	DYNAPOS AM/AT	DYNAPOS AM/AT R	DYNAPOS AM/AT RS
Det Norske Veritas (DNV)	DYNPOS AUTS	DYNPOS AUT	DYNPOS AUTR	DYNPOS AUTRO
American Bureau of shipping (ABS)	DPS-0	DPS-1	DPS-2	DPS-3
Nippon Kaiji Kyokai (GL)	DP 0	Class A DP	Class B DP	Class C DP
Registro Italiano Navale (RINA)	DYNAPOS SAM	DYNAPOS AM/AT	DYNAPOS AM/AT R	DYNAPOS AM/AT RS
		IDP-1	IDP-2	IPD-3
Russian Maritime Register of shipping (RS)		DYNPOS-1	DYNPOS-2	DYNPOS-3
Indian Registry of Shipping (IRS)		DP-1	DP-2	DP-3
		GS(KK)	GS(SK)	GS(SS)
China Classification Society (CCS)		DP-1	DP-2	DP-3
Korean Register of Shipping (KR)		DPS (1)	DPS (2)	DPS (3)

Table 1. IMO DP class notations (Brey et al., 2015, p. 23).

SUBSYSTEM OR COMPONENT		MINIMUM REQUIRENTS FOR GROUP DESIGNATION		
IMO EQUIPMENT CLASS		1	2	3
POWER SYSTEM	Generators and prime movers	Non-redundant	Redundant	Redundant, separate compartments
	Main switchboard	1	1 with bus tie	2 with normally open bus ties, in separate compartments
	Bus tie breaker	0	1	2
	Distribution system	Non-redundant	Redundant	Redundant, separate compartments
	Power management	No	Yes	Yes
THRUSTERS	Arrangement of thrusters	Non-redundant	Redundant	Redundant, separate compartments
CONTROL	Auto control: number of control computers	1	2	2+1 in alternate control station
	Manual control: joystick with auto heading	Yes	Yes	Yes
	Single levers for each thrusters	Yes	Yes	Yes
SENSORS	Position-referance systems	2	3	3, including 1 connencted to alternative control station
	Wind	1	3	3
	VRS	1	3	3
	Gyro	1	3	3
UPS		1	2	2+1 in separate compartment
Alternative control station for back-up unit		No	No	Yes

Table 2. IMO DP redundancy requirements (Bray et al., 2015, p. 26).

DPO, training and certification

To become a Dynamic Positioning Officer (DPO) there is a separate schooling that a navigation officer must take in order to be certified. The Schooling has five phases in it that all must be completed in order for an officer to obtain what is called a limited or unlimited DP certificate. There are many companies globally that provides the courses needed to pass through the schooling, but the certificate itself is only provided by a limited number of organizations where The Nautical Institute (NI) is the most recognized globally. The following run through of the process to obtain a certificate is according to NI's five phases from A-E all in NI's Dynamic Positioning Training Logbook of Offshore Scheme (2019, p. 17). See figure five to follow the path from untrained to a certificate holder.

Phase A is an introduction course over five days, finishing with an online exam. When this is passed you will be issued a personal logbook supplied by NI. You can then begin phase B.

Phase B is logging 60 days of DP sea time on board a vessel with DP 1, 2 or 3. You are not allowed to operate a vessel on DP alone, but under guidance of a certificate holder. There is also a section of theory in the logbook that is needed to be finished and signed by an on-board instructor. When this is done you can move on to phase C.

Phase C is a DP simulator course over five days with a final exam. After this is completed, you may start the final steps to obtain your certificate.

Phase D is 60 days of logging DP sea time on bord a vessel with DP 1, 2 or 3 and a confirmation letter from the company you have work on.

Phase E is getting a letter of suitability signed by the master of your last DP vessel.

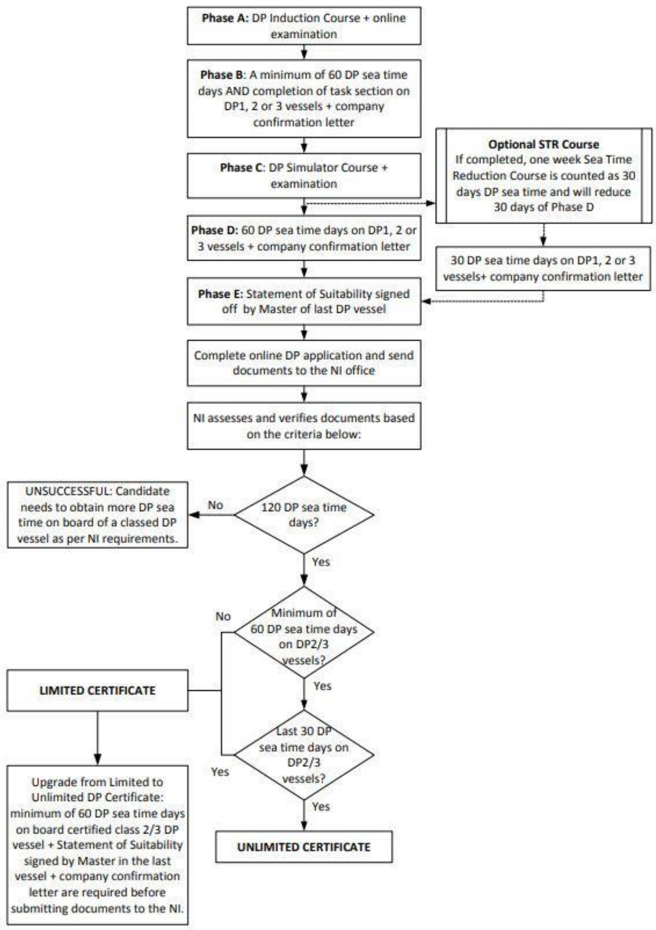

Figure 5. The flowchart shows the phases needed to obtain a certificate as a DPO (The Nautical Institute, 2019, p. 16)

When all phases are completed, an online application form can be completed, logbook and other important papers are sent to the NI office. They will then review your application and depending on the class notation of the vessel you have logged your DP sea time you will get a limited or unlimited or unlimited certificate. You need at least 90 days of DP sea time on a vessel with DP class 2 or 3, of which the 30 last days logged have to have been on-board a DP 2 or 3 vessel to get an unlimited DP certificate. If none of these requirements are met, you will get a limited certificate (The Nautical Institute, 2019, p. 17).

2.3 Augmented Reality and Head Mounted Displays

Augmented Reality

Augmented reality (AR) originated at the end of the 1960s on Harvard university campus, Ivan Sutherland created an AR head-mounted display (HMD) system that can be said to be the first version of what we know as AR/MR glasses today. The technology mostly stayed in labs at universities, companies and government agencies before a German marketing company used AR in adds for BMW cars first time commercially in 2008 (Javornik, 2016). Later, augmented reality has become publicly available and mostly used as gimmicks for games, marketing, and entertainment. As Porter and Heppelman (2017) explains, to experience AR all you need is technology equipped with a camera and a screen to digitally augment your surroundings, all you need today is a phone or tablet to experience it. In addition to AR there are mixed reality (MR), there is very little differentiating these two terms. While AR allows you to project digital objects in a physical world, MR allows the user to interact with the digital objects.

AR and MR works by software allowing the user of an interface to interact with digital content displayed in into their physical environment. The "AR interface superimpose digital information, such as 2D or 3D graphics on the user's view of the physical environment in real-time." (Grubert et al., 2017, p. 1708). In the spectre of virtual and augmented reality we use Milgram et al.'s (1995) *reality-virtuality continuum* as seen bellow in figure six. As seen from the left we have real environment with no digital interference, and all the way to the right we have pure virtual environment all digital. As we travel from left to right on the continuum we augment reality with digital information, hence augmented reality. The further we go from left to right we end up with more virtuality than reality and at a point we end up with pure virtual reality. As soon as we start augmenting the reality we enter a digital space of mixed reality, as long as there are some reality in the virtuality we operate within the realm of mixed reality.

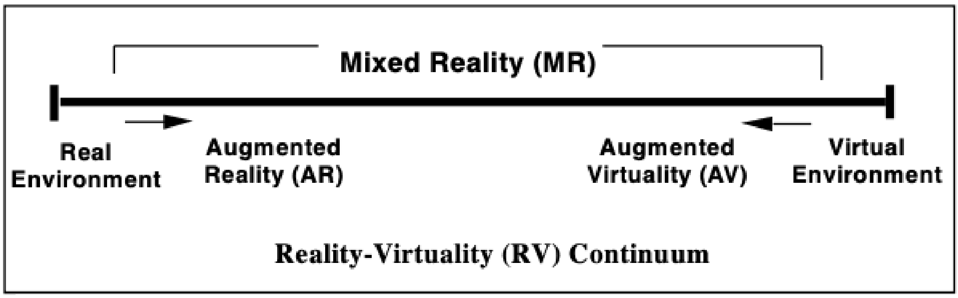

Figure 6. Reality-Virtuality Continuum (Milgram et al., 1995).

