

# AUGMENTED REALITY IN COASTAL WATER NAVIGATION

by

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*For Hannah and Jack.*

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## **Abstract**

When conducting Coastal Water Navigation, a ship's Navigating Officer (NavO) has multiple sources of data to consider. In order to obtain the information required to safely manoeuvre the ship, they make use of specialized equipment. The time spent interacting with the equipment is a risk, as it prevents them from visually monitoring the ever-changing maritime environment. Augmented Reality (AR) offers a way to obtain the information while maintaining a proper and effective lookout. Additionally, our research suggests that the information can be presented in new ways. We created a simulator that allows testing and evaluation of AR Navigation Aids (ARNAs). These visualizations were evaluated by subject matter experts through a user study. The user study suggests that ARNAs can improve maritime safety and assist in the conduct of navigation.

## List of Abbreviations and Symbols Used

<b>AR</b>	Augmented Reality
<b>ARNA</b>	Augmented Reality Navigation Aid
<b>CMG</b>	Course Made Good
<b>COLREGS</b>	International Regulations for Prevention of Collision at Sea
<b>CPA</b>	Closest Point of Approach
<b>CTS</b>	Course To Steer
<b>CTS</b>	Course to Steer
<b>ECDIS</b>	Electronic Chart Display and Information System
<b>ENC</b>	Electronic Navigational Chart
<b>ETA</b>	Estimated Time of Arrival
<b>FixO</b>	Fixing Officer
<b>GDAL</b>	Geospatial Data Abstraction Library
<b>GPS</b>	Global Positioning System
<b>HUD</b>	Heads-Up Display
<b>IALA</b>	International Association of Lighthouse Authorities
<b>IDD</b>	Interface Design Document
<b>IHO</b>	International Hydrographic Organization
<b>IMO</b>	International Maritime Organization
<b>MCTS</b>	Marine Communications and Traffic Services

<b>NavO</b>	Navigating Officer
<b>NMEA</b>	National Marine Electronics Association
<b>ODbl</b>	Open Data Commons Open Database License
<b>OOW</b>	Officer of the Watch
<b>OSM</b>	OpenStreetMap
<b>OST</b>	Optical See Through
<b>PDA</b>	Personal Digital Assistant
<b>PNG</b>	Portable Network Graphics
<b>RACONS</b>	Radar Beacons
<b>RCN</b>	Royal Canadian Navy
<b>ROM</b>	Rough Order of Magnitude
<b>SDK</b>	Software Development Kit
<b>SRO</b>	Speed Rung On
<b>VE</b>	Virtual Environments
<b>VR</b>	Virtual Reality
<b>VTS</b>	Vessel Traffic Service

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# Chapter 1

## Introduction

The duties and responsibilities of professional marine navigators are outline in detail in the American Navigator (Bowditch). These duties are onerous. They require that Navigating Officers (NavOs) spend years mastering an ability to maintain spatial awareness while conducting coastal water navigation (hereafter referred to as Pilotage). Pilotage is a form of marine navigation in which the NavO finds themselves in close proximity to dangers while in high densities of vessel traffic. We use the word “dangers” to refer to potential hazards that may result in grounding of the vessel. This task requires managing multiple and variable inputs in order to prioritize actions. This can be illustrated by considering a NavO making passing arrangements with another vessel over the radio. In order to do so, the NavO has to consider multiple pieces of information. This includes, but is not limited to the following:

- a timely assessment of the current collision situation in accordance with the International Regulations for Prevention of Collision at Sea (COLREGS);
- processing changes in visual bearings;
- proximity to other shipping;
- speed restrictions;
- harbour sailing directions;
- manoeuvrability of ships and other propulsion characteristics; and
- angles off the bow

As if this was not daunting enough, the navigator must also concurrently determine a mental-math heuristically generated trigonometric solution for the course to steer (CTS) that allows an appropriate closest point of approach (CPA) to other ships



and unseen shallow water. These decisions have to be quick and are done under the stress of knowing a mistake could cause loss of life and damage to property.

In order to gather crucial information necessary to conduct safe navigation and collision avoidance, the NavO is forced at times to look away from the quickly changing dynamic environment in order to interact with equipment. For example, this may be the time spent interacting with an Electronic Chart Display and Information System (ECDIS) or a radar display. Although the information gained is vital to Pilotage, interacting with the equipment introduces necessary risk.

This research addresses this problem by suggesting the use of Augmented Reality (AR) to assist in the conduct of Pilotage. We suggest that the vital information required to conduct Pilotage could be displayed on the Optical See Through (OST) device without requiring the NavO to look away from the bridge windows. Examining this issue involves a survey of many different fields of study and current research ventures. In Chapter 2, we examine the state of current related research through a literature review. This involves assessing current augmented reality devices and their capabilities and limitations. We conduct a survey on using VR to design AR visualizations as a way of progressing visualization research and design despite current limitations in hardware. We review existing research related to visualization techniques used in AR, as well as explore methods of appraising and validating those AR visualizations. Finally, we look at the existing body of research using AR Visualizations for Pilotage.

The use of computer systems has had a significant impact on the conduct of Pilotage. In Chapter 3, we explore the current electronic aids to navigation and how they impact Pilotage. We look at existing chart symbols and electronic navigation charting systems. We discuss aids to navigation, such as floating, fixed, and radio aids. We then conclude with a discussion of the use of radar in navigation and automatic radar plotting aids.

In Chapter 4, we explore the IMO e-Navigation Strategy [1]. This strategy outlines a series of requirements that we consider. This includes looking at the user need, operating procedures, decision making process, human factors, resourced, phased roll-out recommendations, and costs.

In Chapter 5, we present a S57 visualization prototype and an AR device simulation prototype. The S57 visualization prototype demonstrates how navigation chart data can be read in dynamically to create virtual worlds. We outline how a ship simulator was created using terrain data and S57 chart information. Additionally, we present a AR device simulation prototype that was created to demonstrate how VR could be use to mimic AR devices. This demonstrates how settings such as field of view (FOV) and stereoscopic separation can impact the presentation of augmented reality visualizations.

In Chapter 6, we survey sources of data for VR terrain generation. This chapter explores the available sources of data such as OpenStreetMap and ArcGIS. We show how this data can be imported into modelling programs such as Blender and used within VR or 3D application development tools such as Unity3D.

In Chapter 7, we describe the created VR system and the generated AR Navigation Aids (ARNAs). We describe the creation of a VR application that uses Oculus Rift, and we describe how this system allowed the development of ARNAs. We describe in detail the created ARNAs, their purpose, and suggested real-world sources of information to generate them.

In Chapter 8, we look at the outcome of subject matter expert analysis of the visualizations through a User Study. This includes looking at each ARNA in turn as well as general commends and feedback. We discuss the observed interaction each user had with the visualizations, as well as their feedback and suggestions.

## Chapter 2

### Literature Review

#### 2.1 Introduction

In this chapter, we conduct a literature review of related research. We start by examining the evolution and the current state of AR devices and their limitations. We look at the research related to designing AR visualizations, including using VR as a development tool. In order to determine the value of the created visualizations, we look at some techniques to appraise and validate visualizations. This is followed by a more specific look at how current AR visualizations have been developed for coastal water navigation.

#### 2.2 Current AR Device Limitations

The ability to augment the physical world with the digital world has widespread application. Use cases have been envisioned for many different aspects of industry, from tourism and sightseeing to unmanned aerial flight systems [2]. Increasing Central and Graphics Processing Units (CPU/GPU) performance coupled with new innovations, such as the holographic processing unit (HPU) of Microsoft's HoloLens, mean these use cases can begin to be realized [3].

Exploring the history of AR helps to identify some trends in how AR is developing. Hardware advances are helping to address some of the issues that have impacted user engagement. The observed trends may give us some insight into the future of AR devices and how these improvements may help increase user engagement.

##### 2.2.1 History of Augmented Reality

Rosenberg was one of the first to turn the idea of AR into reality in the early 1990's. In his research, he presented the idea that abstract percepts overlaid on top of a display could enhance and expand the user's abilities beyond their natural capabilities [4].

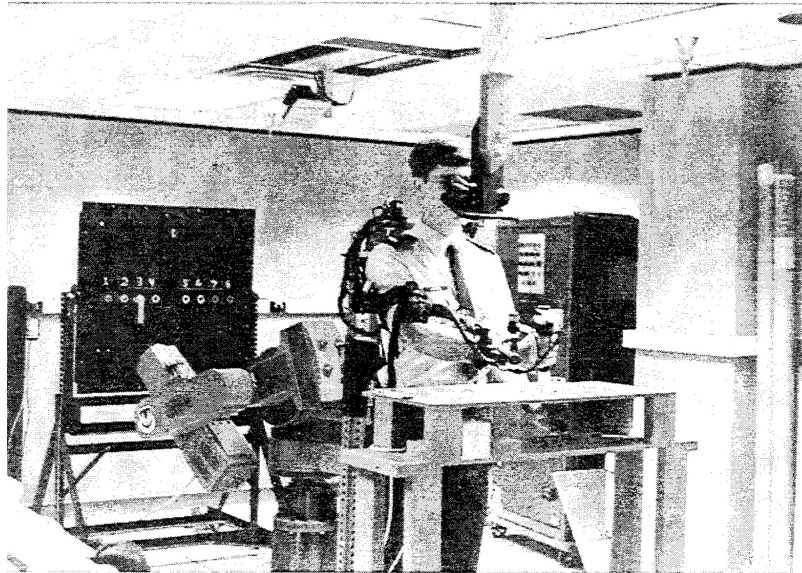


Figure 2.1: Photograph from Rosenberg’s Virtual Fixtures paper of a subject wearing a kinesthetic exoskeleton, one of the first implementations of Augmented Reality [4].

He referred to AR visualizations as virtual fixtures. He suggested that these virtual fixtures could be useful tools, in much the same way a ruler assists someone in drawing a straight line. Rosenberg showed that virtual fixtures improved users performance in tele-manipulation tasks (remotely controlling a robot to place pegs in holes) by up to 70%. Interestingly, he attributed this performance gain to a reduction in information processing required by the operator; the virtual fixtures simplified the perception of the space.

In 1996/97, Thomas Höllerer et al. created a mobile augmented reality (MAR) prototype they called the Columbia Touring Machine [5]. This was comprised of several components. A backpack computer with an upgraded graphics card was hooked into an optical see through (OST) display, which had orientation tracking. They made use of a Trimble DSM GPS receiver for position tracking. In addition, the user had a handheld computer that allowed interaction with the AR user interface (UI). They used radio modems to communicate with their local network. The system was powered by an NRG Power-MAX NiCad rechargeable battery belt for up to 2 hours.

This was the first of a series of prototypes developed by their team. These prototypes were improved upon with hardware updates up until 2001. The upgrades included swapping out the radio modems for WiFi communications, better tracking



Figure 2.2: A person using the Columbia Touring Machine in 1997 [5].

devices and more advanced computers with 3D graphics accelerator chips. These advances allowed for the equipment to become smaller, improved visualizations and registration. Registration is the process of aligning virtual representations correctly with real-world objects.

In 2004, when Personal Digital Assistants (PDAs) were very popular, Goose et al. experimented with AR on these devices [6]. They used the PDA's camera and computer vision to resolve location and registration issues. Unlike the handheld AR UI controller created by Höllerer et al., they made use of speech to interact with the visualization. For example, the user could ask a question regarding the temperature of fluid in a pipe, and a text overlay would indicate the temperature. Contemporary off the shelf technology had caught up with the use case, and they were able to make use of commercially available PDAs for their product. This is in contrast to the custom hardware, such as the backpack computer made up of upgraded components that Höllerer et al. required. Advances in technology were beginning to allow easier integration of research ideas into real world prototypes.

Of course, the popularity and functionality of PDAs was replaced by the smartphone. Modern smartphones combine many of the components that formed earlier MAR prototypes (GPS, camera, handheld control, speech recognition, accelerometers, powerful GPUs, etc). As such, smartphones have become widely used as AR

devices. Avilés et al. demonstrated that smartphones can provide AR visualizations without position markers [7]. This was done by processing the camera's image, filtering pixels in order to identify parts of a circuit board. The AR visualizations were then placed accordingly, merged into the image and rendered to the smartphone's screen.

The gaming industry has shown that AR-enabled applications for smart phones is a viable and lucrative business model. The success of games such as Pokemon GO and Ingress help to make AR more accessible to the average user. This is in contrast to products such as Microsoft's HoloLens which cost much more than a smart phone (as of this writing, the HoloLens sells for \$3,500 CAD). As such, OSTs such as the HoloLens are primarily used by large corporations and for academic research.

Much in the same way the Avilés et al. smart phone app processed the image captured, so too does the HoloLens make sense of the world around it. It generates a 3D mesh of the world around it by using its camera and sensors. This allows the visualizations to interact with the real world in predictable ways such as the occlusion of virtual objects by real world obstacles.

### **2.2.2 Descriptors/Common Traits**

By reviewing the different implementations of AR devices over time, we can see some trends that help to describe the state of AR devices. In this section, we propose a few descriptors that can be used to help describe the differences between AR device implementations, and which may allow us to estimate future implementations.

One such descriptor is weight. The trend here has been to move towards lighter weight devices. Comparing the Columbia Touring Machine against a smart phone or even the HoloLens makes that trend obvious. However, a common complaint with the HoloLens is that it is still too heavy, which becomes an issue when worn for prolonged periods of time.

Another descriptor is processing power, which has naturally increased with advancements in hardware over time. This has allowed the processing required to be done with smaller subcomponents, such as using a smartphone instead of a backpack computer. It has also allowed wearable devices to become untethered, such as the HoloLens. When tethered, the components have also become smaller, as seen with



Figure 2.3: Belt attachment of the Magic Leap [10].

the belt attachment of the Magic Leap shown in Figure 2.3.

Another way to compare AR devices is by the size of their field of view (FOV). A human's FOV has approximately  $210^\circ$  horizontal arc and  $150^\circ$  vertical arc [8]. The HoloLens offers a much smaller field of view ( $35^\circ$ ) that can make the visualizations seem disconnected from the real environment. However, Microsoft may be able to double this with the HoloLens 2 as seen in recent patents [9]. The Meta 2 offers a much wider FOV of  $90^\circ$  but it requires the user to be tethered to a desktop computer.

### 2.2.3 User Engagement

Processing power is directly related to system rendering latency. Poor latency is one of the major issues impacting user immersion [11]. Therefore, as processing power continues to increase and latency issues decrease, user immersion might improve. We may also expect that the negative side effects experienced from latency to diminish, such as motion sickness.

Irshad et al. established an user experience (UX) framework for evaluating user engagement with MAR devices [12]. They proposed a set of considerations for AR design, as shown in Table 2.1. They also characterized the types of experiences evoked when using these systems: emotional, aesthetic, and the experience of meaning. Their research illustrates that MAR UX is unique and that uniqueness should be considered

<b>MAR components</b>	<b>Designable Elements</b>
<b>Information Content</b>	Rich, lively, relevant, provide the user with placement of content, stability of 3D content, user control over 3D content
<b>Functionality and performance</b>	Reliable, useful, user support (feedback low physical efforts), and relevance to the reality, embedded content, personalization of specific content and versatile features.
<b>Interaction</b>	Positive interaction, simplicity, intuition.

Table 2.1: MAR components with designable elements that should be included while scheming for MAR applications [12].

by developers and designers. As these systems become more prevalent, better UX design may also improve user engagement.

#### 2.2.4 Summary on State of Current AR Devices

AR devices have improved significantly from the days of backpack computers and radio modems. Current trends indicate that untethered, standalone wearables are the future of AR. Better FOV arcs, more realistic rendering and better UX design may help to improve user engagement. As hardware becomes smaller, it is expected these devices will continue to become less cumbersome and lightweight. It may take many years before these devices become as lightweight and innocuous as reading glasses, but AR devices are currently finding a place in the market. Other implementations of AR, such as using smartphones, demonstrate the diversity of this technology.

### 2.3 Designing AR Visualizations Using VR

Augmented Reality (AR) can take many forms, such as on a Desktop Computer, via the screen of a mobile device, or through more immersive experiences like OST glasses. Just as AR has many mediums, AR Visualizations can take many forms. The design of these visualizations should consider the medium in which it is being displayed. Additionally, AR visualizations can be made more engaging by incorporating artistic techniques along with the practical representation of raw data. This section is a survey of some of the AR Visualization techniques currently being deployed.



The use of AR in applications continues to grow and has become a hundred-billion-dollar industry [13]. With its quick adoption and wide spread application, AR is an active field of research. This section takes a look at how AR visualizations are being developed. This includes looking at some of the technologies being used to create 3D models as well as tracking software, different example implementations of visualizations, and how the art of designing visualizations is developing.

### 2.3.1 AR Visualizations

AR Visualizations take many forms. Zollmann et al. tackled the problem of change blindness (a concept derived from psychology where a viewer fails to recognize changes in visual stimulus) when visualising time related data [14]. As an example, they applied AR visualizations of a building construction. They broke the visualization down into multiple layers of complexity, from overview to detail, in a blended view. The blended view allowed exploring the progress of the build with specific details about each moment in time. They were quickly forced to deal with the question of what to do with an ever-growing source of data, and the potential for different types of visualizations. They saw multiple fields with which to test their visualization techniques, including everything from instruction manuals to medical applications.

Chang et al. researched designing AR visualizations of a 3D crystal macromolecule. The modelling of the object was quite simply a combination of spheres (representing atoms) and pipes (representing the bonds between atoms) [15]. These simple geometric shapes are well suited to be rendered procedurally using geometry and OpenGL. The source data (downloaded from online databases) can be converted into simple geometric shape meshes that are built up into more complex models by translating the simple parts to their corresponding positions relative to each other. After which, the complete model is translated and placed in the appropriate screen coordinates. Chang et al. used ARToolkit in order to place the visualization in a position and orientation relative to placed cards. Through a process of computer vision, ARToolkit was able to effectively and efficiently calculate the placement of the models.