Augmented Reality/Mixed Reality glasses

For the maritime application that is being discussed in this thesis the choice of tool to project AR has fallen on AR/MR glasses. The reasoning for AR/MR glasses instead of other AR displays is limited space and different tasks performed in that space. As the DPOs are operating the vessel from the workstation, you can in some operations find another operator sharing the same workspace on a different task, using AR/MR glasses gives both operators the ability to build up their own digital work environment specific to them and their task instead of having to share one limited AR display in an already limited space. AR/MR glasses are head mounted displays (HMD) that works like normal glasses, but the glasses hold an extra lens that allows the user to project a digital layer to their physical surroundings. Cameras are usually used to map the surroundings and track head motion to orient the information. One of the most common and consumer available HMD, Microsoft HoloLens 2 (figure seven) holds four cameras to perform this work with additional accelerometer, gyroscope, magnetometer, and time of flight depth sensor.

Figure 7. Microsoft HoloLens 2 (Microsoft, 2022).

Maritime use of AR/MR glasses

Using an HMD on a ship that moves in the waves introduces an external movement in addition to the movement the user impacts on the HMD. Frydenberg et al. (2018, p. 6) discovered in their study that in heavy ship movement using AR/MR glasses (Microsoft HoloLens 2) was very difficult. Especially orientating and balancing yourself equipped with the HMD was difficult in the ships motion, and some users experience increased nausea. There are talks of a software update for the specific hardware from Microsoft that will take the vessels movement into consideration and adapt for this. In short in may reduce the use of accelerators and gyroscopes to measure movement and fully use the cameras and depth sensors to track movement.

How we display information within the augmented reality space is one of three ways. Frydenberg et al. (2018, p. 7) explains these in their paper in the following way. Fixed to a body sphere, this is where we create a digital sphere around the user a display information on this sphere. This way the information will always stay close to the user and in one spot. This means that the user can always find a certain information when looking in one direction, see figure eight. The second is fixed to the inside of a space, in this case bridge. By mapping the inside of the bridge, it is possible to create digital workstations in areas of high activity. At these digital workstations we can display information that is relevant for the work performed there, this way the user does not need to be surrounded by unnecessary information. The third way is fixed to the outside of a space, again in this case a ships bridge. This can be used to highlight data of objects outside of the vessels bridge. Frydenberg et al. (2018) focused on ice navigation for their study and the use of fixed to the outside can then be used to project data on the ice or data on the depths surrounding the vessel.

Figure 8. Shows how augmented reality fixed to a body sphere is oriented (Frydenberg et al., 2018).

Microsoft explains how digital information displayed can be customized by the user and how the HMD can be used to communicate with a second party. The second party can be another department involved in the operation or service technicians on shore. The second party can then through the interface remotely guide the user of the glasses by highlighting or point out important parts of an operation. The goal is to increase safety and while Microsoft haven't published any data on increase of safety, but do report on their webpage that HoloLens 2 has 90 percent increase in efficiency in manufacturing, and 30 percent reduction in ward time for the healthcare sector (Microsoft, 2022). These numbers are a part of marketing and should not be seen as factual reliable numbers but gives an idea of the potential in the technology.

2.4 Situational Awareness

Definition

Situational awareness (SA) is a person's conscious dynamic reflection of a situation (Bedny & Meister, 1999). By using dynamic in the definition, Bendy and Meister shows how a individuals awareness reflects on not only the present, but also the past and future. The past can only be one true past, but the future can be multiple outcomes, and a person with a good or high SA is able to project as many possible outcomes as possible. In other words, SA is an individual's ability to observe and comprehend their surroundings, and to some extent predict the immediate future for your surroundings.

In maritime operations the DPO's SA can be defined has the mariners' ability to obtain information about his/her surroundings and the vessels', all while watching the screens and data projected at them. Today to ensure proper SA one of the requirements for a bridge officer is to go through a bridge resource management (BRM) course. The course aims to test the officer's ability to handle stress and train them in stressful scenarios and is a requirement to get your deck officer certificate. As a mariner to keep good SA it is important to use all of your senses, not all are used equally but in order to fully recognize, understand and organize information about our environment you would need to use all of them to some extent (Patraiko, 2020, p. 5).

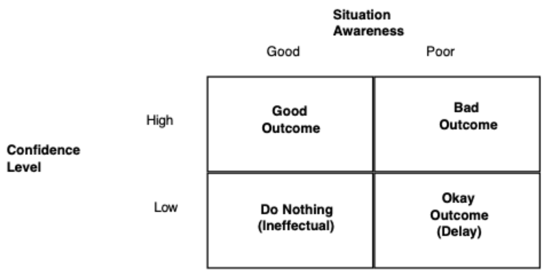

Figure 9. Endsley and Selcon's depiction of the correlation between situational awareness and confidence level (Endsley & Jones, 1997).

A second part to the operators' SA is their confidence in their own SA (M. Endsley, 1988, p. 6). As seen in figure nine, if the operator's confidence level is high but their SA is poor it is very likely that there will be a bad outcome of the situation. A high confident and a good SA gives good outcome. What is interesting is that the difference between low and high confident is not transparent with SA. Yes, low confidence has an impact on the SA but, no matter if the SA is good or poor there is still an okey outcome. The operator might take a little more time with his/her decision making, but it doesn't necessarily make for a bad outcome.

Endsley and Selcon (1988) explains how there are three levels of SA and how you need all three to have complete SA. These are the following levels of SA and what they mean:

- Level 1. The perception of the elements in the environment within a volume of space and time.
- Level 2. The comprehension of their meaning.
- Level 3. The projection of their status in the near future.

As seen in figure ten there are two sides to what affect the levels of SA you are able to obtain. We have task/system factors such as system capability, interface design, complexity, automation, and stress all acting not only directly on the levels of SA but also decision and the performance of actions. On the bottom of figure ten there is individual factors, this is slightly more complex, this is the person's ability to obtain proper SA based on their personal training, experience, and abilities. On top of that, a person's long term memory stores, automaticity, and ability to process information all act on the ability to obtain all three levels of SA, your ability to make a decision and how you perform the chosen action. These also affects the goals and objection as well as preconception you might have. These two also affect the ability to maintain all three levels of SA and decision making. When interfaces of automation systems are too complex, there is pore interface design or a lack of training there is often problems with level 2 and 3 SA (M. Endsley & Kiris, 1995).

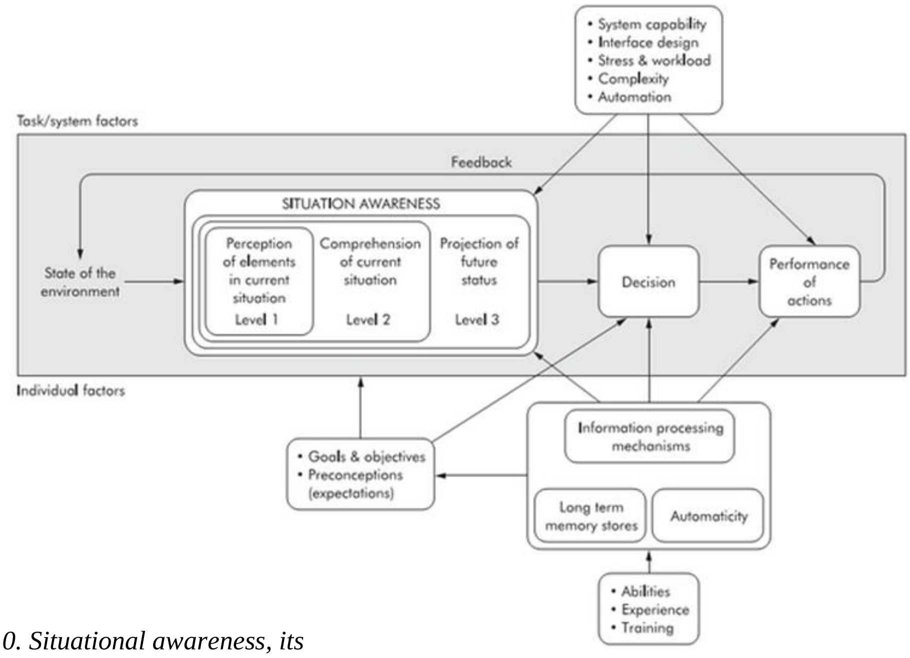

Figure 10. Situational awareness, its levels and how it is affected (Endsley, 1995).

Training and experience are essential to a DPO's ability to keep control of the vessel and their surroundings. Training lays the groundwork for the DPO, and if there has been bad training or the DPO was not motivated to learn dangerous situations can be expected. Especially in the maritime sector where you have to obtain courses or certificates to qualify for certain work, if a DPO has obtained their training or certification on false premise, it is very likely that dangerous situations may occur. Experience may be a solution to lack of or poor training. As the DPO's experience grow, their ability to keep control over their surroundings, prioritize only needed data should make for better SA. The problems becomes when experience turns to confidence and the confidence overshadows their decision making leading to poor SA. There is also the before mentioned automation systems, when they are to complex or poorly designed, they will draw away the attention of the DPO from their surroundings causing to a lower SA.

3 Methods

“A scientific methodology is a system of rules and procedures that provides the foundations for conducting research and evaluating claims to knowledge.” (Frankfort-Nachmias et al., 2015, p. 12). This methodology chapter contains a description of the methods used in the research of the subject. This chapter is in place to create and show the framework that the research is built upon, this is in order for it to be replicated and tested later on if needed. The chapter will go through the participants and sample, tools, procedures, analysis, and ethical considerations.

3.1 Sample

The participants in the sample are currently or have worked on a DP vessel operating the DP system. Parts of the sample are DP operators with a varied experience, ranging from a couple of months to several years. They have also experience from different types of operations ranging from platform supply to more advanced subsea operation. The other part of the sample are certified instructors who are currently working at offshore training centers teaching and certifying DP operators.

The section of participants that are active DPO was recruited through the author’s personal network. The author reached out to a larger group of possible participants through online message boards, whereupon a handful of participants reach out to volunteer. Some participants were also reached out to personally as they hold valuable experience that could fit the research. The sample section of instructors was recruited through an outreach to a handful of DP training centers. Out of these, two training centers had time and people available for interviews but the participant from one of the training centers did not pass the inclusion requirements. From the second training center three instructors passed the inclusion requirements, with one being one of the most knowledgeable on the field of DP globally.

The requirements for inclusion of a participant in the section of DPO’s was not higher than having relevant experience as a DPO and having not been away from the field for more than ten years as there has been some innovations within the field over the past decade. The goal of the recruitment was to interview subjects with varied levels of experience, therefore in the section holding DPO’s there are mostly people with experience ranging from two to four years, and one participant holding just one year of experience and currently undergoing phase C of the certification process as mentioned in section 2.2, *DPO, training and certification.* The reason for this was to see if lower experience would present any other observations than the more experienced DPO's. Some of those who volunteered after the outreach was turned down due to too little experience.

Another goal when searching for DP operators was to find operators working on different vessels and vessel designs. The reason for this is that there is usually a small difference in bridge design and layout of instruments. The hope was that with DPO's working in different bridge environments they would bring different views to common problems and different problems. Except for two of the participants working on the same vessel all the other participants where working on different vessel designs.

For the section of instructors there was a requirement that they are currently active teaching and certifying DP. There was no wiggle room in this requirement as there is very strict requirements for teaching and there is a need to stay up to date on all rules and legislations within the field. Since there is a requirement to have operating experience as a DPO to be able to move on as an instructor all of the participants in this section had more than six years of experience as a DPO alone, then on top of that they had anywhere from a few months to 25 years of experience teaching DP. From a second training center a participant reached out but was rejected as he had not work as an instructor for ten years nor as a DPO for 13 years.

To see a full demographics of the sample, see table three down below.

Sample democraphics.

		n	%
Age (Years)	20 - 25	5	45 %
	26 - 30	2	18 %
	30 - 35	2	18 %
	46 - 50	1	9 %
	61 - 65	1	9 %
Position	2nd officer/SDPO	2	18 %
	2nd officer/DPO	2	18 %
	3rd officer/DPO	3	27 %
	Instructor DP	3	27 %
	Other	1	9 %
Years at sea	0 - 5	6	55 %
	06 - 10	2	18 %
	11 - 15	1	9 %
	25 - 30	1	9 %
	30+	1	9 %
Yeas of experence with DP	0 - 2	4	36 %
	2 - 4	4	36 %
	8 - 10	1	9 %
	18 - 20	1	9 %
	30+	1	9 %
Certification	D1	2	18 %
	D2	6	55 %
	D3	3	27 %
DP certification	DP unlimited	9	82 %
	DP limited	1	9 %
	Uncertified	1	9 %
Sector	PSV	4	36 %
	Construction, topside and subsea	7	64 %
	Inspection and maintenance subsea	6	55 %
	AHTS	5	45 %
	Windmill construction and maintenance	2	18 %
	Teaching	3	27 %

Table 3. Sample demographics

3.2 Tools

The qualitative data was collected digital due to covid-19 restrictions imposed by ship operators limiting visitors on board vessels at the time of execution. The interviews were planned as semi-structured with open-ended questions in order to gain full understanding of the problem the research is trying to solve. Semi-structured interviews are often underutilized, yet they have a great potential, their flexibility allows for structure to answer specific research questions and also leaving space to allow new meanings to a topic (Galletta, 2013, pp. 1–6).

The interview consists of six introduction questions that are there to establish the experience and age of the participant, after this follows 17 questions related to the research questions. See Appendix one to see the complete interview guide. A pilot study also uncovered that due to the participants little knowledge of AR and AR/MR glasses, it was added a section of brief explanation on key concepts with four pictures to ease the understanding of them, see figure eleven through fourteen. Since all the participants and the researcher are native Norwegians, all interviews were performed in Norwegian. The interview was planned and made in English, then translated to Norwegian before the data collection started.

Figure 11. Example of how markings of dangers and traffic can be presented in AR (Courtesy of AHO and SEDNA).

Figure 12. Example of what AR/MR glasses could practically look like out in the field (Courtesy of AHO and SEDNA).

Figure 13. Example of how compass, speed and ECDIS information can be presented in AR (Courtesy of AHO and SEDNA).

Figure 14. Example of how compass, thrusters and RADAR can be presented in AR (Courtesy of AHO and SEDNA).

3.3 Procedure

The planning of the thesis started in the fall of 2021 with the planning of the scope and research questions. The thesis' scope and research questions were narrowed down enough to start build the interview through December 2021. When the initial structure of the interview and the questions was at a satisfying level, details on the interview and thesis was submitted to Norwegian Center of Research Data (NSD) for approval due to private data being collected in the interviews.

In order to ensure quality in the interview a pilot study was performed in January. "A pilot study is a small-scale methodological test conducted to prepare for a main study and is intended to ensure that methods or ideas would work in practice" (Kim, 2010). The pilot study consisted of a one participant with some DP experience. The study was done to see if the interview would produce satisfying data, and to check the quality of the translations of the questions from English to Norwegian. The pilot study did show satisfying results on the data collected and its relevance. It also showed that there were some translations from English to Norwegian had to be adjusted as they did not really grab the essence of the original question. The study also offered great experience to the researcher on how to perform an interview.

The time after submitting the NSD form was spent on reaching out to possible participants and planning interviews. After the pilot study the time leading up to approval from NSD was used on the interview structure and questions, editing, and adjusting according to the notes from the pilot study and feedback from the supervisor. See figure fifteen bellow for the all the phases in the process leading up to data collection.

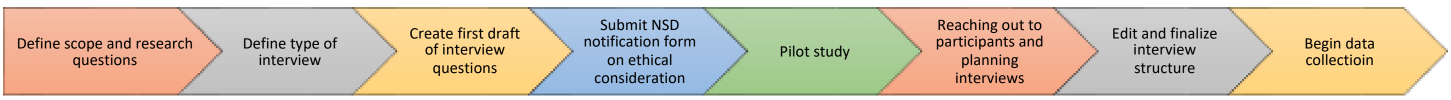

Figure 15. Phases in the process from planning stage to data collection of the thesis.

After an interview was planned with a participant, they received an information letter based on the template by NSD, see appendix three for the complete letter. The information letter contains some information on the thesis and why the participant has been chosen. The most important part of the letter is the final page containing a consent form where the participant consents to participating in an interview, being recorded during the interview, and allowing for their answers being used as the data in the thesis. This had to be signed by all participants in order for them to take part in an interview. But it was also made clear that they are allowed, at any point, to revoke their consent at any time. At the date of submission none of the participant have revoked their consent.

The data was collected between February and March 2022 after the assessment and approval from NSD was received in order to comply with all rules and legislations with exemption of the pilot study which was performed while waiting for the approval. See appendix two for the complete assessment form NSD.

3.4 Data analysis

To analyze the qualitative data the choice has fallen on thematic analysis. While analyzing the data you look for themes that keep reoccurring in the qualitative data. There are six phases to perform the analysis, with the first one being *familiarization.*

Familiarization is reading through the data, getting to know what the data holds and recognizing patterns and quirks. Second phase is *coding*, this is taking the patterns and quirks you have found in familiarization and labeling them by a few words or a pity phrase such as "Likes driving fast" (Terry et al., 2017, pp. 25–26)

Third phase is *theme development*, this is finding common themes in the codes, clustering together similar codes into larger themes (Terry et al., 2017, p. 28).

Fourth and fifth phase is *reviewing* and *defining themes,* Reviewing is quality assuring phase where you check that the chosen codes fit within the themes. Defining is taking a step into the analyzation part. But sometimes more descriptions to a field is needed and in this phase you would write a short description of each theme to explain what it holds an its relevance to the research (Terry et al., 2017, pp. 29–31).

Sixth and final phase is *producing the final report*, this is when you gather all of your writing from phase one through five into a report of data. The analysis should contain a discussion on all of the codes, themes and definitions with a single goal to address the research questions (Terry et al., 2017, pp. 31–32).

The data was analyzed by following the phases explained by Terry et al. (2017). After the interviews was transcribed from the audio file, which also worked great as a familiarization step for the first phase, the data was loaded in to NVivo where the data was coded and themed. From there data falling under the same themes and codes were sorted together and a more complete analysis of the data gathered from there.

3.5 Ethical considerations

As the research in this thesis consist of data collected from semi-structured interviews, and personal data is a core part of contesting the experience of the participants the thesis has been reported to Norwegian Center of Research Data (NSD). After submitting the notification form the project was approved 25.01.2022 under the assessment number 643226, see appendix three for the full assessment from NSD.

4 Results

The following chapter presents the results of the qualitative data collected through the semi-structured interviews. The presentation of the data has been partitioned into subchapters according to the research questions the data addresses. See table four for a summary of the main findings.