Camba et al. demonstrated how AR, and subsequently AR Visualizations, can be delivered in various mediums. These mediums include desktop computers, mobile

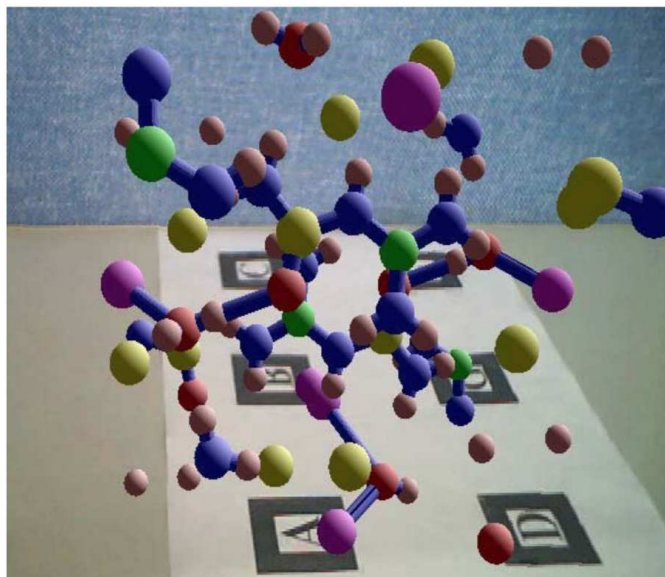


Figure 2.4: AR visualization of 3D Crystal Macromolecule [15].

devices, and the more standard interactive 3D viewer [16]. Their research focused on creating 3D visualizations for engineering student text books. In this discipline, they argue that spatial skills and 3D thinking are directly related to success yet the conventional medium for expressing 3D concepts is still in 2D form. To tackle this, they developed images in their textbooks that had black and white patterns on them. Using a camera, a computer could associate a 3D visualization with the pattern and would then render the 3D Visualization. The visualization was positioned by using a card. The user could then interact with the visualization by changing the orientation and position of the card.

The desktop version required a computer equipped with a webcam that was used in conjunction with the textbook. This allowed the reader to see illustrations of the book come to life on the computer desktop screen, and interact with those visualizations.

Mobile devices provide another way of interacting with AR and AR Visualizations. Now, instead of moving the card, the user could see the model in place on the page by looking at their mobile device screen. The object's position and orientation could now be manipulated by touch gestures. As the visualization and the ways that they are interacted with are tied to the medium, this suggests that visualizations should be developed considering the target environment.

How each medium can exploit human perception and impact interactions with

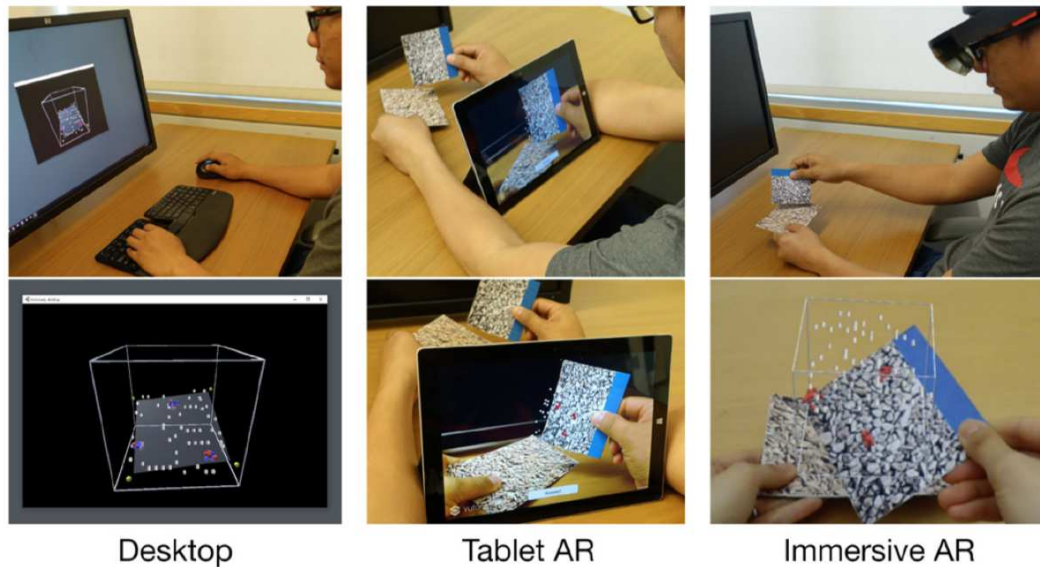


Figure 2.5: Different mediums of AR are better suited than others depending on the task at hand [17].

visualizations was studied in detail by Bach et al [17]. They determined that no one medium is best overall for all tasks, each demonstrating that it could be better suited than the other's based on the task at hand. They also demonstrated that interacting with 3D models can help improve the user's perception of it. The way in which the model was interacted with also changed depending on the medium. They suggested many different combinations of mediums and interactions, swapping from one representation to the other, and combinations of real world visualizations with augmented visualizations, is the future of this technology.

For some specific AR visualizations, we can look to the research of Tsuchimoto et al. and their work with applying AR to the field of medical-physics [18]. Like Chang et al. they made use of OpenGL and ARToolkit. They included different types of visualizations in determining organ tissue stiffness, which can be useful in locating tumours. This included showing the results of measurements as points and numbers. They displayed circles, where the center of the circle corresponded to a measurement point, and the area of the circle implied meaning (the tissue stiffness amount). They employed measurement bars, where the length and colour of the bar corresponded to the magnitude of the measurement. They also displayed coloured contour lines drawn directly on the surface of the organ. They demonstrated that AR visualizations can

take many forms in its representation of raw data.

Geroimenko et al. considered the union of practical visualizations with artistic effects [19]. Rather than have visualizations that serve strictly practical cases or ones that serve no obvious use other than entertainment, Geroimenko et al. looked at how these two polar extremes could be incorporated into more interesting, yet useful AR visualizations. They identified a few key points for integrating a visualization into the real world. These points included how logically relevant the visualization was to the real world, its visual validity, aesthetics and visual plausibility. They referred to the real world as being a new canvas to which an artist can paint AR visualizations. Their user studies showed that their AR visualizations appealed to their users and increased engagement.

### **2.3.2 Summary on Designing AR Visualizations Using VR**

AR continues to become more prominent, and the visualizations used can take many forms. It is important to consider how these visualizations are designed in order to ensure user engagement is maximized. These visualizations can provide the end user with knowledge about his environment, but they should also avoid breaking the viewer's immersion with the world around him[19]. Considering other avenues for visualizations, rather than just conveying pertinent information, may be necessary to ensure user satisfaction.

## **2.4 Visualization Techniques used in AR**

This section presents a survey of visualization techniques used in augmented reality. A few common concerns are apparent when reviewing the literature. These concerns include determining what are the essential visualizations to present, where to best place the visualizations in the user's field of view, and how to interact with the visualizations. This survey indicates that these issues are not a solved problem, and future research is necessary to continue to understand these concerns.

### 2.4.1 AR Visualization Techniques Overview

AR visualization techniques present new challenges and questions to be answered. Such as, how do we display content to the user? This can lead us down the path of different frameworks, not all of which are supported on different platforms. Some researchers limit their findings to the equipment they have at hand, while others attempt to generalize by taking more mathematical and theoretical approaches. How to display the content also involves questions on how to accurately track real-world objects and how to appropriately correlate the depth of the visualizations with those objects.

Once the researcher has determined how to display the information, the next obvious question becomes what should be displayed. Much of the research presented considers this question. Some take experiment driven approaches that allow gathered data to be pushed into machine learning algorithms, while others feel collaborations across scientific disciplines will lead to better results.

Another common area of research is how to interact with the visualizations. It is suggested that augmented reality allows more natural ways to interact, which may be why the research area is showing great interest. Common techniques involve using markers and image tracking software.

### 2.4.2 Survey of AR Visualization Techniques

Ivaschenko et al. proposed adapting visualizations to the user's focus which they termed "accented visualizations" [20]. The benefit of this is to reduce the amount of non-essential data being presented to the user. In determining the visualizations to exclude, they consider both the focus of the user and the current context. They captured the user's focus through the use of eye tracking software. The context was determined by a machine learning process.

The machine learning process involved the use of image capture software and then trained on the sequence of actions used by operators at different skill levels. They considered the use case to be an assembly line worker. As such, they trained their image recognition software to recognize the parts currently being used along with the expected actions by the worker.



Figure 2.6: Important object identified and highlighted [20].

This allowed them to make different predictions about what was currently important to tell the operator, and thus customize the visualization accordingly. By understanding and standardizing the expected operator actions and by processing the operator's current focus, they were able to identify gaps in the operator's attention. When this occurred, they provided new visualizations to pull the operator's focus to where they determined it should be. This involved using texts, markings and highlighting, as seen in Figure 2.6.

However, Olshannikova et al., when looking at big data visualizations using AR, suggest that human eye movement patterns can be impacted by cultural factors [21]. This could in turn impact eye tracking algorithms. They suggest collaborations across disciplines such as ophthalmology and neurology are necessary to support decisions on where to place visualizations instead of machine learning algorithms. They also say attention should be given to the human visual system in order to determine where to best render the images. Their research concludes that most important visualizations should be placed within the central vision of the user.

Kirner et al. suggest that the visualizations in AR can be more useful than those in VR [22]. They reason that the complexity of the VR devices used for interacting with the visualizations, and the training required to learn how to use the devices, distracts from the usefulness of data visualizations. Unlike VR, AR visualizations

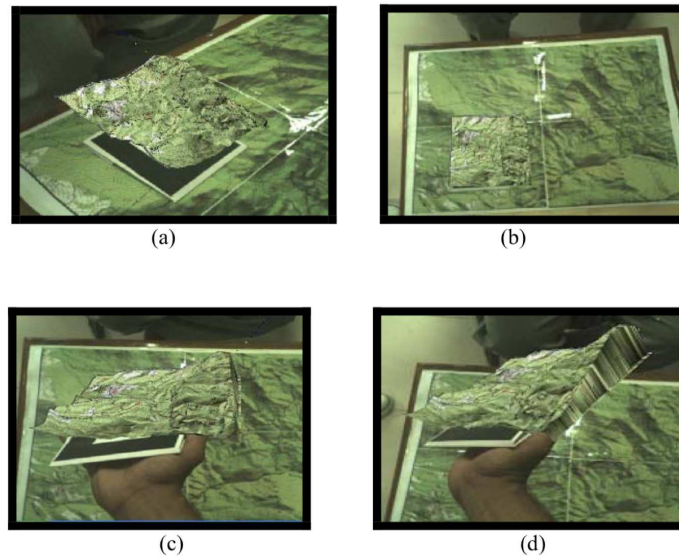


Figure 2.7: a,b) show the terrain on the interactive marker, (c,d) show the user interacting with the selection [24].

can have user interaction without the need of tools. Computer Vision can allow the visualization to react to natural gestures such as hand movements instead.

They placed computer graphics in the real world on markers placed on cards (which they referred to as plates). These plates could be picked up and interacted with by the user by using image capture from webcams and the ARToolKit [23]. Multiple markers on plates were used together to create more complex visualizations that the user could interact with, moving plates and inspecting each subcomponent of the larger visualization. In such a way, they proposed that the visualization framework they developed could allow for the visualization of large volumes of complex data.

Adithya, C. et al also used markers and the ARToolKit [24]. They augmented a paper map by allowing the user to pull a subsection of the map out as an interactive 3D model, as shown in Figure 2.7. By subdividing the map into regions, they are able to provide very detailed visualizations for the currently selected portion. They conclude that these types of visualization techniques are useful in industries such as the military, where use of paper maps for planning are the norm. They suggest that the use of these visualizations will help the user make more informed decisions.

In order to allow the user to take out subdivisions of the map to interact with, they used two types of markers: those used for orientating, and those used for interaction.

They placed four markers on the map, one in each corner. And then, the user placed the interacting marker on the paper map. They calculate the relative transformation matrix between the placed marker and the camera using the ARToolKit. They can calculate appropriate matrices for each marker, and thus determine the individual region of the map. They demonstrate this through a series of matrix transformations. With both matrices calculated, the distance between the two can be calculated, and the position on the map derived.

Ran et al. investigated how to correctly render visualizations with the correct sense of relative depth with relation to the real-world objects in the scene [25]. They were able to obtain an improved sense of depth perception using their developed framework that experimented placing anatomy data (such as a MRI scan) within physical models of humans. Their developed framework, INFOCARVE, primarily uses OpenGL and GLSL Shaders [26]. As many AR devices only support OpenGL ES 2.0 and fail to support its optional 3D texture plugin, they overcame the lack of 3D texture support by unwrapping the 3D image into a 2D texture atlas. Then, their custom GLSL shader accesses the corresponding texels simulating a 3D texture lookup.

For tracking, they made use of product created by Metaio (a company since bought out by Apple whose products are no longer available) for their desktop version [27]. For the mobile platform support, they made use of Vuforia [28]. For capture, they made use of commercially available products such as the sensors on the Epson Moverio BT200 HMD. Then, using OpenCV image processing libraries, they created masks to separate the object of interest from the background [29]. Then, for composition, they combine the image mask with the visualization using their custom GLSL shader. This composition is done through a series of mostly stylized blending techniques that use gradually increasing opacity that is dependent on the geometry of the real-world object, ie. their rendered image becomes more opaque as it moves in from the edges of the real-world object.

### **2.4.3 Summary of AR Visualization Techniques**

Techniques used in Augmented Reality involve the process of combining real-world objects with virtual computer-generated images. This means the real-world objects



and the virtual ones need to be aligned. These images can be aligned to moveable real-world objects, such as the plates described above, allowing interaction with the visualization in natural ways. This natural interaction suggests that augmented reality may be a superior form of data visualization than virtual reality, as the user can focus their attention on the visualization rather than the devices in the middle (using their hands rather than thumb-sticks and buttons).

Of course, what to display is an important question and an active area of research. This may be more important in areas such as big data visualization, where the user could potentially become overwhelmed by the sheer scope of the data. The techniques used above that separate the visualization into separate pieces, each aligned to a marker, is an interesting approach to tackling this problem.

Augmented Reality is a growing field and there is much potential for useful applications outside of gaming and leisure. As these techniques become more studied and implementations become more common, the potential benefits can be explored more thoroughly.

## **2.5 Methods of Appraising and Validating AR Visualizations**

Visualizations provide a method for consumers of information to understand and interact with data. The quality of the graphical representation and the interaction are dependent upon the design and implementation of the visualization. Therefore, it is necessary to evaluate the efficiency and effectiveness of visualizations. How best to appraise visualizations is an area of active research interest. This chapter provides a survey of some techniques developed to evaluate visualizations.

Appraisals of visualization techniques can take many forms. What does it mean for one visualization to be “better” than another? Some researchers take the approach that the visualization that allows one to achieve a task in a shorter period of time with fewer mistakes is what makes it the best. Others apply subjective quality assessments to the visualization, allowing the users to decide which one they liked more. Some overcome the subjective nature of such qualitative appraisals by attacking the problem through controlled experimentation.

### 2.5.1 Survey of Appraisal Methods for Visualizations

Juarez, O. et al. considered appraisal methods that focus on the tasks being supported by the visualization [30]. They deemed it important to have evaluation methods that consider the time required to perform a task and the quality of the solution of the task. They developed software applications that provided different types of visualizations. The software was used by groups of students and their performance was measured. The time to complete each subtask was recorded and a simple metric (a score between 1 and 10) was given by experts to assess the quality of the solution.

Unfortunately, they did not provide concrete ways of assessing the quality of the solution of the task outside of subjective evaluations. As such, they aim to provide a task taxonomy and “definition of quality solution for each type of task”, developing models to analyse task performance, and consider other performance metrics such as data quality [30]. That said, based on their subjective analysis, they formed a few conclusions: users did better when interacting with graphical visualizations and users were more interested in summaries of data than the details.

They do provide some commentary on how best to develop experiments to appraise visualizations. They suggest that subtasks need to be simple enough to be solved in reasonable amounts of time, and the groups of participants should be kept small enough to avoid cost/resource overrun.

Larkin, Jill H., and Herbert A. Simon focus on what they called “external problem representations” [31]. They investigated methods of contrasting diagrammatic representations with sentential representations in information systems. Here, sentential representations form “a sequence corresponding, on a one-to-one basis, to sentences in a natural-language description of the problem.” Diagrammatic representations provide the same one-to-one mapping but via components of a diagram. Unlike sentential representations, diagrammatic representations have the benefit of preserving spatial information, such as “topology and geometric relations among the components of the problem”. That is to say, they compared how people can make inferences from the written word versus the same information displayed as a diagram.

Like Juarez, O. et al., they are faced with the innate subjective quality of categorizing a representation as being “better” than another. As such, they attempt to identify characteristics to apply rigidity to these qualifications. These qualities include

such things as an assessment on the informational and computational efficiency of the visualization. In doing this, they note, that the differences in the operator’s ability to make inferences of the visualization has an impact that needs to be considered, outside of just the differences in the visualizations themselves.

They surmise that the efficiency of a representation of data is dependent upon three main factors: the data structure in place, how it used by a program, and how attention is managed across aspects of the data structure. Here, a data structure can be viewed as the representation of the data, either diagrammatic or sentential. The program is the use of the representation, through searching, to obtain information, with attention management being the shift in focus across aspects of the representation. Ultimately, this leads to inferences being made from the representation. Through a series of methodical examples, they conclude that the human visual system can make inferences from diagrams more efficiently than from the written word. This is not surprising, but what is of interest is the attempt to formalize what it means to deem a visualization to be efficient.

Rhodes, P. et al. determined visualization quality to “mean those attributes that correlate with the ability of a visualization to convey a desired concept” [32]. They present a software package called VizEval that allowed them to design and evaluate visualizations, and experiment with the impacts of changing visualizations. They see the ultimate goal of a visualization as helping the user understand the intended message of the visualization, and as such looked at how visualizations impact user comprehension. They did experiments on how different visualization techniques impact a user’s ability to notice change and to indicate where the change occurred (detection and localization).

Through experimentation, they found that changes in visualization techniques could help detection and hinder localization, and vice versa. This indicates that some visualization techniques may be better suited to some tasks than others. As such, in addition to considering the user’s capabilities, it’s necessary to consider the specific purpose of the visualization.