RQ	Theme	Main Findings
RQ1	Types of operation	Supply Subsea with topside visual reference Subsea without topside visual reference Anchor Handling Windmills
RQ2	Data needed by a DPO	Position References Thrusters Position and vessel movement Wind and weather Power Consumption Consequence analysis Cargo movement
RQ2	Suggested information	Alarms Camera feeds and blind spots Traffic No-go zones and dangers Moves Distance to platform or windmill Objects in the water Winch information Degrees of freedom

Table 4. Summary of main findings.

4.1 Types of operation

The semi-structured interviews mapped the participants experience and asked questions directly on the matters of how a dynamic positioning operation function and what the operator does in an operation. The interviews gave an extensive view inside the operational functioning of a ships bridge in an DP operation. RQ1 is dedicated to understanding what types of dynamic positioning operations augmented reality glasses can be used for, and participants were asked on matters like, what distracts them, what makes them feel overwhelmed and specific scenarios or operations was suggested to get their opinions on them. Table five bellow shows a summary of the main findings for types of operations.

	Theme	Main findings
Type of operation	Supply	Positive feedback from 7/11 participants. A need for reducing time spent looking down at screens. Those negative are not opposed to the idea, some worries on accuracy.
	Subsea	With topside visual referance: Participants are positive towards this as a use case. There is often a need to push limits and a wish to reduce time spent looking down at screens. Without topside visual reference: Participants are mostly negative to this use case. Participants argue, locked to the screen, little interaction with surroundings.
	Anchor Handling	Some positive participants. Not a need for typical operational data, but camera feeds and such. Higher potential that the winch operator will benefit.
	Windmills	One participant argues for large potential and much beneficial to DPO. Operations often involve high pace and maneuvering close to a windmill.

Table 5. Summary of main findings for type of operations.

Why we engage the DP system

First question in the interview addresses what makes the operator activate the DP system in first place. All participants described a need for moving some of the workload to the system in order to manage to perform this type of work for a longer period of time. They also describe the impossible task of controlling the vessel to the precision that some of these operations need, with one basic challenge being, how do you manually control all the vessels thrusters when there are possibly four to eight different levers, and you only have two arms? An advantage of the DP system is as you are lowering the workload of maneuvering you can spend time on other parts of the operation. As a DPO you still have the other obligations that a navigation officer holds. There are logbooks to keep, permits to make and sign along with other paperwork and routine maintenance according to the periodic maintenance program. The last advantage is that the DP system allows you to plan ahead, as participant 10 stated:

"I mean, like, I have sailed a lot on the coast as well, and I bring this in when I teach DP. Just as it's too late to start thinking about Steinsundet when you are in Steinsundet a good DPO has to be 10-15 minutes ahead, have a plan, know what to do."

While participant 11 stated: *"Using a DP system allows me to shift focus to other tasks, and it allows me to interact with clients and discuss further actions and plan ahead."*

Types of operations

When asked if based of their experience if they think that supply operations could be a possible operation for the participants answered the following: Seven participants answered in a positive way that they see the use case in having the technology at hand. Of these seven, five speaks of the value of having the augmented reality glasses to reduce the time they spend looking down. They also speak on the value of possibly knowing distance between vessel and the installation or platform, or where the vessel can move around the installation or platform. But, all of the seven being positive to supply in addition to the five being negative raises a concern on where the information is coming from. With participant 9 and 10 both using the following words to describe the importance of knowing where the information is coming from.

"*Shit in equals shit out, you see if you put bad information through the system, the system is going to serve you bad information or actions."*

The five participants dismissive towards supply as a use case had concerns on where is the information coming from, what will the user interface be like and participant 2 did not see the use for it as they are already sitting there at their workstation where they have access to all of the information on screens right next to them. None of them wanted to be too dismissive on the idea, four of them stated that at this stage there was just more questions than answers on the matter and when there is more of a in hand solution it is possible that the AR/MR glasses has a potential.

Supply partly connects to subsea and construction which was the second direct use case that participants were asked on. The term subsea is more of a collective term on most type of operations where there are work going on under water. Sometimes these operations are at close range to an installation or platform making it relating to supply. In this thesis I have sorted subsea in two different categories, one being subsea or construction with topside visuals, the second being subsea or construction with zero topside visuals. Topside meaning something above the water surface. This sorting happened natural through the data collecting and analysis with the answers being collected.

When the participants were questioned on whether they think subsea could be a viable option for the AR/MR glasses most participants wanted to differentiate between the beforementioned difference of having something visual to look at topside or not. They explained that when they perform subsea or construction without any visual reference topside you are very much locked to the screen and the data presented there. As a DPO your main task is to keep the vessel in its exact position, and with zero topside visual references you reside to pure numerical data driven position reference systems locked in the DP system. The participants argue that since you do not need to look up and out of the window unless you are working in areas with large amounts of traffic close by. As participant 3 explains:

"In subsea or construction when you don't have any visual references nearby I'm struggling to see the relevance. In cases where you don't have a reference you are so locked to the screen, and I fear that you will not be able to get the amount of information needed projected on the glasses and the ability to easily control or interreact with the information through the AR/MR glasses."

And participant 4 goes further and explains other possible use cases:

"In subsea I don't really know what level of use you would get out of it as a DPO. But I think that a ship supervisor or ROV operator could have a really great use of it."

Most participants argue that there could be a great use for AR/MR glasses when you have topside references. Then being able to look out and monitor important data all while watching over your surroundings allowing you to keep or increase your SA. With eight participants talking on the possible positives of having the AR/MR glasses at hand while engaged in subsea or construction operations. Three participants were negative to the idea from the introduction, with participant 8 saying the following:

"I read the information letter to the thesis and this interview, and my initial impression to this is, yes of course it could be nice to have, it has a certain wow factor and cool perspective. But then I sat down, took some time and pondered on the matter and I struggled to find that good and useful case where the technology could be a good fit and where you could argue getting funding for it by the company."

As mentioned, there are so many different types of operations under the term subsea. And the experience of our participants ranges from simple crane operations to more complex such as well stimulation or diving. Again participants have argued that as long as there is a topside visual reference most of the participants see a value in the glasses. But there was one type of operation or scenario where the participants with this experience saw a value in having the glasses when there was no topside visual reference, this being ROV and inspections operations that require the vessel to move under speed. If the glasses then allowed you to visually track the target, i.e., ROV or similar while you are maneuvering the vessel would be very helpful.

Due to some of the participants experience on anchor handling vessels (AHTS) this was one of the additional operations that were brought forward. Now, DPO on a AHTS does not use the DP system in the same way as on other vessels, you usually only use it to control one or two out of three DOFs. With one of the two operators on DP, the other mans the winches and actively controls these while the operation is ongoing. The participants with experience from anchor handling describe a need for keeping attention on their surroundings as well as continuously monitoring thrusters and power management and see that AR and AR/MR glasses could have potential. More on the specific data can be found in chapter 4.2 Information.

One participant had extensive experience with operating in fields of offshore windmills on construction and maintenance had a positive attitude towards the technology and felt a need towards some support in order to keep their SA. Participant 6 describes a field of work where the pace is much higher than traditional DP operations within oil and gas, the participant also mentions that the windmill industry lacks regulations compared to oil and gas. Due to the operating pace, close vicinity to objects in the water (mostly windmills) and at times a lot of traffic in close quarters the participant really sees a potential in having glasses project important information right on the glasses when maneuvering in between windmills.

"*Distance is one of the most important factors for us, that and understanding if the vessel is moving towards the windmill or from it. This can at times be very hard to judge. Especially on the days where we are working on the weather permitting limits. If it is possible then to have some information displayed on the glasses on these matters, it would reduce the stress of having to look down to get watch over the data when all you want to do is look out." (Participant 6).*

When asked directly if there was operations or scenarios where they did not think that the AR/MR glasses would benefit the DPO all participants with the experience mentioned right away what has been mentioned earlier, any operation where there is nothing topside for you to have as visual reference, i.e., open water construction, subsea and anchor handling. In these types of operation, they all struggle to justify using this type of technology. Some participants also struggle to see if the technology can deliver the accuracy that they require to trust the system when maneuvering a vessel close to any object, installation, or platform in the water. Participant 8 states when answering the question on what operations the AR technology would not benefit:

"It has to be subsea again, possibly it has something to do with the fact that my imagination can't imagine what a practical use case for this would be. But also supply, due to the accuracy that must be in place for me to trust in the technology."

4.2 Data needed by a Dynamic Positioning Officer

RQ2 is dedicated purely to understand what type of information and data does a DPO monitor to keep their vessel in position and their importance. Two questions were raised directly on the matter. First, what are the core or basic data that you as a DPO monitor? Second, building on the core information, can you mention some more scenario specific data?

The results from these two questions were analyzed with content analyzing and table six bellow contains the most mentioned phrases and words that describes what type of data that is important to the DPO that was answered.

Theme	Number of participants mentioning	Number of times mentioned
Position refrences (Posref)	6	7
Posref quality	5	9
Position, Posplot	7	8
Thrusters, direction and force	7	9
Power consumption	2	3
Wind and weather	4	4
Consequense analysis	1	1
Distance to object	2	3
Cargo movement	4	4

Table 6. Commonly mentioned phrases and words describing important information for an DPO.

As table six shows all participants mentioned position references (posref), six participants mentioned posref in general and the last five mentioned more specifically posref quality. Se further down for the specific difference between them and what it means. The second most mentioned data was thrusters, their current direction and level of force output from them. The third was position and vessel movement (posplot), fourth wind and weather, five and six is power consumption and distance to object, seven, consequence analysis. Last one is cargo movement which holds a few different scenario specific mentions.

Position References

Position references was the number one type of data that was answered by participants, all participants mentioned this in one way or the other. Six of the participants mentioned just monitoring the posref in general, and the last five stating the importance of not just monitoring the posref's but also the quality of them. Participant 10 stated that not being able to monitor your posref's due to pore user interfaces or just not monitoring them at all equals to "driving with a white cane" and it's imperative that this ability is not disturbed. With participant 8 adding:

"*As a DPO after activating all DOF and setting the vessel on full Autopos according to all checklists I start to monitor all my position references, as they are the foundation for my position. Without them I don't have the accuracy of positioning that what we do require."*

The five participants mentioning posref quality argues that you can't only watch that the posref systems are engaged you also must monitor their quality, as has been mentioned earlier, if the systems receive bad information, it will use that bad information and give you bad positioning. Therefore, you must also monitor the quality of the data so you can be sure that the system is running properly. Participant 8 mentions the following quality measures to watch over:

"Watching over DNGSS, their DQI and HDOP values and satellite geometry. Watching relative distance measurements, if you are using a laser system you want to watch that there aren't any physical obstacles in way of the system."

Thrusters

The participants mentioning thrusters explains that watching over the thrusters seeing how the DP system chooses to react to the imputed data, how you easily can read the system and forces acting on the vessel. For the participants with experience from AHTS, they explain how thrusters and forces are essential to their work and it often involves a huge amount of force. Participant 1 starts by stating on the importance of thrusters with:

"Thrusters, they are just as important to monitor, how are they positioned and how much force are they using, I find them just as important or maybe more than watching the posplot."

Participant 6 later follows up with:

"When manoeuvring, thrusters are all that I monitor, that simply because of the tight margins, so you always have to monitor them. You know, it takes time for one to turn around and so on. If you do anything to make the vessel end up imbalanced, making a thruster turn the wrong way, using too much force or something similar, it will take time to turn the thruster back around. When you are 10 meters away from the windmill you don't have the time to wait for it turn back around, there aren't margins for that."

Position and Vessel Movement

Seven participants mention position and vessel movement as part of the data they watch when monitoring the DP system. All of the participants who mentions this also mentions a feature more commonly known as posplot in the k-pos system, this feature shows how much off the set position the vessel is visually on the DP screen. The participants mentioning this are participants working mostly on open water subsea. They describe that when you do not have a visual reference you are locked to look at the posplot to see how the vessel is moving relative to the set position.

Vessel movement was mostly mentioned by the participants with experience in operations such as anchor handling, pipelaying or pipe survey, where the vessel is constantly moving. Most of these participants explains a need to always have with them the speed of the vessel in all directions. Participant 7 mentions the following:

"Speed is key if we are trenching, but we also use a couple of features called follow target and range and bearing to target in some operations to follow targets under water, and in these operations knowing your speed especially compared to the target is very important."

Wind and Weather

Wind and weather is one of the determining factors in a DP operation, if the weather or the winds are to strong/high the work will stop. It was therefore expected that this would be mentioned more than it was. Four participants mentioned weather and wind. One of these participants, participant 4 explains the following:

"You operate in areas where the wind turns and changes fast, in five minutes it can move 90 degrees and increase to storm, that changes everything for the DP system and its capability to keep the position. So weather is always important to watch."

Power Consumption

Two participants mention power consumption as something the monitor directly to see the power distribution across the switchboards and main-buses. The participants mentioning this explains that they want the ability to see that they still have power to spare for unforeseen events. It is also worth mentioning that more participants mentioned power consumption, but it came up if the participants talked about what they have on their DP screens and not what they are monitoring.

Distance to Objects in the Water

Two participants with an extensive experience on operations close to installations and platforms mentions how they monitor the distance to an object in the water. They explain that they often monitor a laser system that gives them the distance to the object.

Consequence Analysis

Participant 2 mentioned consequence analysis, due to a specific operation and area of operation. Since they at times were operating at the limit of available power, they were constantly running the consequence analysis to be aware of what the consequence would be of a single point failure at all times. The reason for it to be singled out in this section is that it was casually mentioned at other times by other participants during the interview, but not in regards to information constantly monitored which is what this section is looking to discover.

Cargo movement

In this section there are four different data types, all with a certain similarity, they all involve cargo operations, two participants mention cargo valves and pump pressure, another mentions ballast valves and heeling tanks when using cranes for heavy lifting, and the last one mentioned attention to objects and wires going into the sea either over the ships side or through the moonpool. The reason for placing this last, even with a larger number of mentions than other themes was the added commentary that unless heavy lifting this was the least important of what they mentioned in this section.

4.3 Information Displayed Suggested by Participants

Alarms

Some participants argued that getting information of alarms displayed in augmented reality could be useful but should possibly be limited to heading warning and alarms and keep other alarms away from the augmented reality. The participants argued that having the alarms centralized in one place easily accessible for all operations could improve the time it takes to respond to an alarm.

Camera Feeds and Blind spots

One of the most suggested information to be displayed was camera feeds, one suggested that in anchor handling operations when you are attached to an anchor and moving towards the platform you are seated backwards, so you are really not seeing the platform you are moving towards, so then being able to have a sort of a back-up camera displayed in the augmented reality could be really useful.

Other participants suggest to move some of the camera feeds available on dedicated screens over to AR to be able to remove the amount of screens taking up important space on the bridge. They also suggested to mount cameras around the outside of the bridge to cover typical blind spots reducing the DPO's SA.

Traffic

Three participants mentioned traffic as data they would like displayed in AR. It was not mentioned as data they monitor in normal operations, and most of participants explain that there are often very little traffic in the areas that they perform DP operations and therefore they stay attentive to their surroundings but does not spend too much time looking out for traffic. But in certain areas or when traveling to and from the area of operations they could see a practical use case for having traffic information displayed in the AR/MR glasses.

No-go zones and Dangers

Some participants explains when operating around oil and gas platforms there are areas that you are not allowed to enter and there are dangers close to some floating platforms anchored to the seabed. Having these zones and dangers mapped in the AR/MR glasses would ease the workload on the DPO.

Moves

Participant 5 mentions when moving around platforms and installations there are at times limits to how far you can travel at one time inside the 500-meter safety zone. Say you are moving 200 meters inside the safety zone but have a limit to 50 meters per move. Having then displayed targets for each 50 meter move in-between the 200 meters would make this a lot easier than trying to track the 50 meters the way they do today.

Distance to Platform or windmill

Multiple participants mentioned having the capability to watch the distance to a platform or windmill, with some of them commenting on having distance from forward, midships and aft to the platform or windmill displayed in AR to be very useful. But there are concerns regarding the accuracy.

Objects in the Water

Participant 7 mentioned from their experience of picking up floating survey nodes in the water, that having the nodes tracked in AR and displayed on the glasses to be very useful when you are manoeuvring to pick them up and that this was something that he and his colleges had already discussed on watch.

Winch Information

The participants with experience from anchor handling argue that the winch operator could have a lot of use of the AR/MR glasses. One thing is getting the winch data of tension, force and lengths of wire out displayed in the augmented reality. As the winch operator you are also watching over the multiple camera feeds to watch the winches, and having these displayed in AR. Participant 6 argued for this to improve ergonomics, as the camera feeds you often find hanging high up above the windows and the winch data you will find down on the bridge console, due to all of the moving of the head the participant could tell that after a watch in the winch chair he would often experience neck strains, and maybe the glasses could reduce this.

Degrees of Freedom

Participant 6 also suggested having each of the DOF in individual boxes displayed like they are on the keyboard of the DP unit in the glasses and then have them turn green when they are activated. This is due to how you are activating the DOF’s on the system and how easy it is to think that you have activated them, when you haven’t.

5 Discussion

The goal of this thesis is to identify scenarios or operations where the DPO will benefit from the AR technology, and what data should be displayed in the glasses in order for the technology to do just that. Through the thematical analysis of the semi-structured interviews several themes came up in the results. In regards to research question one the following themes has been presented: Supply, Subsea, Anchor Handling and Windmills. For the second research question themes such as: Posref and their quality, Thrusters, Position and vessel movement, Wind and weather, Power consumption, Consequence analysis and Cargo movement. In this chapter the themes and the results of the thematical analysis will be discussed in correlation with existing research, findings, and rules. Firstly, it will discuss what scenarios or operations that are fitting for the AR technology, then later it will move on to discuss what information that is important to the DPO and whether it is fitting to be displayed in the HMD. As mentioned earlier in the thesis, we are looking into a problem brought forward by technology and automation and trying to solve it with more automation technology a theory stemming from Bainbridge's (1983) conclusion on ironies of automation.

5.1 What operations?

Regarding research on what operations DPOs will benefit from the AR technology there are little existing directly on the matter as chapter two the literature review shows. Again, therefore there will be a need to break down the problem and results in different sections and compare that to existing research.

Supply, subsea and construction with visual references topside, anchor handling close to installation or platform and offshore windmills related operations was the use cases with highest **positive** feedback from participants although there are some participants negative to each of these. The common factor in all of these is the object that is above the surface that gives the DPO a reference of vessel movement and something to watch over, and if the vessel where to hit the object it could have huge consequences, not only financial but also environmental. The results indicate that in most of the before mentioned cases the participants interviewed agree that being equipped with AR/MR glasses would benefit them in the DP operation and improve their ability to be in control over the current situation. However it is possible that this is a misinterpretation, and like Grech and Horberry (2002) revealed, what they actually will get is increased information processing and not automatically improved SA. It is actually likely that technology and more automation will decrease their SA when not done correctly.