Paudyal, Pradip et al. researched how different representations of Light Field (LF) images, such as with “digitally extended depth of field, 3D, parallax, and 360 degree display”, impact the viewer’s perception of the quality of the experience [33].

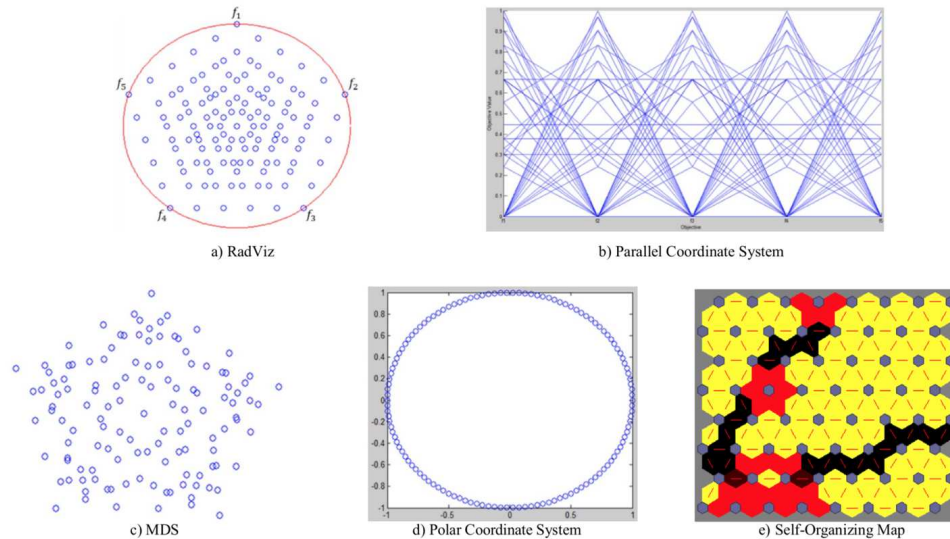


Figure 2.8: He, Zhenan, and Gary G. Yen. consider a diverse selection of visualizations against a complex list of criteria [35].

They conducted an experiment to obtain the subjective assessment of the use of different visualization techniques. Of note, they made use of the Absolute Category Rating (ACR) method as a quality assessment protocol, which they report as being an established protocol used for video assessment. This is just a five-level score (Bad, Poor, Fair, Good, Excellent) which is given by the user after viewing the visualization. They presented the user with 136 different LF images, gathered their assessments, removed outliers and performed a statistical analysis on the results.

Fittkau, Florian et al. suggest that empirical methods, such as controlled experiments, are required to assess the efficiency and effectiveness of visualizations [34]. After they conducted an experiment to assess the difference between two different visualizations, they conducted a second experiment to validate their results. By successfully arriving at the same outcome again using a different group of participants, they were able to increase confidence in their results.

They made use of a between-subjects design for their experiments, which means that each subject only encounters one representation. This presents the issue that there might have been a biased skill distribution across the two different groups which could influence the results. On the other hand, they used a blind review process to grade solutions to avoid bias towards one visualization over the other.

Yet another set of criteria is established by He, Zhenan, and Gary G. Yen [35]. They suggest that visualizations, which are normally either three dimensional or two dimensional should “exactly and effectively reflect the information from the higher dimensional space.” This may be problematic as visualizations may summarize data in a way that is more easily digestible to the user which would allow them to gain insights into the data without containing all information. He et al. show in Figure 2.8 that just as visualizations can be quite different, the methods in which they are compared can also take many different forms [35]. Additionally, they suggest that an important criterion is the ability of the visualization to support decision making specific to the current task. They construct a detailed list of objectives and then compare how each visualization supports each of the desired outcomes. Lastly, they suggest that the visualization should be scalable to any dimension. The researchers fail to describe why this is a necessary criterion and how it could possibly be realized.

### **2.5.2 Survey of Appraisal Methods for AR Visualizations**

Hasan et al. comprised a model to assess 3D video without having the original 2D video available for comparison. They created an appraisal model that combined dissimilarity measurements, perceptual differences and a quality assessment criteria. More specifically, they obtained disparity information between two stereo frames using a block based stereo matching algorithm. Also, they generated an edge based perceptual difference measure in order to assess the loss of edge magnitude (which would result in decreasing image property information capture such as depth and surface orientation). Finally, they generate a QA metric for 3D video through a combination of the two measures (ie. by combining the dissimilarity and perceptual difference measure) [36]. As a way of applying a index to a 3D image, this appraisal technique could potentially be applied to AR visualizations. Assessment of the visualization as a static image capture would allow comparison of different AR visualizations.

### **2.5.3 Summary of Appraising and Validating Visualizations**

There is no standardized way to evaluate a visualization as being superior to another. Many researchers apply different techniques to appraising the efficiency and effectiveness of visualizations, and yet feel confident in declaring one visualization better

than another. In all likelihood, a combination of qualitative and quantitative data collection is necessary when attempting to compare different representations of data. The issue is made complex due to the inherent differences between users, personal preferences, affinity towards different representations. Additionally, applying mathematical/statistical analysis on results is only as good as the data points collected.

## **2.6 Augmented Reality Visualizations for Coastal Water Navigation**

In this section, we survey the current research into visualization of coastal water navigation data using AR. We conduct a review of the domain issues identified by the current research, along with different ways in which AR is seen as a way to address these issues. This section looks at how different researchers have attempted to resolve the best way to visualize this data. We conclude with the researcher's observed benefits and issues with these visualization implementations.

Research into the use of augmented reality for coastal water navigation is limited. Regardless, there are still important lessons that can be obtained by an examination of the current work. Of note, a common thread across the research corpus is an appreciation of the cognitive overload experienced by persons conducting coastal water navigation. In addition, decreasing the time spent and complexity of the mental transformations from two-dimensional visualizations of geospatial data to the real-world is seen as having a positive effect on maritime safety. Also, decreasing the amount of time spent engaging with current visualizations, which require the navigator to divert their attention from the outside world, is directly correlated to increased maritime safety.

Depending on the amount of subject matter expert engagement, the visualizations across implementations varied significantly both in their presentation and in their usefulness. This review of the research suggests that the benefits of subject matter expert engagement have not yet been fully realized.

### **2.6.1 Identified Issues in Coastal Water Navigation Visualizations**

Xueling Wu et al (2008) examined organizing and describing geospatial data through the lens of cognitive psychology [37]. They examined the process of making mental transformations between the real-world view and the geographic representations.

They determined that these mental transformations directly impacted decision making ability.

Morgère et al (2014) indicated that the matching of items on a nautical chart to the real environment is error prone and has a large time cost [38]. They determine that this issue is made more challenging in cases of restricted visibility, at night and in bad weather, with operator stress being the greatest contributor to error. They identify that the unstable nature of a ship compounds this issue. Morgère et al determine that displaying all available information at once would overload the user, and there needs to be a determination of what information is best to display. Supporting these findings, Jaeyong et al (2016) indicate that one of the main issues with current navigation equipment is the excessive amount of information [39]. This is compounded by large amounts of unnecessary information which they determined interfere with safe navigation.

Another factor affecting safe navigation is the current way in which the information is visualized. Current visualizations require the navigator look down and away from the bridge windows. Vlaming et al (2013) indicated that when the officer is looking at instrument panels and charts, their attention is turned away from the view outside the bridge [40]. They refer to this as head-down time, the length of which has a direct impact on maritime safety and the officer's situational awareness.

### **2.6.2 Engaging Subject Matter Expertise**

Engaging subject matter experts can help identify what information is essential and what should be the focus of visualizations. When Wisernig et al (2015) developed an augmented reality system for captains of sailing vessels, they received continuous feedback from experienced sailors in order to determine what information was most relevant and important to be displayed. They tested their system at sea on their research vessel and made changes to their design based on the feedback received. The subject matter experts in their study indicated that they had a need for reducing the amount of data, making the data standardized, and combining it into one interface.

Vlaming et al used questionnaires and interviews with seafarers in an attempt to determine what information should be displayed [40]. In doing so, they determined that augmented reality can provide the information in a heads-up display thereby

decrease head-down time and improving safety. Their feedback suggested the priority of information was own ship information, navigation aids and fairways, followed by collision regulation information. Secondly, they were concerned with shallow water and information on other vessels.

Likewise, Jaeyong et al proposed using AR to provide more effective ways of representing navigation information [39]. As a first step in their process, they conducted user surveys of twenty experienced ship officers. The surveys indicated that most ship's officers envisioned the information being presented to them in ways with which they are familiar. For example, they would expect the graphics used to be consistent with chart symbology. In addition, being able to see the distance to a fairway was deemed important. This allows the navigator to know what water is safe to transit. Their subject matter experts ranked the priority of information in the following order: own ship information, other shipping, and then Electronic Chart Data.

### **2.6.3 Visualization Implementations**

Morgère et al (2014) developed a system they named Marine Mobile Augmented Reality System (MMARS) as a solution to the cognitive load issue. They choose to superimpose three dimensional models over real world objects in an attempt to improve contrast. In addition, they used large arrows pointing from the sky down to the point features. In recognizing the pose of the user wearing the device, Morgère et al made use of an InvenSense IMU which they described as being a combination of a 3D magnetometer, a 3D accelerometer and a 3D gyroscope MicroElectroMechanical (MEM) system. They determined that using a simple camera based approach to determine head position was not sufficient due to environmental conditions and light-contrast issues.

Vlaming et al assessed own vessel information as being the most important visualization. They determined the ground track of the vessel should be shown as a coloured line with the true direction shown in degrees. They suggested incorporating information from the RADAR to correct this track based on wind and speed, making the visualized track be the course made good. In addition, they suggested showing the speed the ship was travelling and the planned track (Figure 2.9). Warnings could



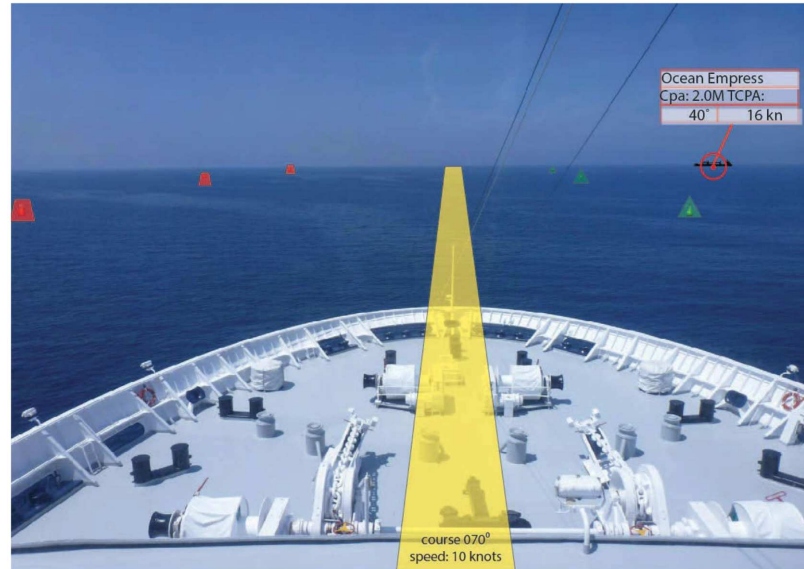


Figure 2.9: Vlaming et al. proposed implementation [40].

be given when the operator moved away from the planned track. The next visualization idea they received from user engagement was to render buoy and shipping lanes, followed by other shipping information when there was a risk of collision. Their research suggested incorporating shallow danger information from the ECDIS system and warning the operator when he was approaching water of insufficient depth, then display the hazard at that time.

Jaeyong et al. proposed an overhead data display for rendering own ship information (Figure 2.10). They chose to represent other ship information as overlays in the position of the other shipping. As for the ECDIS data, they filtered the data based on location and used the same symbology used on S57 electronic nautical charts (ENCs).

Butkiewicz (2017) rendered a compass ring surrounding the vessel at the waterline at a distance of 20 meters (Figure 2.11) [41]. On the compass ring, they added symbols for point features that were along that bearing. Taking the same approach as Jaeyong et al., the symbols were consistent with symbols used on S57 ENCs. Additional information, such as the name of the point feature, distance and bearing were only displayed when the observer looked towards it. Butkiewicz observed that operators had issues appropriately judging distance with the overlays. In an attempt to overcome this, they used a chevron pattern for the planned track instead of a straight line.

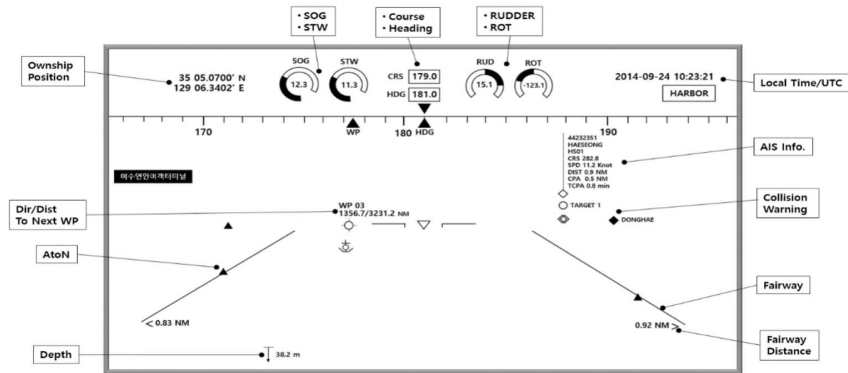


Figure 2.10: Jaeyong et al (2016) proposed visualization [39].

To support shiphandling, Butkiewicz added a visualization of surface currents in the form of multicolored vector lines. They found that the visualization became too cluttered the further removed from the ship; as such they lowered the number of currents displayed based on range to reduce clutter.

#### 2.6.4 Visualization Implementation Benefits and Issues

From experimenting with their system, Jaeyong et al found that the overlay of ship information was more effective than existing navigation systems [39]. However, sometimes the overlay interfered with recognition. In addition, they used the same size symbols for point features. This caused an issue with not being able to accurately judge distance. In addition, there were issues with the traffic information being impossible to distinguish as multiple ships along the same bearing had their information blended together. Additionally, the GPS had location errors that caused registration errors. Also, there was a harder time distinguishing data due to excessive amounts of information on the horizon.

Xueling Wu et al establish that registration is one of the key issues [37]. They conducted research in camera based approaches, making a series of matrix transformations from real world coordinates systems to virtual coordinates systems and finally to screen coordinates as an attempt to solve the problem. Jaeyong et al tackled the issue of registration by positioning the camera in virtual space based on latitude and longitude information from GPS and attitude (pitch and roll) information from an Attitude/Heading Reference System (AHRS) sensor.

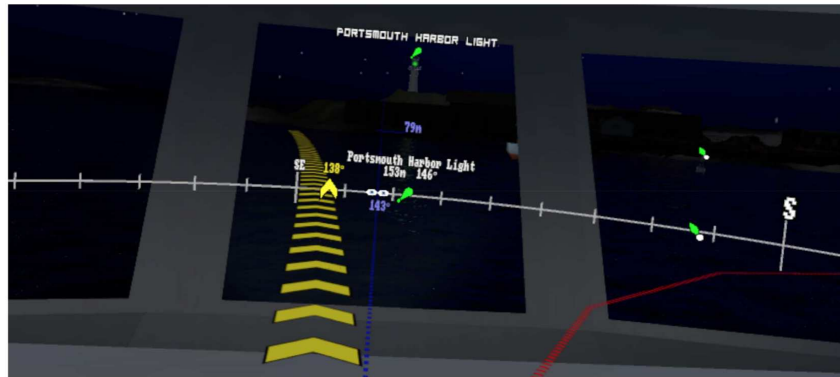


Figure 2.11: Butkiewicz (2017) Virtual Reality Simulation [41].

Butkiewicz noted that excessive light on the water caused by reflections made contrast of the overlays very important. In addition, white text was not visible against a cloudy sky or in fog. Therefore, they surrounded the white text with a black border. They addressed the registration issues by placing the world camera at the location of the ship bridge.

### 2.6.5 Summary of Coastal Water Navigation Visualizations

There have been a few attempts at visualizing navigation data for use in coastal water navigation. These visualizations have been varied, with some showing more promise than others. One major contributor to the differences in the visualizations is the degree to which subject matter experts have been engaged. For the same reasons, which inputs were deemed essential had a similar significant variation.

Some prototypes and implementations used much more significant methods of incorporating different input streams, while others focused more on the aesthetics of the visualization.

A common suggestion made in the consulted research is that additional study is warranted. Future work could focus on combining better data fusion techniques with appropriate filtering techniques to reduce clutter.

## 2.7 Visual Effects to Facilitate Depth Perception

This is a survey of the current research in the use of visual effects to facilitate depth perception in Virtual and Augmented Reality (VR/AR). Findings of the existing research are contradictory. Experiments have produced conflicting results into which visual cues have significance in depth perception. Although there is widespread consensus that users tend to underestimate distances in virtual environments (VE), there is evidence that this bias can switch based on distance to the AR object.

A number of experiments into how different visual effects influence depth perception in VE have been conducted. These experiments look at depth perception in both VR and AR. When dealing with AR, significant challenges are faced to create visual cohesion. Visual cohesion is achieved when the combination of virtual objects with real world objects are done in ways that make sense to the user and preserve a sense of immersion.

Proprioceptive information is sensory information derived from muscles, tendons and ligaments that allows a person to sense their body's location and its movement. There is conflicting findings related to whether visual cues have more of an impact than proprioceptive information. Determining which visual cues are most important to improving depth perception, how different visual cues interact with each other, and how to render these objects in real-time are areas of active research.

### 2.7.1 Survey of Using Visual Effects to Facilitate Depth Perception

Cidota et al. explored and compared depth perception and task performance for spatial placement tasks in Optical See Through (OST)-AR and VR Head Mounted Displays (HMD) interfaces that support Natural User Interaction (NUI) [42]. They created a sorting game where the user had to sort packages into boxes. They conducted a user study that compared three visual conditions: standard stereo vision, object fade and object blur to see which one facilitates the best performance for completing a depth perception based task. They investigated how presence and task engagement are impacted under different visual conditions. After using the system for approximately thirty (30) minutes, the users were given a twenty-five (25) question questionnaire. Their results showed that in AR, the best measured performance, the

best depth perception and the best perceived performance were achieved under the standard stereo condition. In VR, the fade and blur effects had a higher positive influence on the measured performance than the standard stereo condition. They noted that depth perception and perceived performance were contradictory. Additionally, visual effects influenced the user's level of presence negatively. It was questionable about how they came to their conclusions, as they had to exclude data in order to achieve statistical significant results.

Jones et al. noted that underestimation of depth decreases with experience in virtual environments regardless of explicit feedback [43, 44]. They conducted a series of experiments to attempt to determine what inexplicit feedback was helping to improve depth perception. They investigated whether the improvement was the result of proprioceptive information gained from repeatedly walking a prescribed distance, or whether the improvement was a result of peripheral visual information. Their results showed that proprioceptive information had little to no impact, while peripheral visual information was strongly correlated to improvements in depth perception. This indicates that improvements in depth perception are not solely the result of training in the VE, but can be made through changes in the visual input. In follow on work, they also determined that motion parallax had no impact on depth perception within their VR and AR experiments, but did have an impact when wearing the headset and walking in real world environment. As such, Jones et al. suggest it is possible that the mass of the headset has an impact on depth perception.

Swan et al. focused on how to correctly display and convey depth in OST-AR devices. They noted that one obstacle with these devices results from having a fixed accommodative focal depth and restrictive field of view [45]. Also, as the user can see collocated real objects, the virtual objects have to appear at the same depth. Another issue is the conflicting depth cues caused by the x-ray vision effect of AR objects occluding items that are nearer. They conducted some of the first experiments that measured AR depth judgments at medium and far distances. Their experiments provided evidence for a switch from underestimating to overestimating distance at 23 meters. Their experiments also provided evidence that the egocentric depth of AR objects is underestimated at distances of 3 to 7 meters but to a lesser degree than virtual reality environments. They found that a restricted field-of-view along with

preventing the user from scanning the ground plane from near to far caused depth underestimation.

Kan and Kaufmann addressed the issue of combining virtual and real objects together to create “visual cohesion” [46]. They showed that making use of more advanced rendering techniques, such as ray tracing, can help with depth perception. Their choice of visual effects included light reflection, refraction, anti-aliasing, depth of field (DoF) and caustics. They found that all effects increased the sense of realism, with anti-aliasing having the largest impact and caustics having the lowest. Their results from a user study indicate that one of the reasons users tend to have depth perception issues in VR and AR are largely due to the use of simple graphics and shaders.

Hebborn et al. addressed the issue of creating realistic real-time occlusion of virtual objects in AR [47]. They created an algorithm that determined a blending coefficient between each pixel by using raw depth data from sensors. First, they render the 3D scene. Then, they generate a trimap of foreground, background and unknown pixels and augment it with a fourth colour (red) for invalid pixels. They generate the augmented trimap using depth information from sensors and the rendered scene. They propagate known foreground and background regions into the unknown sections of the image. Then they generate their blending coefficients and combine the real and virtual scene together. By focusing on the unknown regions, they are able to control the search space and achieve a real-time capability.

Diaz et al. explored techniques to design virtual objects to improve depth perception. They determined a list of factors to consider and how design decisions could account for them. They chose to look at atmospheric effects, shadows, shading models, billboarding, dimensionality, and textures. Their experiments found that users tend to underestimate distances in virtual environments and that casting shadows had the largest impact on improving depth perception. They also found that combinations of these design decisions were really important as they interacted in complex ways. This suggest that using techniques to address all of the listed design decisions may not be better than choosing a subset. The participants in their user study demonstrated a preference for drop shadows and found spatial alignment tasks much harder without them. Diaz et al. deemed the complex interactions between different

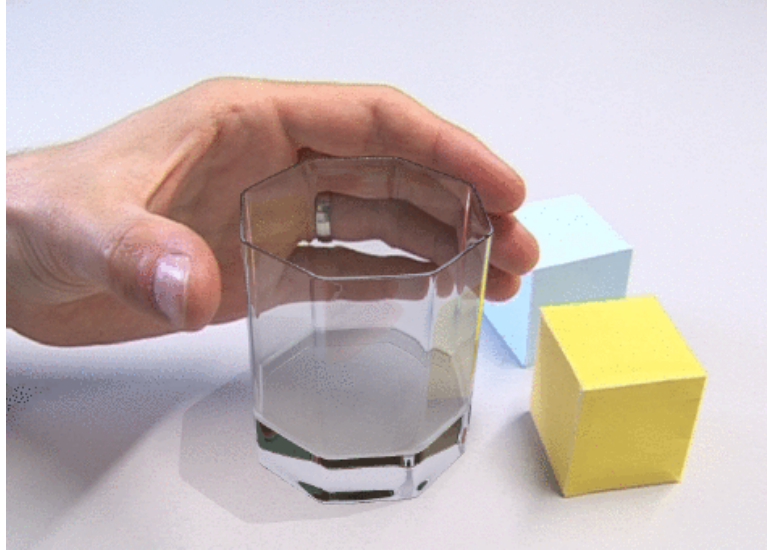


Figure 2.12: Refractive virtual glass surrounded by the real environment. Note the correct refraction of the hand in the glass obtained by the reprojection method (Kan, and Kaufmann).

virtual cues as an area for more study. They state:

We hypothesize that the primacy of cast shadows indicates the importance of virtual objects acting on the physical world for precise positioning. Purely virtual cues (texture and billboarding) and physical-to-virtual cues (aerial perspective and shading model) primarily helped when used in conjunction with virtual-to-physical interactions (drop and cast shadows) [48].

Thomas et al. determined that textures enhanced depth cues of large homogeneous objects [49]. They noted that rotation of large homogeneous objects with clear edges can completely destroy any sense of that object's depth. They were able to counteract this effect by texturing the objects. They noted that orientation of the texture and its coarseness had impacts on depth perception, and found that texture information won out over edge information when the two were in conflict.

Schmidt et al. looked to perceptual psychology to take advantage of illusion techniques [50]. They made use of four illusions: colour temperature, luminance contrast, blue and binocular disparity. They determined that depth perception could be adjusted using these illusions. For short distances, they found that binocular

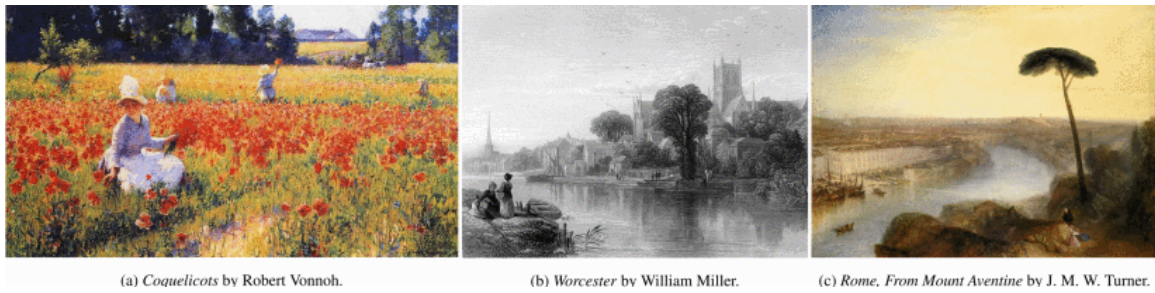


Figure 2.13: Artwork featuring (a) color temperature, (b) luminance contrast and (c) blur as depth cues [50]

disparity had the largest impact. They also found that for objects at large distances, the blur effect had significant impact. This suggests that the applied visual cue should be different based on distance of the object from the user.

Binocular disparity was explored in depth by Zhu et al [51]. They used a different approach to create a 3D effect, and thus an illusion of depth, other than the conventional technique. Rather than using two cameras (one for each eye), they computed a model-view-projection (MVP) matrix for each eye. Then, they multiply the computed matrices against the vertices of their 3D objects and compute the new vertex positions in the left and right eye coordinate systems. Stitching these two images back together allowed them to create naked eye 3D images and 3D in VE.

The more standard technique of using two cameras to create binocular disparity was investigated by Moreau [52]. His findings indicate that, when recombining the two camera images, the combined image should be isomorphic to the real world. In order to achieve this, he suggests three conditions need to be maintained: (1) the distance between the two cameras should be the same as the distance between the eyes; (2) the angle of FOV should remain the same at the acquisition level as it is at the display level to avoid stretching or flattening the depth dimension; (3) the distance between the cameras and the main observed object should be the same as the distance between the image of the object and the observer.

### 2.7.2 Summary of Survey on Depth Perception

Depth perception in VE is an active area of research that combines visual perception research, psychology, design and graphics research. As systems become more capable of performing real-time processing, the combination of virtual and real objects will



become much more cohesive. When systems are able to combine the realistic rendering demonstrated by Kan and Kaufmann with the occlusion techniques demonstrated by Hebborn et al. in real-time applications, depth perception is likely to improve. However, other factors are clearly at play beyond just graphical visual cues.

Depth perception in VE is impacted by a combination of design techniques, graphics, proprioceptive information, cognition factors, experience and training. As such, it is not surprising that research that narrowly focuses on a small subset of these factors without controlling for other influences would produce conflicting results. As more is learned about the impact of each of these depth cues, better experimental controls can be established.

## **2.8 Summary of Related Research**

In this chapter, we reviewed related research. We see that current AR Devices may not be suitable for Pilotage, but device hardware is improving. As such, it is conceivable that hardware devices may be suitable in the near future. This presents an interesting challenge. We do not exactly know what hardware specifications are required to be effective and safe for use in Pilotage. Also, we would like to continue research into the effectiveness of AR in the use of Pilotage, including the design and evaluation of AR Visualizations. We looked at how Virtual Reality (VR) can be used to simulate AR hardware specifications and create AR Visualizations. This allows us to experiment with AR Visualizations without the expense and danger of testing in situ and without the required hardware components.

## Chapter 3

### Existing Navigation Aids and Tools

In order to establish domain knowledge and to determine the types of visualizations which would be beneficial in improving navigation, we take a look at the existing tools and aids to navigation developed for this purpose. We consider how real world objects are visualized on paper and electronic displays in the form of chart symbols. As electronic charts are used for safe navigation, they are one of the primary sources of data that we can leverage. As such, we briefly discuss how this data is encoded and determine that we can extract the information required. We see how these charts are read in and displayed in interactive ways through the use of the Electronic Chart Display and Information System (ECDIS). After which, we consider other sources of information used by the NavO when conducting Pilotage, such as floating and fixed aids to navigation. We also take a brief look at radio aids to navigation which includes the Global Positioning System (GPS). Finally, we consider the other main tool at the NavO's disposal which is the Radar with its Automatic Radar Plotting Aid (ARPA).

#### 3.1 Charts

A nautical chart is a crucial element of navigation. It is used in the planning and execution of navigation passages. In the planning stage, it allows the NavO to identify courses and planned course alterations. These courses are plotted with consideration of hazards to navigation, ship's turning characteristics, depths of water in relation to the ship's draught and safety margins, and navigation aids. In the execution phase, the chart is used to fix the position of the ship in relation to the plan track, and determine appropriate courses to steer in order to regain the planned track. In fixing and plotting the ship's position, the NavO is able to obtain the impact of ocean current and wind. The course through the water is a combination of ship's heading, speed rung on and environmental factors. This course is known as the Course Made Good (CMG). Once the NavO is able to determine the CMG, by correcting for this

impact, the NavO is able to determine the Course To Steer (CTS) to maintain the desired course.

Charts provide a two-dimensional representation of a geographic region. Charts depict the accurate location of objects of interest to a NavO, such as location and topology of land and shallows, depths of water, bottom type, and location of aids to navigation. These details are depicted in a regulated and consistent fashion through the use of chart symbols.

### **3.1.1 Chart Symbols**

Charts are produced by different nation hydrographic's services. Each producer of charts has an associated legend for the symbols, abbreviations and terms used in the charts. In Canada, the Canadian Hydrographic Service (CHS) produces a publication called Chart No.1 [53]. Other nations have similar products [54, 55]. The differences in chart symbology between most nations of the world is minimal. That is due to conforming to a set of guiding principles and specifications produced by the International Hydrographic Organization (IHO) [56]. As this standard is currently adopted by 89 countries, the symbology used is "consistent and recognisable by all seafarers and for other users." [57]. As this symbology is so widely used and accepted, it would stand to reason that any visualizations we create should consider the existing standard.

### **3.1.2 Electronic Navigational Chart**

Although paper charts are still in use, they are primarily kept only as a backup in case of equipment failure. They need to be manually updated, and plotting position is much more timeconsuming than using a system that can interact with ENC's. ENC's allow interaction with sensors, such as the Global Positioning System (GPS) during navigation, to constantly update the location of the ship on the chart. These charts must conform to international standards in order to be deemed safe for navigation and be used within these systems, known as Electronic Chart Display and Information System (ECDIS).

Charts can be encoded in different ways, such as the S-57 Vector format used by CHS [58]. This format is the accepted format in use by the Royal Canadian

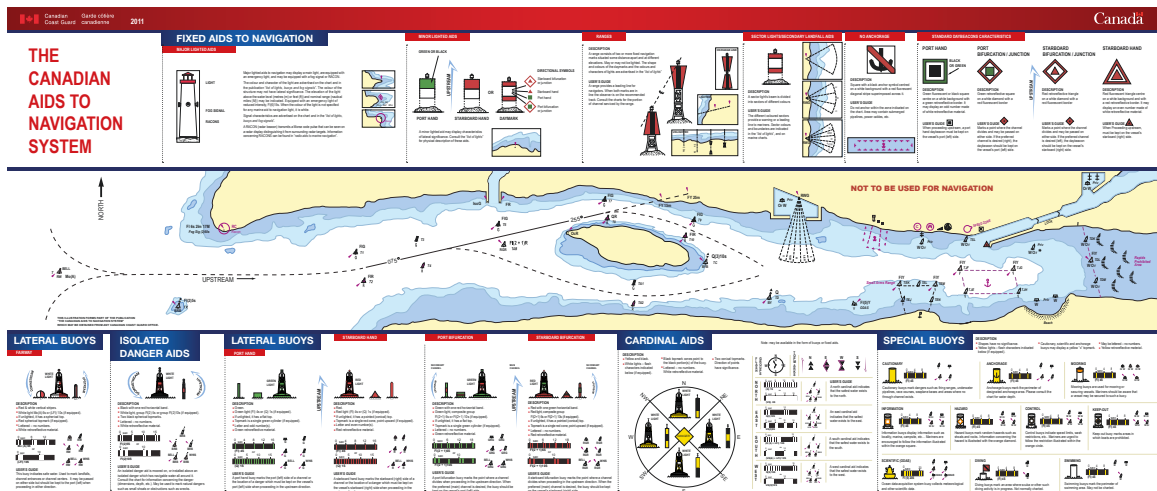


Figure 3.1: The Canadian Aids to Navigation System [61].

Navy (RCN). It is a data structure that contains many layers of information. These layers can be decoded and analyzed using the Geospatial Data Abstraction Library (GDAL) [59]. By representing the chart in this manner, computer systems can be used to visualize the data in interactive ways.

### 3.2 Electronic Chart Display and Information System

ECDIS systems provide nautical chart data in an interactive way. One version, known as the SHIP's INtegrated Navigation and Display System (SHINNADS) is used by the RCN. This system allows the NavO to augment the current nautical chart in many ways. A full list of these augmentations can be found on page 8 of [60]. These chart augmentations, such as Limiting Danger Lines (LDLs) and Clearing Bearings are carry overs from paper chart navigation. As such, they are very familiar to the NavO and remain critical in the conduct of navigation. As such, these augmentations will be considered when determining and designing ARNAs.

### 3.3 Aids to Navigation

As seen in Figure 3.1, there are various types of different types of aids to navigation. In this section, we offer a cursory look at the different types. This includes looking at floating aids, fixed aids, and radio aids.

### 3.3.1 Floating Aids

Different types of buoys convey meaning to the NavO through a combination of distinguishing features. In addition to determining the identity of a buoy by verifying its position with a navigation chart, there are visual cues that can help determine the buoy's identity. At day, the type of buoy can be determined by its colour, labelling and its topmark. At night, for lit buoys, the identification of the buoy type can be determined by its light, through a combination of colour and flashing characteristics.

As an example, let us consider the difference between a port and a starboard hand lateral buoy, as seen in Figure 3.1. These buoys are some of the most widely used buoys in navigation as they clearly mark safe water and indicate the channel for the NavO. In the IALA B region, which is the region which Canada falls within, a common mnemonic used by the NavO is “Red Right Returning”, meaning that the red buoy is kept to the right of the ship when proceeding in the upstream direction.

At night, this colour scheme is crucial as the buoys structure colour and topmark are not visible. Normally, all that can be seen at night is a flashing light, once every 4 seconds (alternatively, the buoy could flash once every second). If all else fails, a NavO can be well served to point the ship between the red and green lights. Likewise, seeing a flashing light rapidly changing bearing on the wrong side of the bow will mostly likely spell disaster.

However, in some cases, light colour conveys little meaning. If we look at cardinal buoys, for example, we can not determine the cardinality of the buoy simply by the colour of its light (all are white). Cardinal buoys indicate the cardinal direction of the safest water. For example, an east cardinal buoy means that the safest water is to the east of the buoy. Here, the cardinality is determined based on the flashing characteristics. Navigators remember the flashing characteristics by picturing a compass overlaid upon a clock face - where North is 12 o'clock, east is 3 o'clock, south is 6 o'clock and west is 9 o'clock. Looking at Figure 3.1, we see that the comparison of flashing pattern to time is an easy one to make. For example, east has 3 very quick flashes, south has 6, and west has 9.