Supply is a straightforward case, here you will find the vessel located close to the installation or platform while cargo is transported by crane or pumped in hoses to or from the supply vessel. There aren't too many variations in these types of operations and most of supply operations should be fitting due to its simplicity in the complexity of DP operations.

Moving over to **subsea or construction** operations the questions of what types of these operations are fitting gets more complicated at once. Subsea and construction are collective terms for a large variety of operations, the participants range of experience, table 3, captures only a small part of it. During the interviews of the participants a natural grouping of the operations by the participants themselves. They pointed out the large difference between having something physical topside to monitor in relations to the vessel's movement compared to nothing but ocean all around, the grouping of operations without an object topside the results show's that it was dismissed right away by most participants. There is always the possibility reduce the number of screens necessary on the bridge and replace them with the AR/MR glasses, but then again, major issues could be introduced if the user is highly used to a screen and they are not available in an emergency (Bainbridge, 1983). There is no, to little research within this exact field that this thesis is looking in to, but existing research on industry use cases such as Röltgen and Dumitrescu (2020) *Classification of industrial Augmented Reality use cases*, points towards the common factor of having an physical object that requires attention in their surroundings for the technology to be of any use. There was one suggestion where AR/MR glasses could be a fitting tool for the DPO when not having a visual reference topside. When maneuvering the vessel while inspections of subsea installations that requires the vessel to be on the move following an ROV or a similar tool below the surface. Then it could be useful for the DPO to have visually displayed in the glasses the target, its speed and your own speed. Due to the mostly negative feedback to this group of operations there seems to be no reason to further discuss them.

For the group of **subsea and construction operations with a topside reference** the results did indicate a positive trend towards these types of operations. But there are some factors to consider. One being the level of information needed in these types of operation and how much information can you have on the AR/MR glasses before it becomes too much, and the concept of information overload will be introduced. It is possible that this will occur with lower levels of information than usual due to the how we as humans focus over attention on information. The way a human usually will process information is by first using selective attention to narrow down where to focus further attention, otherwise known as focused attention. There is then a chance that the AR/MR glasses with the projected information close to the user's eye or point of perception the salient feature of an information may cause the selective attention to turn your focused attention, which job is to maintain processing of wanted information source (Wickens & Carswell, 2012). Therefore, it is possible if not moderated correctly the information presented in the AR/MR glasses could take the complete attention of the DPO, reducing their attention of the surroundings and SA, therefore overshadowing the very goal when introducing AR/MR glasses to these types of operations. Then again, the operators who would use the technology are trained to read, process and act according to this very specific type of information, which could reduce this problem.

AHTS vessel performs work either close to an installation or platform where the object is to secure said installation or platform connecting/disconnecting anchors or they work in open sea. As the results only indicated a possible need for AR/MR glasses when the vessel is close to platform or installation the following discussion will only be on that type of operations. A notable point on these types of operation was that the DPO's with this type of experience did not mention operation specific data to be projected, but more supporting data such as video feeds, bringing back Bainbridge (1983) argument on how major issues can occur in emergencies when the critical information is removed from their traditional place. There is a possibility to use the AR/MR glasses to project a "back-up" camera to increase the peripheral view of the operator which should improve the vigilance of the operator, and according to Endsley and Kiris (1995) this is something that should improve the DPOs SA. For the winch operator there is a need to improve ergonomics, which is well known to impact performance as well. But there are other benefits to improving ergonomics as well, as Beevis and Slade (2003) present in their journal article, *Ergonomics – Costs and Benefits*, which shows that there is financial gain as well from improving ergonomics. It is very possible that by introducing the HMD to all the operations mentioned in this section a bonus benefit from this could be improved ergonomics and cost benefits. The cost benefits could be enough to convince the ship owner to invest in a system like this.

Last operation type with positive feedback was operations tided to **offshore windmills**. Multiple participants argue that the work that they perform is "*a slow sport*" or is "*slow and boring*", but when talking to the participant with extensive experience from the field of offshore windfarms they talk about a work pace far higher than they are used to from oil and gas. In this fast-paced work they describe a need to constantly look out of the window to watch the vessels movement relative to the windmill all while also monitoring the thrusters. Challenging the DPO's dynamic working memory, operations like these heavily challenges the DPO's ability to keeping track and maintain their SA. An overload of the working memory would immediately lead to failure of SA up to level 2 (Wickens & Carswell, 2012). It is possible that fitting the DPO with AR/MR glasses in these types of operations would highly benefit the DPO and their SA, again, as long as it is done properly.

From the participants who voiced **negative feedback** on these cases, they all raised concerns on the quality or accuracy of the data projected in the glasses. Now this could come from the training the DPO undergoes in order to be certified as a DPO, in which you are repeatedly being told to never trust the data or automation of the system. You are to monitor the data, and not only processed data, but raw data. As a DPO you should know how to read the raw data, and also see what the processing does to the data.

Thrust in technology in general is based upon many things, among those are accuracy and the operators ability to understand the technology processes (Lee & Moray, 1992). Therefore, it will be highly important to document the accuracy of the technology in order to build a bond of trust between the users who are naturally hesitant towards technology and the technology. Just as with any new technology that has been introduced to a ships bridge over these past decades there has been strict rules for training. One example for this is the introduction of electronic chart display (ECDIS). It was introduced with an obligatory course to properly train the officers, but still the number of groundings went up, this was due to officers placing to much trust in the system (Kjerstad, 2015). After this, it seems that mariners and governing organizations developed a general fear to place too much trust in technology, which as mentioned can still be found in the mindset of mariners and governing organizations.

Hopefully by performing thorough research on the matter and implementing a good training regime and possibly certification on the technology a relationship of thrust to the level that is between a DPO and the DP system today can be created.

5.2 Information

The results shows that **position references** are the most important to the DPO. These are then a foundation for the position and being able to monitor these is then highly important for the DPO. As Bray et al. (2015) explains, there is no perfect system, that is the reason to way we have to introduce posref's in the first place, because the vessels GNSS systems is not accurate enough. Posref's are not without its shortcomings, there are limitations and pitfalls, and it is the DPO's job to evaluate each of the posref's quality and monitor them constantly (Bray et al., 2015). This reinforces what the results shows of the importance of position reference and justifies having it integrated into the AR.

Second on the list was **thrusters**. The thruster data represents not only how are each of the thrusters behaving, but how is the DP system as one large organism behaving. Then there is also the consequence of a failure of a thruster would have on the vessels capability to maintain position. Existing rules from governing class societies reinforces the importance of thruster information, DNV (2021) *Rules for classification part 6. Additional class notations, chapter 3. Navigation, maneuvering, and position keeping. Section 7.4.1 and 7.4.2,* specifically describes requirement for the DP control station to display information on each thruster. In addition to this, it shall also be displayed thruster information always readable from normal operating position separate from the DP system, always showing information on thruster force, direction RPM and so on (DNV, 2021, p. 59). Information on the vessels thrusters is deemed so important that it is not only enough having it displayed on the DP system or a conning display, but by law it should be a separate display readable to the DPO during operations, all this above reinforces the results on the importance of thruster information and justifies making an integration of thruster UI to be displayed in AR. The UI to project all information on all thrusters can grow quite exponentially in size as the number of thrusters grow, due to this it will be important to not create an interface that is overloading the user.

The results shows that the third most mentioned information monitored was **position** and **vessel movement**. The feature more commonly known as posplot on Kongsberg K-pos is what all participants mentioned with the terms position and vessel movement mentioned, some also added that they had a separate GNSS receiver that also tells them vessel movement in all DOF's. Again, if we look into the rules set by DNV, in *Rules for classification part 6. Additional class notations, chapter 3. Navigation, maneuvering, and position keeping. Section 6.10.1* we see that “The display unit shall present a position plot…” (DNV, 2021, p. 53). This reinforces the results indications of importance of posplot, and justifies giving it the possibility to be integrated in AR.

Wind and weather are the uncontrollable forces acting on the vessel, monitoring these are an integral part of what you monitor as a DPO. Every vessel will have a limit to the wind and weather its DP system is capable keeping the position, and some operations have wind and weather limits lower than what the vessel is capable of. There is also the laws of the logbook where the DPO is obliged to keep a record of wind and weather in their logbook, taking recordings at every substantial weather change and once every forth hour (Kjerstad, 2013, pp. 2-78-2–82). It is no doubt that wind and weather is an important factor for a DP vessel, a traditional interface for wind and weather are not large in size and therefore it should be easy to digitally place in AR and be a good fit for the information to be projected in the AR/MR glasses.

Consequence analysis is a feature that works in the background of the DP system working on a preset interval, the analysis looks at the vessels ability to maintain after worst case failures. There is no requirement that the consequence analysis needs to be displayed at all times to the DPO but, DNV’s *Rules for classification part 6. Additional class notations, chapter 3. Navigation, maneuvering, and position keeping. Section 6.13.2* States that “The operator shall be able to monitor that the analysis is in progress.” (DNV, 2021, p. 55). At times where the vessel and DPO is working at its limits it will be a tool that the DPO will lean on to justify their decision to continue their work. Having the consequence analysis available to easily open and look at if there suddenly is a shift in weather and wind or other factors leading to the vessel operating at its limits.