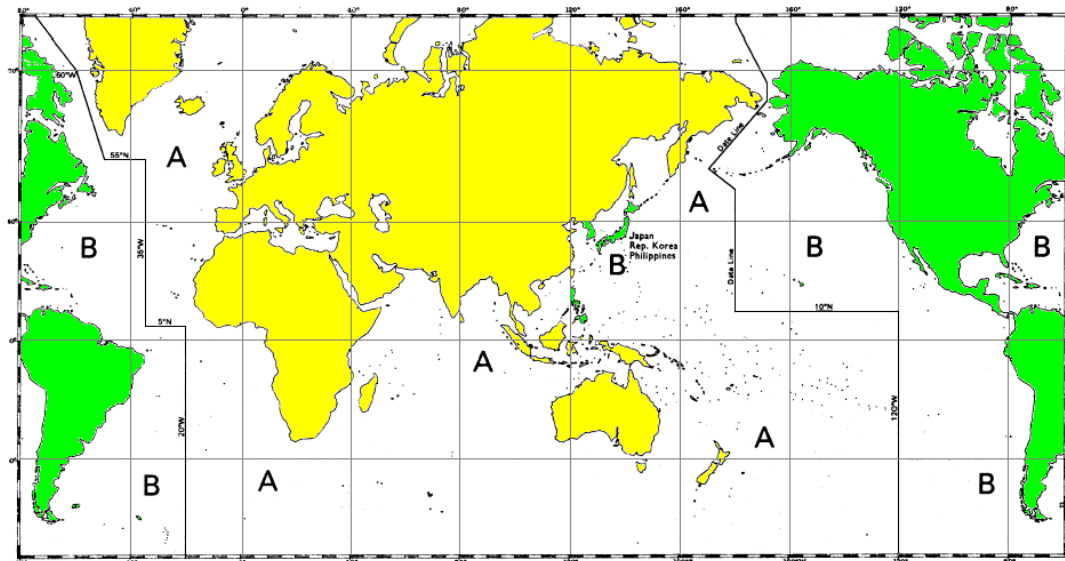


Figure 3.2: The IALA World Distribution [62].

### 3.3.2 Fixed Aids

Similar to floating aids, fixed aids use a combination of colour and shapes to help in their identification. Unlike floating aids, fixed aids can take advantage of their known position. Although floating aids are fixed to the ocean floor, ocean currents and sea swell can affect their exact location by several metres. For example, slack in the anchor chain can allow a buoy to lie in the direction of the wind away from its charted position. In contrast, as fixed aids location are known, they can be used in ways that are not feasible for floating aids.

Additionally, fixed aids can be used in combination with other fixed aids. For example, ranges can help the observer know how they are in relation to the planned navigation track (Figure 3.3). The NavO can immediately determine through observation if they are on track and, if they are not, which side of the track they are on. The range operates by placing two marks along the same bearing with one a large enough distance behind the other and at a higher elevation. If both lights are in transit (one directly above the other) than the ship is on the recommended track for the channel. Alternatively, if the lower light is to the right, the NavO can determine that the Ship is Port of track and vice versa. This is so easily apparent that maintaining of this track is often delegated to the Officer of the Watch (OOW) who is told to “drive the transit”. The OOW can easily steer the ship to port and starboard to maintain

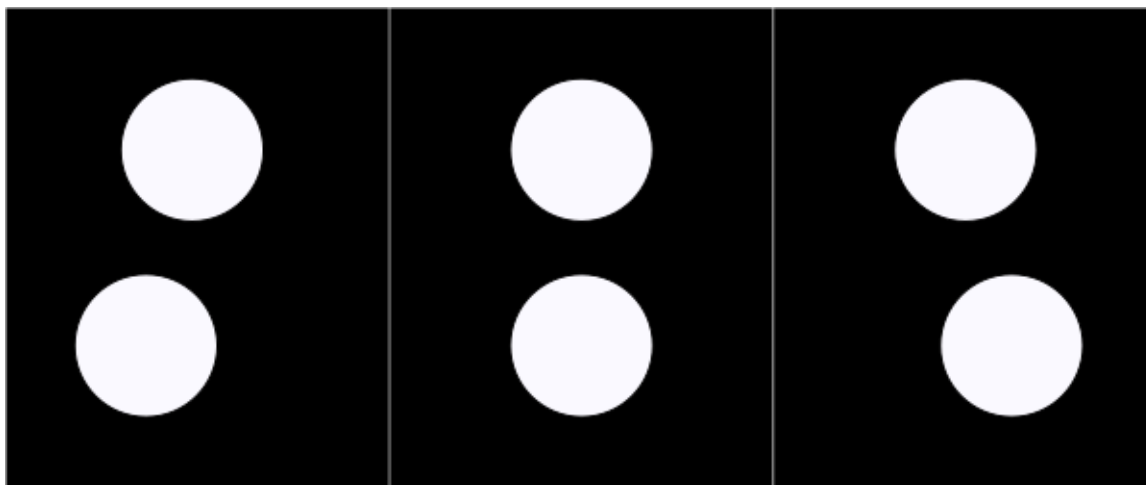


Figure 3.3: Left: Range Lights showing a ship Starboard of the recommended track. Middle: Range Lights showing a ship on the recommended track. Right: Range Lights showing a ship Port of the recommended track.

the ship along the recommended channel, freeing the NavO to focus on other tasks.

Another interesting use case for a fixed navigation aid is a sector light. Once again we see the use of colour to assist the NavO in determining information about the Ship's location. A sector light defines what colour is visible within certain bearing sectors of the light. Without taking a bearing, a Navo can determine how the ship lies in the channel by the colour of a sector light. If the sector light is showing a white light, then the NavO knows that the Ship is in the center of the channel. However, if the light is showing red, than the ship is on the Port side of the channel. Likewise, if the light is showing green, the ship is on the starboard side. There is overlap between the sectors, normally of 2 degrees. If the ship starts to veer into unsafe water, a sector light will immediately provide that information to the NavO or OOW, who can take immediate action to resume safe water.

### 3.3.3 Radio Aids

One example of a Radio Aid to Navigation are Radar Beacons (RACONS). They can be attached to fixed and floating aids. These emitters provide a signal that can be interpreted by a radar display and drawn when the ship is at a specified range from the beacon. The line originates from the estimated position of the beacon and is drawn in a line towards the ship. The line can take a pattern of short and longer

lines, like the dots and dashes of Morse code, or it can be a solid line [63].

### **3.4 Radar**

Radar is an essential tool in the conduct of navigation and collision avoidance. Even without electronic navigation charts and GPS, it is possible to conduct safe navigation in restricted visibility with the use of radar. This section explores some of the methods in which radar is used in the determination of ship's position, lateral displacement from track and distance to course alteration.

#### **3.4.1 Use of Radar in Navigation**

A radar can be used to fix the ship's position. A radar fix uses the cross-section of range arcs from identified points of land. In order to plot the radar fix accurately, the points of land should be approximately 60 degrees apart and apply an estimate of the radar range error. The range error can be calculated on a paper or electronic chart through trial and error, by either adding or subtracting a set distance from each range and inspecting the change in the intersection of the radar range arcs. With electronic charts though, this is often done more easily by correlating the difference in a range from the known GPS location with fixed points of land compared to the same point on the radar display.

One method of using a radar for navigation is to use Parallel Index (PI) lines. PIs are normally preplanned and can be loaded on a track by track basis by an operator using Radar systems with internal or external memory, such as the Kelvin Hughes radar in use on Halifax Class Frigates.

#### **3.4.2 Automatic Radar Plotting Aid**

Coastal water navigation occurs within a dynamic environment. A radar with a Automatic Radar Plotting Aid (ARPA) is essential in making sense of the changing elements in that environment. Each radar sweep can add help to make sense of the world around the ship. ARPA can be used to distinguish fixed points from moving objects. When doing so, ARPA can make a determination of a moving object's course and speed. A comparison of the objects course and speed with own-ship's course and



speed allows the calculation of the closest point of approach (CPA) and the time to CPA (TCPA). The CPA is presented normally as a range and bearing from own-ship. Comparing the current position of the other ship to the CPA can help in making the determination of what rule of collision avoidance is currently applicable as well as in the determination of appropriate action to avoid collision.

### **3.5 Summary of the Existing Navigation Aids and Tools**

We have seen that colour is an important component in determining the meaning behind navigation aids. For example, lateral buoys clearly mark a channel and inform the NavO which side to leave the buoy based on whether it is red or green. Also, the colour of the light seen can tell the NavO crucial information regarding proximity to dangers.

We have also determined that NavOs have experience with a standardized set of symbols representing objects of interest. These symbols are consistent across paper and digital mediums. As such, when designing ARNAs that represent these items it may help recognition if these symbols are incorporated.

## Chapter 4

### IMO e-Navigation Strategy (IMO 2008)

#### 4.1 Introduction

In designing our AR navigation system, it is prudent to consider the IMO e-Navigation strategy [64]. IMO is working to produce guidelines and standards on how e-Navigation devices should be developed in order to ensure a harmonization of marine navigation systems. Although this strategy is still in draft form, the use of AR devices at sea for marine navigation will need to conform to the IMO e-navigation device guidelines once developed.

This chapter will look at the IMO e-Navigation strategy implementation plan in order to best align our design with the strategy's high-level requirements.

#### 4.2 How ARNAs align with IMO e-Navigation strategy

The IMO e-Navigation strategy analysis on the need for electronic aids to navigation are in line with the motivations of this thesis. The IMO's research shows there are an increasing number of marine collisions and groundings and that 60% were caused by direct human error.

The IMO e-Navigation strategy suggested solution to reduce this risk involves secondary review of decision-making processes and improved on-board systems. Although the approach taken by IMO to provide the secondary review is to send that review to a shore facility, similar benefit could be obtained by a Commanding Officer having a ARNA enabled display. That said, improving onboard navigation decision making systems is one of the main motivators of this research.

As for on-board navigation systems, the IMO e-Navigation strategy outlines the following vision: navigation systems that benefit from the integration of own ship sensors, supporting information, a standard user interface, and a comprehensive system for managing guard zones and alerts. Core elements of such a system will include,

actively engaging the mariner in the process of navigation to carry out his/her duties in a more efficient manner, while preventing distraction and overburdening [65]

### **4.3 Basic Requirements**

The IMO e-Navigation strategy outlines a series of basic requirements for the implementation and operation of e-Navigation [64]. These requirements are outlined here along with a summary of how the development of the ARNA system can fulfil the requirement.

#### **4.3.1 Requirement: User Needs**

According to the IMO e-Navigation Strategy Implementation Plan, the “implementation of e-Navigation should be based on user needs not technology-driven and over-reliance should not be placed on technology to avoid, for example:

1. system failures causing delays because the ship is now deemed unseaworthy;
2. loss of basic good seamanship by crews;
3. inappropriate substitution of the human element by technology; and
4. degradation of bridge resource management and best practices by the crew.

” [65].

In Table 4.1, we consider how the development of ARNAs relates to these considerations. In short, the ARNA system aims to augment the current navigation and decision making systems rather than replace them. Also, it aims to assist humans by presenting information consistent with current navigation practices.

#### **4.3.2 Requirement: Operating Procedures**

The IMO e-Navigation strategy presents the following requirement: “operating procedures should be put in place and kept under review, most notably in relation to the human/machine interface, the training and development of mariners and the roles, responsibilities and accountabilities of ship- and shore-based users”.

<b>Impacts to Consider</b>	<b>How do ARNAs mitigate the impact?</b>
<b>System failures causing delays because the ship is now deemed unseaworthy</b>	The ARNA system augments navigation decision making and current navigation systems. Failure of the system will not result in the ship being deemed unseaworthy, as current practice and navigation systems are still in use.
<b>Loss of basic good seamanship by crews</b>	The design of ARNAs must be made in accordance with current best-practice for the conduct of navigation at sea. That is, rather than replacing current methods, the ARNAs will visualize the method. This will ensure that the navigator continues to implement these practices.
<b>Inappropriate substitution of the human element by technology</b>	The ARNA system is focused on providing visualization to assist the human decision-making process and does not aim to replace the navigator.
<b>Degradation of bridge resource management and best practices by the crew</b>	The development of ARNAs is aimed to facilitate bridge-resource management by allowing the NavO to spend less time extracting information from data. By presenting the information in a heads-up display, the NavO will be better able to make decisions and focus his attention on managing the bridge and the team.

Table 4.1: How do ARNAs mitigate the potential impacts of technology on Navigation. The impacts of technology on Navigation was obtained from the IMO e-Navigation Strategy Implementation Plan. [65]

The development of an ARNA system will have training impacts. In initial cadre training, the NavO will require training with and without the ARNA system.

Any changes to existing bridge resource management procedures should be considered carefully. For example, there may be impacts on navigation reports being delivered from the NavO to the CO. Much of the current navigation block report is “painting the picture” for the CO so that he understands the information being presented. If the CO also has an ARNA enabled display, a visualization already may make this information clear. As such, there might be a tendency to limit or modify these reports as it would result in reduced noise on the bridge and less distraction. If so, there would be risk of skill degradation if navigation block reports were no longer being used. This would have a negative impact on bridge resource management if the ARNA system malfunctioned and prior navigational practices resume. Therefore, operating procedures may want to ensure that current navigation reporting processes are maintained with the ARNA devices simply augmenting the decision making process.

#### **4.3.3 Requirement: The Mariner should continue to play the core role in decision making**

The IMO e-Navigation strategy presents the following requirement: “the mariner should continue to play the core role in decision making even as the supporting role of the shore-based users increases.”

The ARNA system is solely focused on providing an onboard system. Even if shore-based information is provided to the ARNA system the data would be presented to the user to assist in their decision making process.

#### **4.3.4 Requirement: Human Factors and Ergonomics**

The IMO e-Navigation strategy presents the following requirement: “human factors and ergonomics should be core to the system design to ensure optimum integration including the Human Machine Interface (HMI), presentation and scope of information avoiding overload, assurance of integrity and adequate training”.

Our research considers how best to visualize information and present it to the operator in a way to ensure an optimum HMI and information presentation. The purpose of ARNA is to reduce operator overload. As such, verification of this requirement is

assessed via user study and results analysis.

#### **4.3.5 Requirement: Adequate Resources**

The IMO e-Navigation strategy presents the following requirement: “adequate resources should be made available and assured both for e-navigation itself and the necessary enablers such as training and radio-spectrum”

The number of resources should be determined through a risk analysis conducted for each end user. That said, a few basic assumptions can be made to provide resource recommendations. For every ship, there should be a minimum of 1 x headsets available for each operator. Discussion with end users in the development of the CONOP will indicate the number of end users. But, for RCN it is anticipated that as a minimum the CO and the NavO would require headsets. In addition, there should be spare units available in case of device failure. Due to the expected low cost of the device, having a spare device for every user would not be prohibitive. As such, for every RCN ship, a minimum of 4 headsets would be expected. This would result in approximately 120 headsets for the fleet.

Training facilities, such as Naval Officer Training Centre (NOTC) VENTURE would require devices for the training of ship’s officers for each of the centre’s Navigations and Bridge Simulator (NABS). For training facilities, every bridge simulator should have multiple headsets for use by students as well as instructors. As such, there may be 4 headsets in use at a time per bridge. It is estimated that there are 10 NAB trainers at NOTC resulting in approximately 40 headsets. 10 spare headsets should be more than adequate in ensuring training can continue if there was a device failure. As such, NOTC VENTURE would require approximately 50 headsets.

The naval school in Halifax conducts team training as well, and it was anticipated that approximately another 10 devices would be required. Therefore, it is expected that the Royal Canadian Navy would require an initial procurement of no more than 200 headsets (allowing for some contingency).

Additionally, considering the facilities mentioned above, approximately 80 computer systems will be required to integrate with the headsets and have appropriate spares.

### **4.3.6 Requirement: Measured Implementation**

The IMO e-Navigation strategy presents the following requirement: “implementation should be measured and not over-hasty”.

An introduction of a system like the ARNA system proposed here will need to be phased in over many years. It is expected that it would be like the approach taken by the Navy to integrate the ECPINs system. The phased systematic role out will require individual training, team training, harbour and sea trials, and safety and security analysis. Additionally, each ship’s crew would need to be periodically evaluated for competency using the system via the Navy’s Sea Training work up schedule.

### **4.3.7 Requirement: Costs**

The IMO e-Navigation strategy presents the following requirement: “costs should not be excessive”. Considering that the MicroSoft HoloLens is available at approx of \$3500 per headset, it is estimated that the manufacturing of the headset would not exceed \$5000 [66]. Each computer system would require appropriate graphics cards and memory similar to a AR/VR enabled gaming computer. It is expected that this could be produced at no more than \$10,000 for a commercial grade computing system.

In order for commercial-grade computing systems to be used onboard a RCN ship, they need to be mounted inside cabinets that meet defence specifications. Pre-existing cabinets are already installed on ship that could be used. These cabinets will allow commercial grade equipment inside of the cabinet to be connected via MIL-SPEC connectors to the cabinet’s I/O panel. External cabling to the cabinets requires MIL-SPEC connectors and cabling. The costs of these connectors would need to be considered when factoring in production costs. Moreover, the time spent by engineers to update shipboard drawings, develop engineering change guidance packages, and to create cable run sheets and pinnouts would need to be factored into installation contracts. It is estimated that an additional \$2000 per ship would address cabling and connector hardware costs. Engineering design costs is highly variable and negotiable, but it is expected the work could be completed in approx 400 hours. Therefore, assuming an hourly rate of \$150 per hour, then this could be achieved for approx \$60,000.

<b>Item</b>	<b>Number of Units</b>	<b>Cost per Unit</b>	<b>Cost</b>
ARNA Headset	200	\$5000	\$1,000,000
ARNA Computer	80	\$10,000	\$800,000
MIL-SPEC Cabling and Connectors	80	\$2,000	\$160,000
Engineering Guidance Package Production			\$60,000
<b>Total Estimated Hardware Production Cost</b>			<b>\$2,020,000</b>

Table 4.2: Estimated Hardware Production Cost.

<b>Item</b>	<b>Cost</b>
Design	\$400,000
Code and Debug	\$600,000
Test/Verification	\$400,000
<b>Total Software Cost</b>	<b>\$1,400,000</b>

Table 4.3: Total Software Development Cost.

Therefore, the cost to produce the hardware required for the Navy would be approximately \$2 million as outlined in the following in Table 4.2.

A rough order of magnitude (ROM) of software development costs is shown in Table 4.3.

As such, the total estimated cost to produce the hardware and software for the ARNA system is \$3.4 million. This would place it as a small-scale procurement and cost effective with ample room for profit to a company wishing to produce the product at scale, with follow on in-service support contract options and upgrades. For example, the contract awarded to provide ECDIS displays to the CCG was \$7.2 million [67], and the cost to carry out the Underwater Warfare Suite Upgrade for the Navy was \$103 million [68].

#### 4.4 Summary of Consideration of the IMO e-Navigation Strategy

This chapter demonstrates that the approach taken in developing our ARNA system is in line with the high-level requirements of the IMO e-Navigation strategy. In addition, we identified that cognitive load on the user should be an item assessed during user studies. Also, we presented a ROM to compare against other awarded government contracts in order to illustrate the cost effectiveness and business case validity of our proposed ARNA system.



## Chapter 5

### S57 and AR Device Simulation Prototyping

#### 5.1 Introduction

In this chapter, we present two prototypes that were developed to test the feasibility of the thesis's hypothesis and to help inform the thesis's project design. First, a S57 visualization prototype that was created that explores how S57 information can be used to produce ARNAs. Secondly, a AR device simulation was developed to show a VR application can make use of a AR device simulation to allow for the creation and testing of AR visualizations without access to the necessary hardware.

#### 5.2 S57 visualization

This section details the creation of a prototype ship simulator which allowed visualizing of ENC data. The prototype decoded and rendered ENC charts and provided a platform for designing and experimenting with ARNAs. The prototype demonstrates that ARNAs can be created dynamically from ENCs. Additionally, it demonstrates that a virtual world can be generated dynamically using ENC data combined with a priori height map information.

##### 5.2.1 Motivation to Create the Prototype

One major source of input the NavO must process is a 2D visualization of ENC data. Prior to conducting a navigation passage, the navigator spends hours working with this visualization in order to plan the navigation passage. They determine their planned courses and wheel-over bearings (measured bearings of prominent landmarks to determine when to alter course). They also measure bearings to allow estimations of lateral distance to dangers (clearing bearings). They measure opening bearings, which are the bearing at which points of interest (such as landmarks and buoys) obscured by land become visible. They also preplan ways of calculating the bearing

error of the polaris, known as gyro error, by measuring the bearing line across the planned track when prominent landmarks are in transit.

The NavO records data obtained by working with the ENC data visualization into a notebook. When conducting the navigation passage, the NavO refers to the information in their notebook. The NavO also spends time interacting with the ENC visualization on the Electronic Chart Information and Display System (ECDIS). This is similar to engaging with the data beforehand, but it now has the benefit of having sensor input and real-time updates of position. While engaging with this system, they are diverting their attention away from the dynamically changing world around them. This head-down time is considered a necessary risk in order to obtain spatial awareness. The navigator trains to limit this head-down time in order to mitigate the danger.

OST devices provide an AR overlay of information to the user in their line of sight. It is hypothesized that these devices could reduce the NavO's head-down time and reduce their cognitive overload [69]. For example, consider the use case of determining proximity to unseen shallow water dangers. Currently, the navigator needs to consult their notebook for a clearing bearing and then negotiate which landmark the bearing references. They take a sighting of the landmark using the ship's polaris and obtain its current bearing. Then, to approximate the distance to shallow water dangers, the navigator uses mental math heuristics to solve for the Sin of the angle between ship's head and the bearing obtained multiplied by the distance to the landmark. The distance to the landmark is often approximately based on a pre-measured mid-track distance recorded in the NavOs notebook, which induces error.

As an alternative consider an ARNA that provides a textual reading of the current distance to unseen dangers in-place of the danger when in the NavO's line of sight. This provides an immediate indication of safe water without constantly checking and identifying new clearing bearings as the ship progresses down a track. This prototype was the first step in providing a way to design, visualize and test such ARNAs.

### 5.2.2 Overview

An application for providing 3D visualizations of real-world geographic areas and ENC point features was created. After loading of the application, the user is asked to

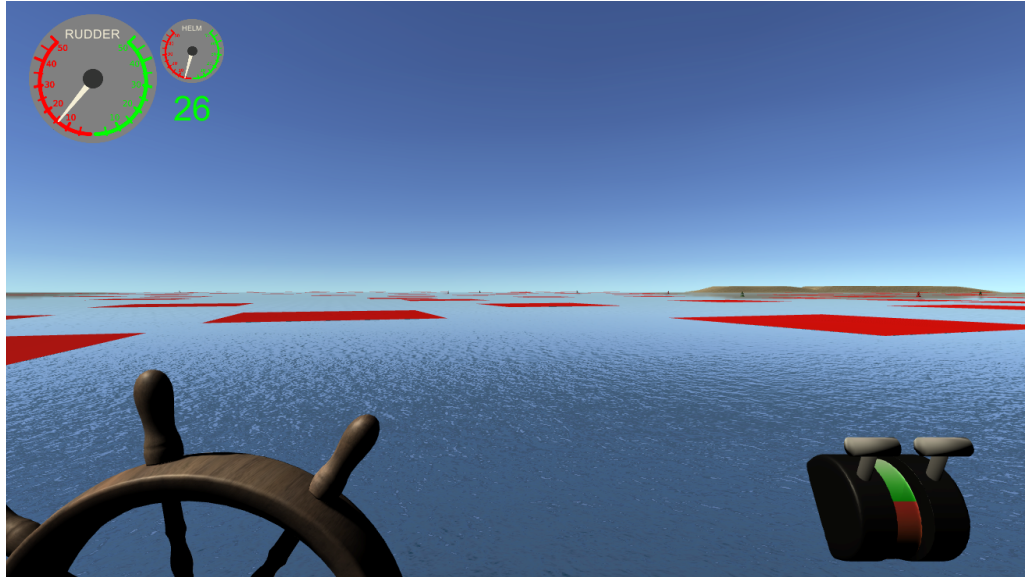


Figure 5.1: Screenshot of application with red planes being used to mark shallow water dangers.

make a selection of an S57 ENC. Once the chart is imported and processed, the user is presented with a 3D visualization of the geographic area associated with that chart. Point features, such as buoys and lights extracted from the chart data, are rendered in 3D in their appropriate locations. The user has virtual ship controls (helm, port and starboard throttles), that allow them to navigate the space. They are provided with an heads-up display (HUD) that provides rudder, ordered helm angle and ship's speed. The user can navigate the space and observe AR visualizations associated with the point features.

### 5.2.3 Implementation Details

The application was written in C#, Python and Bash, and it was developed in Unity3D [70]. Standard Assets provided by Unity3D were used to for terrain generation and water simulation. 3D models, such as those visualizing ship controls and point features (buoys and lights, etc) were created using Blender [71]. Textures for the 3D models and 2D UI elements were created using Inkscape [72] and GIMP [73].

## Terrain Generation

The website `terrain.party` was used to obtain accurate land representations [74]. This website allows downloading of black and white PNG images representing the geographic terrain, where black is the lowest height. These images can be used with Unity's terrain generator to create the land mass corresponding with the chart being used.

In addition, the prototype used hand selected areas from `terrain.party` that roughly corresponded with the charts being used. These terrain maps were then aligned to the geographic location represented in the ENC. This was a convoluted process that determined the differences of the extents of the areas (the lower left hand and upper right hand geographic coordinates) in order to align them. In order to avoid this, the prototype was updated to obtain the height map images through specific URL requests to `terrain.party`. These URL requests allow generation of terrain height maps that correspond to the exact latitude and longitude extents of the associated ENC. This also extended the scalability of the application, as one could implement downloading the height map image associated with the selected ENC at run time when the extents of a loaded ENC chart could be determined. The extents of the selected ENC are easily obtained within the header of GDAL feature extraction replies [59].

## Feature Extraction

S57 is a publication by IHO that standardizes the storing of chart data into a multi-layer data structure. Using GDAL, information about individual layers of instances of this data structure can be extracted. For example, lateral buoys are navigation aids defined by the International Association of Lighthouse Authorities (IALA) that help to define safe water and navigable channels [75]. Within the S57 data structure, there exists a feature layer called `BOYLAT` that contains data related to lateral buoys within the extents of the ENC. Each of these feature layers contains structured data with specific details such as location, colour, and name.

`Ogrinfo` is a python application within GDAL that takes a feature layer as an argument and extracts that layer from a provided chart instance. During prototyping, a C# script within Unity3D invoked a bash script that called `ogrinfo` with arguments and parsed its output. The bash script provided a simplified output of data that

could be used by the application.

Extracting the appropriate layers from an S57 chart, using GDAL, is done by invoking the following command:

```
ogrinfo {ChartPath}{ChartName}.000 Layer > {Destination}name.txt
```

After implementing data extraction for additional S57 layers, it was determined that the process could be modified to capitalize on the commonalities in the formats for each layer. As such, the output provided by GDAL can be processed directly within Unity3D without the need for preprocessing. This allows for easier integration of new point features as customized Bash scripts to format the layer extraction data are not required.

## Integrating GDAL

Ultimately, GDAL will need to be included within the application's build dependency. This could be done in different ways. If a variant of this software was used onboard ship as way of providing input to a AR system, the software would run from a dedicated computer node installed onboard ship. In such a scenario, the computer nodes configuration would include GDAL as a Free and Open Source Software (FOSS) dependency. The application would guarantee access to GDAL through the requirements of the operating environment (OE) configuration and installation procedure. Here we imagine the system as a delivered closed system that ensures the necessary dependencies.

For other cases, where the application is running from a laptop, cross-platform issues need to be considered. Including the .dll C# wrappers within the Unity3D build process would improve the ability for the application to run on different operating systems. Such .dll wrappers have been written for Windows and LINUX machines.

### 5.2.4 Ship Simulator

As seen in Figure 5.1, the application provides a ship simulator. Figure 5.2 highlights some visualizations of ship controls and indicators in more detail. The user interacts with these ship controls via mouse or a laptop's trackpad.

## Throttle Controls

The port and starboard throttles can be manipulated independently, thus allowing control of each engine (the prototyped ship assumes a ship with two propellers). When adjusting the controls, the speed that is being set appears above the throttle being manipulated. Once set, the assigned speed fades to no longer clutter the display. In the screen shot in figure 2, we see the speed already beginning to fade for the starboard throttle, and the port throttle speed is not visible. The throttles can be set forward or in reverse. The differences between the two are visualized using green and red colours on the throttle base. The speed values that are displayed are colour coded accordingly.

## Indicators

Rudder and Helm indicators are provided. The rudder indicator indicates the current rudder angle while the helm indicator indicates the ordered rudder angle. The rudder angle adjusts its angle to be closer to the ordered rudder angle. Both angles are important in controlling the ship, however the rudder angle is the most important as it what directly impacts the ship's movement in the simulator. As such, its importance is emphasized by size.

## Helm

The helm is a textured 3D model. It rotates left and right when clicked and dragged by the user. The angle that the helm can be turned is clamped to 60 degrees starboard and port off centre angle. This angle is converted to a maximum 30 degrees of rudder angle. The difference in the two allows greater fidelity of movement when manipulating the helm and more accurately simulates physical controls.

### 5.2.5 Point Features

Layers of ENC's can be extracted and processed using methods outlined above. Each layer presents an opportunity for visualizing the structured data in 3D space. For this prototype, lateral buoys, point lights, and depth sounding layers were used as inputs for visualizations. Now that the framework of extracting the layers, parsing them

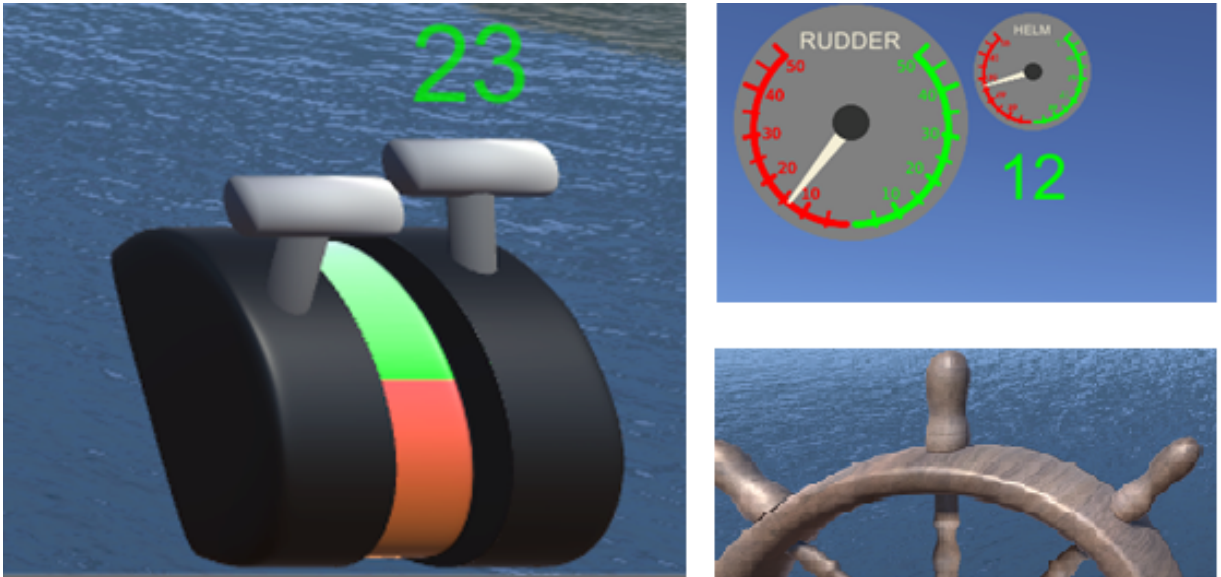


Figure 5.2: Port and starboard throttles (left), Rudder/Helm indicators (top-right), helm (bottom-right).

and rendering them has been implemented, adding new features presents challenges solely related to how the data is best visualized.

### 5.2.6 Preliminary ARNAs

A few preliminary ARNAs were created as a proof of concept. The depth sounding layer was extracted from the ENC and filtered out based on soundings that were a danger to the ship. The locations of these soundings were rendered as red planes, clearly marking shallow water. Future work will have this expanded to join these isolated depths together into areas that are unsafe for the ship to navigate. By doing so, we will be able to mark larger areas more clearly as dangers.

By pressing the ‘c’ key, a rendering of the paper chart is presented directly in view. This may be something that could be beneficial to the NavO when operating on the bridge wing and without quick access to the ECDIS system. An add-on to this visualization could be a presentation similar to the ECDIS display that has a icon on the chart indicating the current ship’s position.

### 5.3 AR Device Simulation

This section details a project that examined creating a VR application that housed a AR device simulator. Simulations of AR devices may be used in determining the necessary hardware specifications required to perform different tasks. Such a tool may be useful by hardware engineers when developing AR device prototypes.

Additionally, a simulation of an AR device allows for the creation and testing of AR visualizations without the necessary hardware. This could be useful in developing AR visualizations that are not currently viable due to technological limitations [41]. Being able to develop and test AR visualizations before the hardware is available may decrease time to market. Having an AR device simulation may not replace the need for experiments such as those conducted by Diaz, Catherine et al. that look specifically at how virtual objects and real-world objects interact [76]. But, it may help with the design and evaluation of AR visualizations and hardware.

#### 5.3.1 Developing the Virtual Reality Application

Development of the VR application started with creating the necessary 3D models and then importing them into Unity3D. The models were created in Blender using box modelling techniques. A series of 3D models were created to simulate a living room of a house. The models included furniture such as a couch, a chair, a coffee table, a book case, wall-mounted TV and pictures, as seen in Figure 5.3.

All of the textures were created by taking pictures using an iPhone 6S camera and image editing software such as GIMP, with the exception of the floor texture which was obtained online [77].

The 3D models were imported into Unity3D as a blend file and converted to Unity3D game objects. The floor of the room and other game objects that would be considered obstacles to a person walking were given a mesh collider. This included models such as the couch and coffee table. I initially added a FPSController to allow walking around the room to explore the space. However, this did not translate to VR as the viewer is stationary.





Figure 5.3: VR models of living room

## GoogleVR

In order to convert the existing Unity application into a VR application, we first explored the use of native Unity support for OpenVR Software Development Kit (SDK). This SDK is developed by Valve Corporation and requires a Steam account, install of Steam, and SteamVR [78]. Additionally, SteamVR does not wholly support Mac OSX.

Next, we explored the GoogleVR SDK [79]. This SDK is developed by Google for use with the Google Cardboard [80]. The downloaded SDK was imported into the project as a custom package. The package contains a series of prefabs, some of which were added to the Unity scene in order to add Google Cardboard support. This includes `GvrControllerMain`, which allows moving of the camera with the headset. `GvrEventSystem` was added to handle processing of events in the application. `GvrEditorEmulator` was added to test the application in the Unity window. In the Unity Editor window, one can change yaw/pitch using `Alt + Move Mouse` and change roll by using `Ctrl (Command) + Move Mouse`.

`GvrRecticlePointer` was another prefab added to the Unity scene. This prefab gives a round pointer cursor in the center of the screen that can be used to interact with objects. In order to adapt the lack of select button on a headset, a C# script was developed to allow selection of an object by maintaining gaze on the object for



Figure 5.4: Noon VR headset used in project.

a timed duration (dwell selection). When looking at an object that has an event trigger, such as a button, the cursor expands when hovered over the object. This gives a visual cue to the user that the button is reacting to the gaze. After 2 seconds, the selection is made in the same manner as if a mouse click was performed.

## NoonVR

The headset used for the application was the Noon VR headset 5.4 [81]. It is a device developed by a South Korean company that can turn a smartphone into a set of VR goggles. Although normally intended to view content provided through the Noon VR application, this device proved useful to prototype the VR application. Unlike the Google Cardboard, this device comes with a head strap. This means that the rotation is based on neck turning speed versus the torso turning speed of the Google Cardboard.

It has a much larger FOV ( $95^\circ$ ) than currently available AR devices such as the MicroSoft HoloLens's FOV of  $35^\circ$  [82]. This makes it suitable for testing AR device FOV above what is currently available.