Distance to object, power consumption and cargo movement, the results shows that different participants in small numbers mention these three as something they monitor. None of these are regulated by governing class societies or industry standards nor are there any relevant research on this matter. Distance to an object in the water can be argued that it is important for the DPO to know, also if the distance is increasing or decreasing. Knowing that the vessel is at a safe distance especially in cases where part of the platform or object is overhanging and out of sight for the DPO. Some DPO’s like to watch over the power consumption in order to monitor that they have enough power on both sides of the bus-tie breaker to run the thrusters. This can especially come in handy when operating in bad weather and there is a large need of power. But it will not require constant monitoring as if there is a need for power more generators would be automatically started to manage the power consumption if there is engine power to spare. If the limit is reached on power available, the vessel would cancel current operations. Due to this, there might not be a need to have it displayed at all times but have the option for it to easily be opened in AR. Cargo movement involves information on cargo unloading or loading at sea (to and from platform or other vessels), tracking what leaves the vessel, but also more importantly heeling and ballast during cargo movement. Although the vessels stability is important and in operations of heavy lifting a critical part of the operation, in general it will not be needed to be displayed at all times in AR, but again having it easily available for the DPO when needed.

Information suggested by participants

The participants all had suggestions beyond what they use today on their traditional DP system. The results indicated that the themes were suggested as solution to a problem that they currently experience. Most central themes mentioned was **Alarms, Camera feeds and Blind spots, Traffic, No-go zones, Dangers and Distance to platform or windmill.** Alarms are heavily regulated in the rules of class societies and national standards. Any alarms and warnings are to reflect the current status of the DP system, and the DP control station shall not present any alarms not relevant for the DP systems operational functioning (DNV, 2021, pp. 53–54). If alarms where to be displayed on the DPO's AR/MR glasses there are some regulations to keep in mind, Bainbridge (1983) speaks of how a "proliferation of flashing red lights will confuse rather than help." (Bainbridge, 1983, p. 776). It is also important that alarm information is available to all operators at the bridge, if an alarm is sounded and the DPO misunderstands said alarm, the other operator on watch should be able to monitor the same alarm panel in order to monitor the situation and possibly intervene (Norwegian Petroleum Directorate, 2001, p. 20). Therefore, it might not be a reasonable solution to introduce alarms in the AR.

The use of camera feeds was to project video in AR to replace unnecessary screens and cost on the bridge. It would also more easily allow for customization of what feeds to show and what number of feeds to have displayed. As long as the displaying of camera feeds does not get intrusive it should not be a problem. As camera feeds are not critical to most emergencies, Bainbridge's (1983) argument that major issues can occur when information the user is used to find on screens are no longer there will not be applicable to this and moving camera feeds to AR could be a safe starting point for the technology.

Highlighting traffic was also brought forward, having the ability to easily gather information about a vessel in the vicinity of your own vessel just by looking at it and therefore reducing the time spent looking down at the RADAR or ECDIS. Again, increasing the DPO's ability to stay vigilance of their surroundings, and as previous research shows staying in the loop when working with automation systems is very much dependent on the operators ability to stay vigilant (Endsley & Kiris, 1995). It is then very likely that by having traffic displayed on the AR/MR glasses the DPO's SA will improve. The participants that mentioned traffic, described using it outside of DP operations, traffic was also not mentioned as something that they monitor under normal operations, most likely due to the fact that normal operations are usually outside what would be main traffic fairways and in restricted areas. Therefore, it may not be an important feature to focus on early in development in regard to DP operations but should be on the list of features for development at a later stage or normal navigation operations.

Highlighting no-go zones, dangers and projecting distance to platform or windmill is all building on the same principles as traffic, it is very much about helping the DPO stay vigilant of their surroundings and improve their SA. Having no-go zones around the platform or windmill would ease the workload of having to spend too much time on orientating themselves. Then having the distance to that platform or windmill displayed as well would allow for the DPO to possibly more accurately know how their vessel is moving compared to the platform or windmill. There is some research existing on using no-go zones during ice navigation where Frydenberg et al. (2018) performed field studies with the Norwegian coastguards icebreaker receiving positive feedback on projecting no-go zones and dangers on the AR/MR glasses for the operator during an ice navigation operation. There is a certain resemblance to the no-go zones we are discussing in this matter, and there is reason to believe it should be beneficial to the DPO. On knowing the distance to platform or windmill there is no existing research on this exact matter, but if made accurate and not intrusive to the wearer there is no reason to believe it would not benefit the DPO during an operation.

5.3 Limitations

There are three limitations to the research performed in this thesis, there is **Sample, Interviews,** and **Analysis.**

Sample

Only certified DPO's and active DPO's and instructors was recruited to participate in the interviews. Of the eleven chosen with purposive sampling, the sample is a mix of experience both in numbers of years working and types of operations. Due to this not all types of DP operations were covered by the samples experience and on some types of operations covered by the experience, only a small part of the sample has extensive experience in that field. The validity of the results in some fields of operations are therefore lower than others.

Interviews

Semi-structured interview has a tendency to bring forward the personal opinion of the participant, this means that you as a researcher might not collect data on correct procedures and standards (Longhurst, 2003). In this thesis, what the research was aiming to understand was how information is used with the does and don'ts and not standard procedures. But this does mean that further developing the technology based on the results might not make it satisfactory to today's standards and regulations. Interviews were performed while the participants were out of the work environment that is being discussed, it is possible that it would be more beneficial interviewing the participants face to face on a bridge having the DP-console as a tool during the interviews. Removing the participant from the subject that is being discussed may have caused some loss of data.

Analysis

Working with information that does not have standards for terminology made the process of coding and themes harder. The choice fell on using the terminology used by the market leader Kongsberg DP due to their large market share and it was the system that all participants was trained on. Thanks to the flexibility in thematic analysis, this didn't turn out to be a problem but this flexibility can also lead to inconsistency and or lack of coherency (Nowell et al., 2017).

Reliability

As the interview was constructed reliability issues are introduced when the questions were translated to Norwegian for the execution of them. Luckily the pilot study uncovered the flaws in the initial translation and corrections where made. After the analysis the direct quotes to be used directly in the thesis was translated back to English for use. To ensure reliability in the data the translations were checked by a second pair of eyes to ensure correctness and quality. Although there is inconsistency in the fact that the raw data contains different terminology on the same matter, the results show consistency when given a common therm. The reliability is therefore considered to be good. It should not be a problem to recreate the results presented in this thesis under the same conditions.

Validity

The number of participants combined with their experience within each field of operation do call for reduced validity for some type of operations. There is also little specific research existing on the data presented in this thesis reducing the validity of all of the results a little. But the fact that the results should be easily reproduceable it holds the data to a fairly good validity.

6 Conclusion

To conclude the findings of this thesis, according to the possible end-user's, head-mounted displays using augmented reality to convey information to the dynamic positioning operator has potential to benefit the operator. That is if used in the correct operations and displaying the correct type of information and amount of information.

To answer research question one the following operations were found fitting, supply operations with a vessel maneuvering close to a platform loading or offloading cargo. Offshore construction or maintenance performed topside or subsea with a visual reference above the ocean surface. Offshore windfarm construction or maintenance where the vessel is within safety zones of the windfarm and working close to a windmill or other installations. Anchor handling operations that are close to a platform or windmill. In operations where there is no visual reference above the ocean surface or no platform or installation in close vicinity there is little to no need for the AR/MR glasses.

To answer research questions two the following information was found to be important to the dynamic positioning operator listed from highest to lowest importance: position references and their quality, thrusters their bearing and force, position and vessel movement, wind and weather, power consumption, distance to object, consequence analysis and cargo movement. Although the results from the research in this thesis do show that the participants are hesitant to move critical DP system data from today's screens over to the AR/MR glasses but instead have supportive information such as camera feeds, no-go zones and dangers, distances to platforms or windmills and traffic.

Recommendations

- **Other possible users to look into:**
  Winch operators, anchor handling.
  ROV operator, subsea and construction.
  Ship supervisor, anchor handling, subsea and construction.
- **Introduce non-critical information first in AR.**
  Start by introducing non-critical information first such as camera feeds.

- **Trust from end-user is of the upmost importance for success.**
- **AR/MR glasses needs to add something new to be of use.**

Issues for further research

Suggestions for further research in this section derives from the main concerns and following four points are suggested for more research.

1) Comfort in wearing and using the AR/MR technology over long periods of times. Not only wearing the headset but also the strain on the user's eyes in relations to fatigue.
2) Interface, there is a need to interact and adjust perimeters for several types of information involved in a DP operation.
3) Training and certification, what type of training and certification is needed to ensure correct use of the technology.
4) Redundancy and accuracy are one of the most talked about terms in DP operations, the system cannot be integral to the operation to a point where a failure could make for dangerous situations. The accuracy of the information presented in the display must be of such high accuracy that it holds value to the dynamic positioning operator.

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Appendix One

Start the interview by defining the interview objects experience.
- Age?
- Months/Years of experience at sea?
- Current occupation or position onboard?
- What is the current level of maritime certificate you hold?
- Months/Years of experience with advanced maritime operations (DP operations, etc.…)?
- What is your current experience with AR or VR technology, have you ever tried it, and if so, how many times?