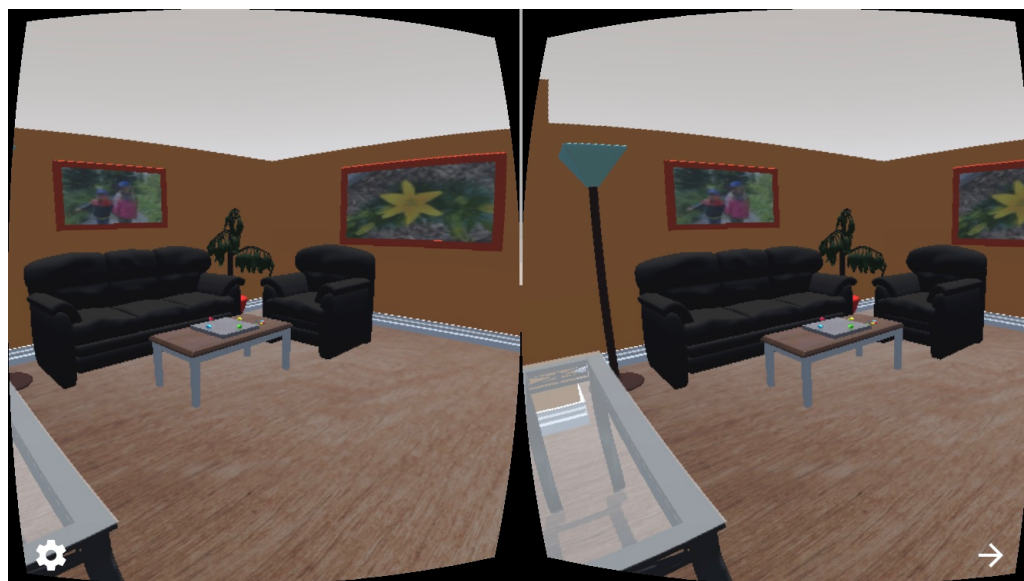


Figure 5.5: Screen capture from iPhone running VR application.

### **XCode and iPhone6S Setup**

To allow the VR application to be used with the Noon VR goggles, we built and deployed it to a iPhone 6S. In Unity, after adding iOS support to the application, we switched the build platform to iOS. Within the Player panel in the Inspector, we gave a unique Bundle Identifier for the application (this has to be changed from the default in order to deploy). We created a new Apple ID to establish a free Personal iPhone Developer’s license. Opening up the downloaded iPhone Development certificate in keychain access, we found the organization ID. We added this alphanumeric code to the “Automatic Signing Team ID” field. We attached an iPhone to a computer using a USB cable and built and ran the application. This created an XCode project that allowed the application to be deployed to the device. On the iPhone, we added the develop id to the list of trusted developers in order for the application to be launched.

### **Anti-Aliasing**

One of the first things that stands out when looking around the environment in VR is the “stair-casing” effect on straight edges. This has to do with the lack of anti-aliasing as GoogleVR is rendering the image to a RenderTexture object and is using OpenGL to draw it the screen on the iPhone. Attempts to change the effect, such as increasing

the multi-sample counts, seemed to have little impact. Adding anti-aliasing support is left for future work.

### 5.3.2 Augmented Reality Simulation Implementation

In order to simulate the AR Device, we added another camera to the scene for rendering the AR Visualizations. This AR camera is set to depth level 1, while the main camera is set to depth level 0. This allows the AR camera’s rendered texture to be placed in front of the main camera’s rendered texture.

We created a layer called “AR”. The main camera’s culling mask property list the layers that it renders. We removed the “AR” layer from the list so it will render everything but this layer. In contrast, the AR camera has only the AR layer in its culling mask. In addition, the AR Camera has its “Clear Flags” property set to “Depth Only”. This ensures the AR camera will only render GameObjects that have been added to the AR layer and that the main camera’s view is still seen in the background (versus being overwritten by the Unity SkyBox or a solid colour).

When selecting one of the predetermined configurations by gazing at one of the configuration buttons, the AR camera settings are set as outlined in the associated file.

### In App Configuration Menu

Having the user change multiple configuration settings in app by using gaze-selection is not practical – it would be time consuming and tedious. As such, I added the choice to select one of three configuration files that describe all of the possible variables via gaze as demonstrated in Figure 5.6. This allows the developer to have multiple different configurations ready, and can switch between them in app to see the differences. The configurable file format is presented in Table 5.1.

### 5.3.3 Future Work

Now that the VR Application has been developed with the AR device simulation established, AR Visualizations can be developed. A few rudimentary visualizations were added to the scene as a proof of concept. This included a game piece board that

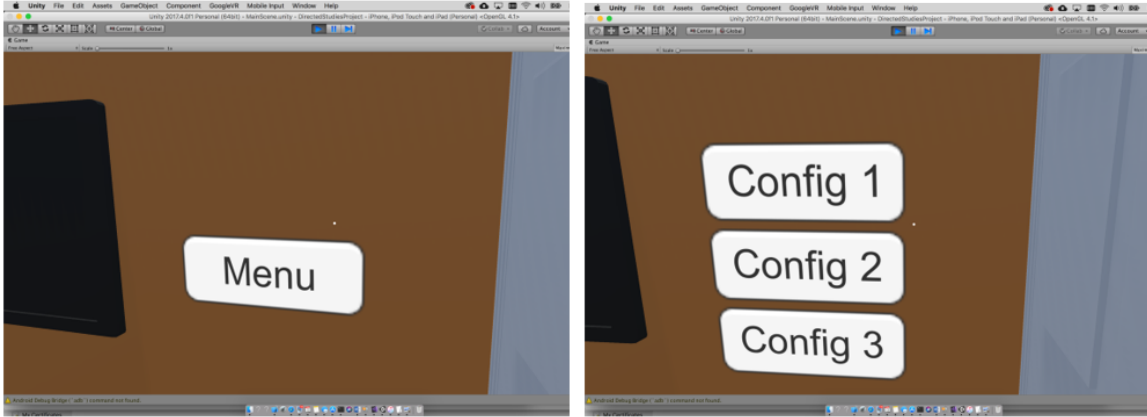


Figure 5.6: In App Configuration Menu.

Parameter	Description
FOV N	N is an number between 0 and 95 that represents the field of view.
NEAR N	N is a number for the distance to the near clipping plane
FAR N	N is a number for the distance to the far clipping plane
RECTX N	N is a number between 0 and 1 representing the X location of the viewport rect
RECTY N	N is a number between 0 and 1 representing the Y location of the viewport rect
RECTW N	N is a number between 0 and 1 representing the width of the viewport rect
RECTH N	N is a number between 0 and 1 representing the height of the viewport rect
STEREOSEP N	N is a number representing the Stereo Separation
STEREOCONV N	N is a number representing the Sterio Convergence
TARGETEYE N	N is either Both, Left, or Right

Table 5.1: AR Application Configuration File Format

is on the coffee table, and a blue cube that spins and rotates about at a fixed position in space.

These visualizations serve little more than to see how the impact on visualizations of changing the AR camera's settings. However, this is was the first step in producing a tool for developing an AR Visualization. It also lays the framework for a tool to determine how changes to the AR device specifications will impact the user experience of a visualization.

Another improvement, as mentioned above, is to incorporate anti-aliasing. This, along with other graphical improvements could help with the feeling of immersion. Adding the ability to move about the room would also improve immersion. Enabling this through keyboard and mouse commands is rather rudimentary, but developing a UI/UX experience that makes this possible with only gaze selection may prove challenging. One option is to have landmarks in the room, that when gaze-selected, the user is teleported to the location. This may be useful in viewing visualizations from different angles.

#### **5.4 Summary of S57 and AR Device Simulation Prototyping**

The S57 prototype demonstrated that features from ENC's could be rendered in 3D space using Unity3D and GDAL. It also created an avenue for future research into ARNA design and implementation. In addition, it provided a tool for exploring chart data in 3D space.

Another use case of the application is by NavOs during the pilotage planning phase. In such a scenario, we see the navigator using the application to visualize the transit in order to help prepare. For this use case, the application could be deployed to a laptop in a similar fashion as currently prototyped. The 3D elements, such as the terrain and point features created here, would help the navigator visualize the passage in 3D versus attempting to picture the world from currently existing 2D visualizations.

This phase of development also determined a method of creating a VR application that simulates an AR device. Through the use of multiple cameras, culling masks and layers, we are able to separate the VR from the simulated AR device. The AR Device Simulation prototype was another step towards creating a tool that could be

useful in experimenting with and developing AR visualizations with the end device in mind. Vice versa, it may help to determine what device specifications are necessary in order to fully evaluate an AR visualization.

## Chapter 6

### Sources of Data for VR Terrain Generation

#### 6.1 Introduction

In this chapter, we examine the availability of open source data and tools that can be used to dynamically create virtual worlds. These virtual worlds are useful in that they provide an environment to test ARNAs as well as provide a way to explore and visualize geographic regions associated with a navigation chart. These tools and datasets can generate these environments more economically than 3D modelling.

#### 6.2 BlenderGIS

BlenderGIS is an add-on for Blender that allows importing geographic data including shapefiles, geotiff digital elevation models (DEM), and OpenStreetMaps [83]. It can be used to interact directly with web maps, produce location specific terrain meshes, and import open street map data including buildings, roads and rivers. This plugin allows Blender to be a toolkit for generating virtual environments for export as well as for direct visualizing of geographic areas and S57 layers.

##### 6.2.1 Basemaps

One very powerful tool within BlenderGIS is Basemaps. As seen in Figure 6.1, the Basemaps tool allows the user to interact directly with web maps to locate the exact geographic location of interest. The tool allows searching within the map for locations via a search bar, but also provides a zooming and panning capability. Once the location of interest is within the viewport, the user simply presses “E” to export the portion of the map in view to a new textured plane.



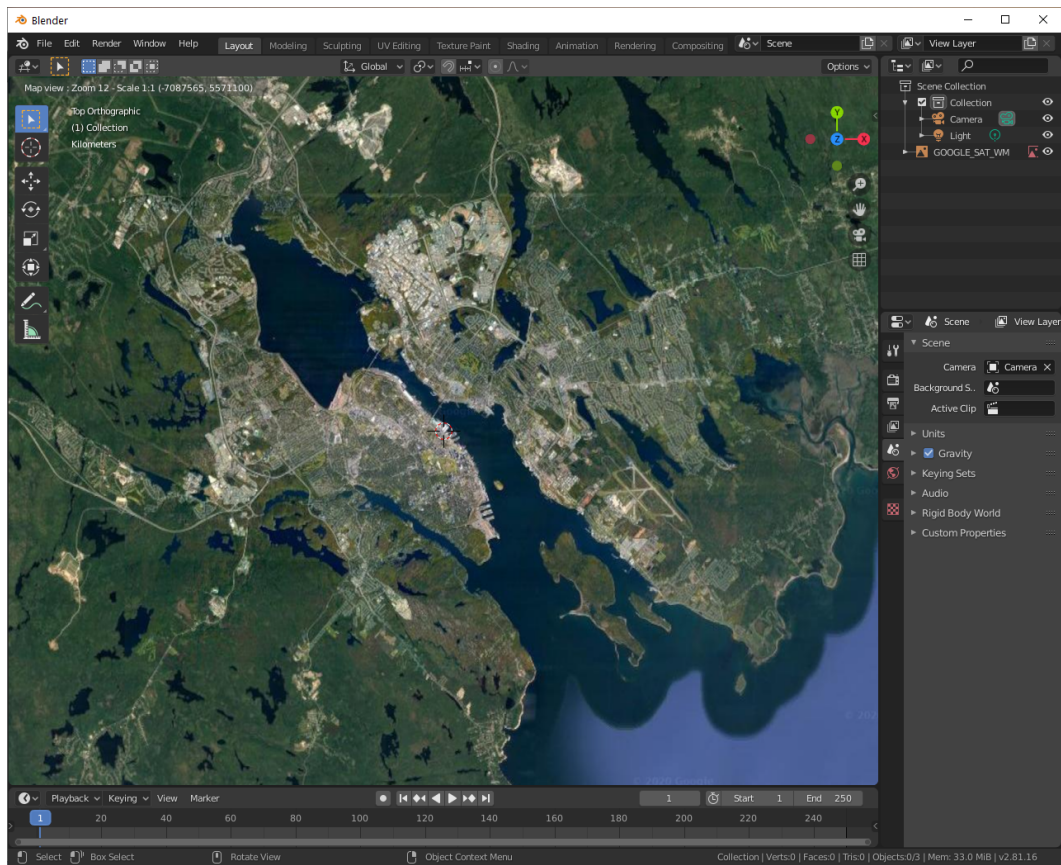


Figure 6.1: Screenshot of Displaying Dynamic Web Map inside Blender Viewport

### 6.2.2 Shuttle Radar Topography Mission

SRTM (Shuttle Radar Topography Mission) is a high-resolution topographic dataset of the planet Earth that was produced by the NASA Jet Propulsion Laboratory using the Space Shuttle Endeavour. The SRTM was generated using two radar antenna sweeping the Earth's surface over a period of ten days. It was released globally by the United States Government in 2015 [84]. The dataset provides height map data with data points providing a 30 metres sample resolution. Notably, BlenderGIS allows direct importing of this data into the geo-referenced plane, converting the plane into a mesh with heights proportional to the associated geographic area. This can be done directly to the textured plane generated using Basemaps, as shown in Figure 6.2.

### 6.3 OpenStreetMap

OpenStreetMap (OSM) is a community driven project started in 2004 by Steve Coast that provides geographic data of the world under the Open Data Commons Open Database License (ODbl) [85]. It is built based on contributions from volunteers via a collaborative mapping processes using tools such as portable satellite navigation devices [86]. The data provided is validated using a series of quality assurance measures including tools for bug reporting, error detection, visualization, monitoring and others [87].

Some governments including the governments of the United States of America and the United Kingdom, have released data under licenses appropriate for use within the OSM database [86].

### 6.4 ArcGIS

ArcGIS is a framework developed by Esri that “combines data, visualization, analytics, and collaboration technology to enable governments and citizens to work together on real-world initiatives that tackle the most pressing issues in their communities” [88]. It provides a ready source of standardised spatial data stored within a geodatabase [89].

The Halifax Regional Municipality provides data to the general public via an

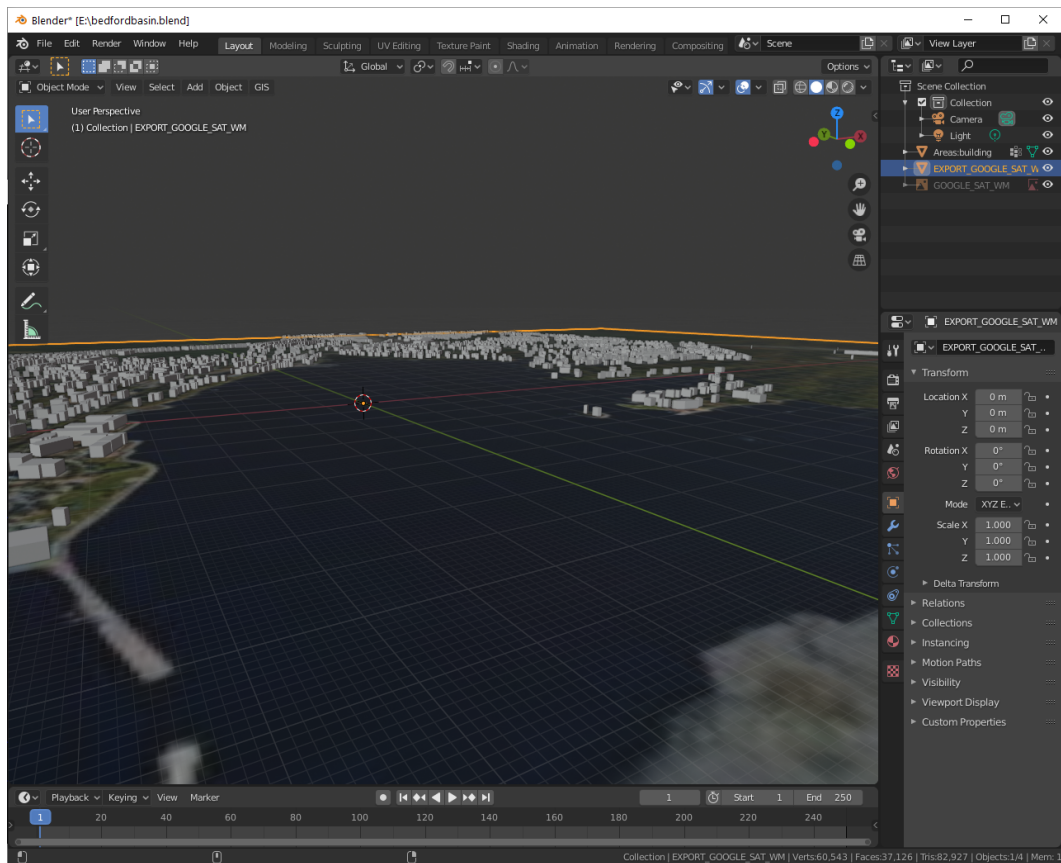


Figure 6.2: The Dynamic Web Map has been converted to a textured plane. Then, it was combined with NASA SRTM mission true elevation data before being superimposed with buildings retrieved from OpenStreetMap data.