Start next step of the interview by explaining the theory and concept of the technology and the hope of increased safety and situational awareness.

- Can you describe your own experience and background as a DP operator/technical superintendent/teacher?

- How/why is the DP system deployed or engaged. What defines the limit or point where you as an operator feel the need to deploy the system.

- Based on your experience from AMO, what would you say is the core or general information on the vessel or operation that you constantly watch over, and use?
  - Please elaborate on why this information is of such importance

- Building on the core information, can you mention some more scenario specific data that you find of special use on certain operations?
  - Please elaborate on why you find this information important

- Could you explain DP operations onboard, with regards to working with other members of the crew?
  - More exact communication.

- As a DP operator, what are some of the biggest challenges with the current DP system?

- Are there any other common reasons to why you as an operator/your operator's situational awareness is impacted negatively during DP operations?

- Have you experienced any moments where the DP system has created dangerous situations, and can you describe what caused it?

- A suggested scenario could be platform supply operations, from your experience, do you think a DPO could benefit from the technology in this scenario, if not, please explain why?

- Another possible scenario could be Subsea, from you experience, could you identify certain times, or examples of scenarios where you as an operator could have benefitted from the technology, if not, please explain why?

- Can you describe specific situations where you have felt overloaded as an operator?
  - Please explain why.

- Is there any of those situations where the AR technology could have been helpful?
  - Please elaborate.

- What are your general feelings towards all the technology that has been introduced to the ship bridge over the past couple of decades?

- If you take one minute to think about what we have talked about, and the technology presented. Do you think that the technology could help (you as an operator/your operator/the future operators)?

- Then the opposite, is there any operations or moments of certain operations where you think you would not benefit from the technology?

- What are your main concerns about the technology?

- Would you feel comfortable using the technology or applying the technology to operations you supervise, if not, what would it take to make you feel comfortable with the technology?

Finish the interview by thanking the participant for their cooperation and taking time to be a part of the project, and again informing them that they can withdraw their consent at any time, without any negative consequences.

Appendix Two

NSD NORSK SENTER FOR FORSKNINGSDATA

Assessment

Reference number

643226

Project title

Master Thesis: Exploring scenarios for AR technology supporting operators in advanced maritime operations

Data controller (institution responsible for the project)

Universitetet i Sørøst-Norge / Fakultet for teknologi, naturvitenskap og maritime fag / Institutt for maritime operasjoner

Project leader (academic employee/supervisor or PhD candidate)

Steven Mallam, steven.mallam@usn.no, Tel.: 31009252

Type of project

Student project, Master's thesis

Contact information, student

Henrik Aasgaard Carho, henrik.carho@gmail.com, Tel.: 91387575

Project period

01.01.2022 - 30.09.2022

Assessment (1)

25.01.2022 - Assessed

Data Protection Services has carried out an assessment of the processing of personal data in this project. Our assessment is that the processing will comply with data protection legislation, so long as it is carried out in accordance with what is documented in the Notification Form and attachments, dated 25.1.2022, as well as in our message correspondence.

TYPE OF DATA AND DURATION

The project will process general categories of personal data until 30.9.2022.

LEGAL BASIS

The project will gain consent from data subjects to process their personal data. We find that consent will meet the necessary requirements under art. 4 (11) and 7, in that it will be a freely given, specific, informed, and unambiguous statement or action, which will be documented and can be withdrawn.

The legal basis for processing general categories of personal data is therefore consent given by the data subject, cf. the General Data Protection Regulation art. 6.1 a).

PRINCIPLES RELATING TO PROCESSING PERSONAL DATA
We find that the planned processing of personal data will be in accordance with the principles under the General Data Protection Regulation regarding:
lawfulness, fairness and transparency (art. 5.1 a), in that data subjects will receive sufficient information about the processing and will give their consent
purpose limitation (art. 5.1 b), in that personal data will be collected for specified, explicit and legitimate purposes, and will not be processed for new, incompatible purposes
data minimization (art. 5.1 c), in that only personal data which are adequate, relevant and necessary for the purpose of the project will be processed
storage limitation (art. 5.1 e), in that personal data will not be stored for longer than is necessary to fulfil the project's purpose

THE RIGHTS OF DATA SUBJECTS
We find that the information that will be given to data subjects about the processing of their personal data will meet the legal requirements for form and content, cf. art. 12.1 and art. 13.

Data subjects will have the following rights in this project: access (art. 15), rectification (art. 16), erasure (art. 17), restriction of processing (art. 18), notification (art. 19) and data portability (art. 20). NB! Any exceptions must be justified and have a legal basis. These rights apply so long as the data subject can be identified in the collected data. (refer to arts. 21-22 if applicable).

We remind you that if a data subject contacts you about their rights, the data controller has a duty to reply within a month.

FOLLOW YOUR INSTITUTION'S GUIDELINES
Our assessment presupposes that the project will meet the requirements of accuracy

(art. 5.1 d), integrity and confidentiality (art. 5.1 f) and security (art. 32) when processing personal data.

To ensure that these requirements are met you must follow your institution's internal guidelines and/or consult with your institution (i.e. the institution responsible for the project).

NOTIFY CHANGES
If you intend to make changes to the processing of personal data in this project it may be necessary to notify us. This is done by updating the information registered in the Notification Form. On our website we explain which changes must be notified. Wait until you receive an answer from us before you carry out the changes.

FOLLOW-UP OF THE PROJECT
We will follow up the progress of the project at the planned end date in order to determine whether the processing of personal data has been concluded.

Good luck with the project! Contact person: Lisa Lie Bjordal

Appendix Three

Are you interested in taking part in the research project ” Exploring possible scenarios for AR technology to assist operators of advanced maritime operations”?

This is an inquiry about participation in a research project where the main purpose is to explore possible scenarios where it is fitting to introduce AR technology as a support tool for DP operators in advanced maritime operations. In addition to possible scenario there will be some research on the necessary information needed to be projected. In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project
The project is a part of a master thesis in the field of maritime management at the University of South-Eastern Norway. The scope of the project/thesis is to explore what scenarios the AR technology can work as an assistive technology to the operator of a DP system in an advanced maritime operation. This is to be done by speaking to industry, and interviewing operators. As a part of this process the is also a wish to explore what type of information the operators find most important to be displayed.

The two research questions regarding the project/thesis are:

RQ1: What type of dynamic positioning operations could the operator benefit from augmented reality glasses?

RQ2: What information is needed to be displayed in the Augmented Reality in order for the operator to safely perform their work?

Who is responsible for the research project?
The University of South-Eastern Norway is the institution responsible for the project.

The project/thesis will also be to some extent a part of the OPEN AR research project.

Why are you being asked to participate?
In order to get the most precise data for the project/thesis, I am interviewing participants with actual experience from advanced maritime operations and DP systems. You are being asked to participate in this project/thesis based on you experience with DP systems and advanced maritime operations.

What does participation involve for you?
If you chose to take part in the project/thesis, this will involve that you sit down for an interview either in person or online. The questions are related to your experience operating a vessel on DP, what’s important to you as an operator, and your user experience with a DP system. The interview is projected to take approximately 30 minutes. During the interview the audio will be recorded, this data will be anonymized as soon as the interview is finished.

Participation is voluntary
Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data
We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act).

- Only researchers connected University of South-Eastern Norway and this project will have access to the data. Those researchers being Thesis student Henrik Aasgaard Carho and Supervisor Steven Mallam.

- All personal information will be stored on a computer belonging to data collector and thesis student Henrik Aasgaard Carho. The files will only to be shared with the researchers involved in the data collection, this being Mr. Carho and Mr. Mallam. All personal data will be anonymized as soon as it is collected, your name and personal details will be replaced with a code to identify the data. The solution file that contains the list of names and their respective codes will be stored offline on a separate storage device from the data itself.

- Personal information collected will be limited to age, current position at work and experience.

- Participants will not be recognisable in any publications regarding the thesis or public presentations. All data collected will be anonymized.

What will happen to your personal data at the end of the research project?
The project is scheduled to end *by the* end of September. At the end of the project all data is anonymized. All personal data will be deleted.

Your rights
So long as you can be identified in the collected data, you have the right to:
- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?
We will process your personal data based on your consent.

Based on an agreement with University of South-Eastern Norway, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?
If you have questions about the project, or want to exercise your rights, contact:

- University of South-Eastern Norway via Henrik Aasgaard Carho, Email: henrik.carho@gmail.com, Phone: 0047 913 87 575

  Supervisor, Steven Mallam, Email: steven.mallam@usn.no.

- Our Data Protection Officer: Per Are Solberg, Email: Paal.A.Solberg@usn.no. Phone: 355 75 053
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Yours sincerely,

Project Leader/Student

Henrik Aasgaard Carho
Email: henrik.carho@gmail.com
Phone: 0047 913 87 575

Supervisor

Steven Mallam
Email: steven.mallam@usn.no

Consent form

I have received and understood information about the project ***Exploring possible scenarios for AR technology to assist operators of advanced maritime operations*** and have been given the opportunity to ask questions. I give consent:

- to participate in an interview.
- to allow my answer to be recorded.
- to allowing my anonymized data to be used in this thesis.

I give consent for my personal data to be processed until the end date of the project, approx. 30.09.22

(Signed by participant, date)