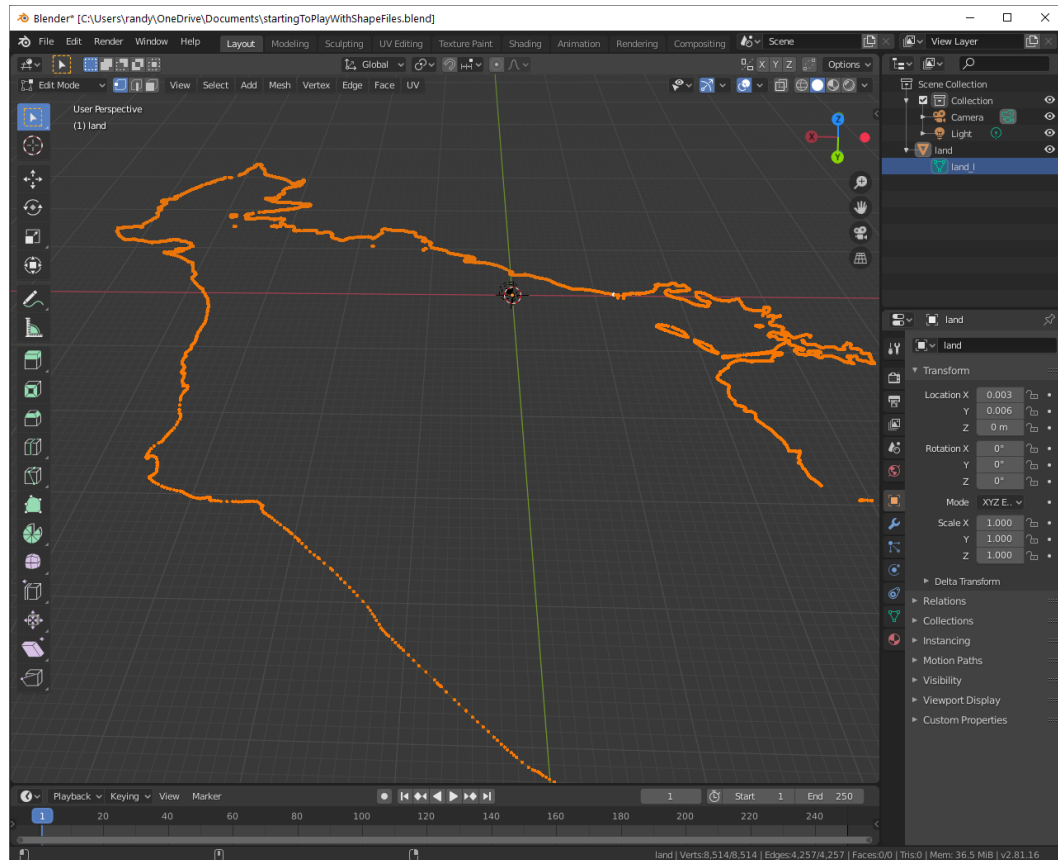


Figure 6.3: BlenderGIS can be used to generate meshes from extracted S57 layers. This screenshot displays the coastline of Bedford Basin, NS extracted from a S57 chart using ogr2ogr and imported into Blender.

ArcGIS REST Services Open Data Portal [90]. This data includes 3D contour polylines at various resolutions generated through a combination of LiDAR data and photogrammetry. These contour lines are another opportunity to generate terrain meshes. The raw LiDAR datasets are also available. Additionally, data is also available on vegetation patches, cultural areas, park regions, and others.

## 6.5 Summary of VR Sources of Data

There are various sources of geo-spatial information available online. Plugins, such as BlenderGIS allow manipulation and visualization of geospatial information within a 3D modelling program. This data visualization can then be saved as a 3D terrain mesh which can be read dynamically by application software or directly imported into Unity3D to create VR worlds. When combined with S57 navigation data, the

possibility exists to create a 3D virtual world surrounding the navigation data area consistent with the real world.

## Chapter 7

### VR Implementation and ARNA Development

#### 7.1 Introduction

A VR application was developed for Oculus Rift in Unity3D that allowed for the development, visualization and testing of ARNAs. The application simulated being on the bridge of a frigate transiting a navigation passage. The ship follows a planned series of tracks in close vicinity to underwater hazards, buoys, and other shipping. As seen in Figure 7.1, the user is able to look around the environment in 3D wearing the headset as the ship travelled the navigation passage free of user input.

This chapter explores how the prototype was created by looking at the techniques and Unity plugins used and describes the developed ARNAs. This is followed by a discussion on how the ARNAs relate to current practices, and how they could be generated in real time using available sensors and a priori data.

#### 7.2 VR Prototype Creation

As shown in Figure 7.2, this prototype was created in Unity3D for the purpose of testing and experimenting with ARNAs in controlled scenarios. We have explored previously how terrain and navigation landmarks can be generated automatically using a priori data. Here we provide conditions favourable for a controlled and sequential evaluation of ARNAs by creating the environment manually.

##### 7.2.1 Models

Some 3D models used in the application were developed in Blender3D using box modelling techniques. Other assets, such as warship and fishing vessel models, were imported from the Unity Asset Store. Some primitives, such as the components of the track ARNA, were developed using 3D primitives offered by Unity3D. Some models such as the ship's steering wheel and throttle controls were modelled for the

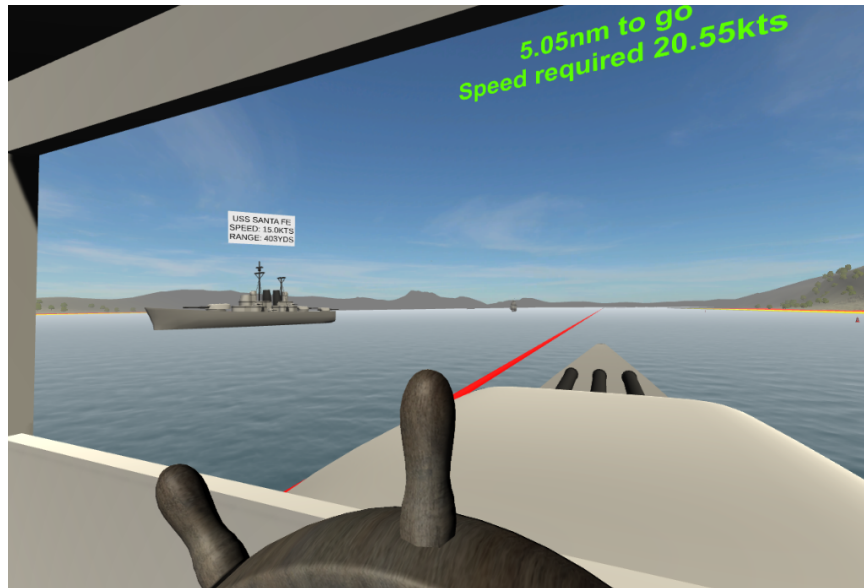


Figure 7.1: Screenshot from VR application. A few ARNAs are visible including (1) a Contact information panel (shown as a white background with black text above a ship (left), (2) a red line representing a navigation passage track that the user is currently starboard of (middle), and (3) a heads up display (top) showing the distance to go and speed required.

standalone desktop prototype and reused here.

### 7.2.2 Oculus Plugin

Although the Oculus headset worked natively within Unity, the “Oculus Integration” plugin developed by Oculus was imported from the Unity Asset Store [91]. From the plugin, the OVRCameraRig prefab was used in place of the default camera gameobject provided by Unity3D. This prefab improved the user experience by offering better resolution and decreased staircasing effect.

### 7.2.3 Water

The water shader provided by Unity3D and used in the standalone desktop prototype was not compatible for VR. As such, a VFX Shader was imported from the Unity Asset Store [92]. From this shader, the “Ocean” prefab was used with the “Ocean Daylight” shader. This provided a VR compatible ocean shader.

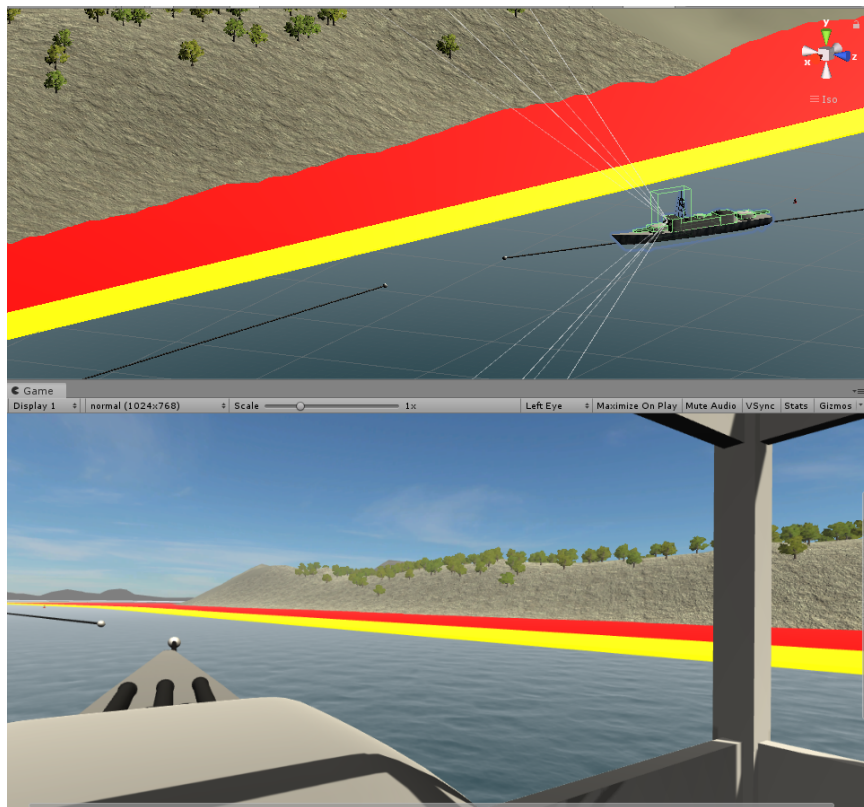


Figure 7.2: Screenshot showing Unity Application. We see the Unity Scene (top) and the user's view (bottom). LDL, Clearing Depth, and Track ARNAs are shown.



#### **7.2.4 Terrain**

To add to the environment, Unity's Terrain Tools were used. The tree models were placed on the terrain using SpeedTree, which is a third-party product by IDV that is integrated natively within Unity [93]. A free SpeedTree tree model package was imported from the Unity Asset Store to allow for the placing of tree model prefabs on the terrain [94].

#### **7.2.5 Ship's Movements**

Ownship and other ship models were moved through the environment by providing a individual ship's speed and a series of waypoints. This allowed ownship and other ship's to proceed along preplanned routes.

When moving ownship towards the next waypoint, the height position of the next waypoint was set manually. This allowed for simulation of ocean movement and helped to avoid the ship model from moving outside realistic vertical positions in the water.

The orientation of the ship would rotate towards the next waypoint and move towards it at the indicated speed. The rotation speed was a function of the ship's speed and angle of rotation. This mimicked turning the ship more sharply at higher speeds.

### **7.3 Prototype Hardware**

The prototype made use of a VR headset manufactured by Oculus VR. The headset was the the Oculus Rift Development Kit 2, shown in Figure 7.3. This headset provides 960x1080 resolution per eye via a low-persistence OLED display [95].

### **7.4 ARNAs**

This section describes the proposed ARNAs and how each can be generated in real time using common navigation sensors and a priori data. The ARNAs were created manually through a iterative process of modelling, coding and evaluating. By creating an ARNA prototype and then viewing it through the Oculus Rift in the VR



Figure 7.3: The Oculus Rift Development Kit 2 Headset [96].

application described above, we could develop and modified the proposed ARNA until it was deemed ready for evaluation by subject matter experts.

#### 7.4.1 Track ARNA

The Track ARNA helps to visualize the ship's location in relation to a planned navigation passage, as shown in Figure 7.4. A navigation passage is a series of disjointed tracks. Each track consists of two waypoints and a leg. The two waypoints are the starting waypoint (latitude and longitude) and the ending waypoint. The leg of the track is the line that connects the two waypoints. Tracks are disjointed in that they do not connect directly to other tracks, ie. the ending waypoint of a track is not equal to the next track's starting waypoint. Instead, the ending waypoint can be considered the "wheel-over" position of the ship, which is the geographical position when the ship plans to begin turning to the next track. The starting waypoint of the next track is the location expect upon completing the turn and steadying the ship on the next track. In order to determine the waypoint position, the NavO uses the ship's turning characteristics and planned rudder angle.

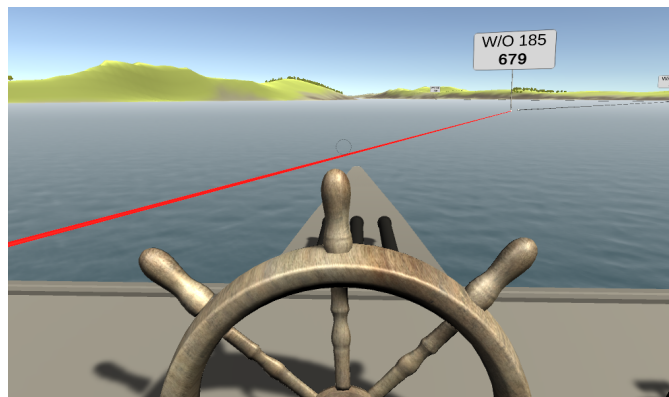


Figure 7.4: The Track ARNA allows the NavO to visualize the ship's location in relation to the planned navigation passage.

### User Interaction - Track ARNA

The Track ARNA uses colour to inform the user of location relative to the planned track. When on track, it is coloured black. Black was chosen as it is the colour used for tracks on the ship's ECPINS as well as the colour of tracks drawn on paper navigation charts in pencil. When starboard of track, the track is coloured red.

Red was chosen because it is the colour associated with port in the Navy, and reflects the track is to port, and making the colour reflective of the helm ordered to return to track. With ship's with a rudder, the order would be "Port" + the number of degrees of rudder angle (such as "Port 15"). When port of track, the track is coloured green. Likewise, green was chosen because it is associated with starboard in the Navy. By choosing the colour associated with the direction of turning and thus the helm order required, it is expected that this would decrease the delay in reaction time caused by the Stroop effect and minimize the occurrence of incorrect helm orders [97]. Due to the association of colour with direction and the risk this may cause in giving incorrect helm orders, validation of the impact on the colour choice could be tested in a ship-bridge simulator through controlled experimentation before being used at sea.

In addition, the NavO is provided with a range to the track (both port and starboard) as text on a white panel. This is only displayed when the ship is more than 50 yards from the track. The text positions are positioned at the intersection of the track with a lines directly abeam of the ship.

## Real World Source of Information - Track ARNA

A NavO plans a navigation passage using an ECPINS laptop. The passage information is saved to file and loaded via floppy disk to the ship's ECPINS systems (both primary and back up computers). Alternatively, the NavO can make changes directly on the ECPINS system itself, normally on the designated planning system and then copied to the monitoring system.

Part of this information is the track data, including the expected wheel over positions. The ECPINS system information can also be exported to a file readable by the ship's navigation RADAR. As such, multiple options exist to have the data imported into the ARNA system such as:

1. The RCN could engage OSI Maritime Systems to establish an ARNA-ECPINS interface design document (IDD) to communicate the data between the two systems [98];
2. The RCN could engage OSI Maritime Systems to establish an export option to disk of the track data in an agreed upon format, similar to the current system in place for the navigation RADAR;
3. If not proprietary, the exported format used for the navigation radar could be examined and parsed to be used by the ARNA system;

Without an automated function, the NavO could read the information from the track created in the ECPINS and enter it manually into the ARNA system.

### 7.4.2 Danger Area

When creating a navigation passage, the NavO establishes a Limiting Danger Line (LDL). That is, a series of connected points that follow a pre-calculated depth of water. Crossing the LDL and entering the area between the LDL and the land could result in grounding of the ship. Calculation of the LDL uses the following information:

1. The draught of the ship;

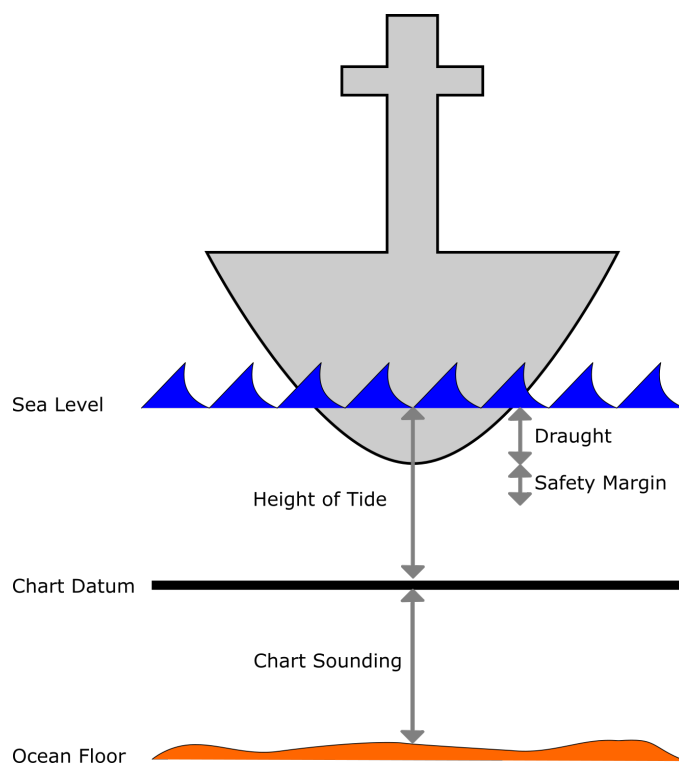


Figure 7.5: Limiting Danger Line (LDL) is calculated by adding the ship's draught and a safety margin (normally 2 metres) and then subtracting for the height of tide.  $LDL = \text{Draught} + \text{Safety} - \text{Height of Tide}$ . The safety margin can also consider the impacts of squat.

2. Safety Margin. An additional safety margin is normally applied to the LDL. This safety margin is often 2m, but can be increased or reduced based on approval by the Commanding Officer. One factor that can affect the safety margin are the expected impacts of squat;
3. The squat calculation of the ship. “The squat effect is the hydrodynamic phenomenon by which a vessel moving quickly through shallow water creates an area of lowered pressure that causes the ship to be closer to the seabed than would otherwise be expected” [99]. The squat calculation uses the ship’s hull characteristics, expected depth of water, and expected speed of the ship. As the expected speed of the ship varies throughout the navigation passage, this squat value can be different throughout the passage. As such, the resultant LDL calculation can differ throughout a navigation passage if absolutely necessary. A navigator would normally choose the safest depth unless navigable water was needlessly restricted due to an overly onerous safety margin; and
4. The height of tide. The expected height of tide is impacted by the location and the expected time of day the NavO will be conducted the passage. Again, the height of tide can change throughout the passage and can be impacted if the starting time of the navigation passage is impacted.

### **User Interaction - Danger Area**

When planning a navigation passage, the NavO measures the distance to the LDL from visually recognizable navigational marks along the planned track and records this information in a notebook. This allows the NavO to know how far from the point the dangers extend. In addition, the NavO must measure the corresponding planned closest point of approach to those danger if on track. For example, they might record the dangers extending from a prominent point of land or those marked by a navigation mark like a lateral buoy and then calculate how much safe water they will have when abeam of the dangers. When conducting the navigation passage, the NavO conducts a track assessment to see how far off course they are and then correlates the information in the notebook to determine the new amount of safe water remaining abeam.

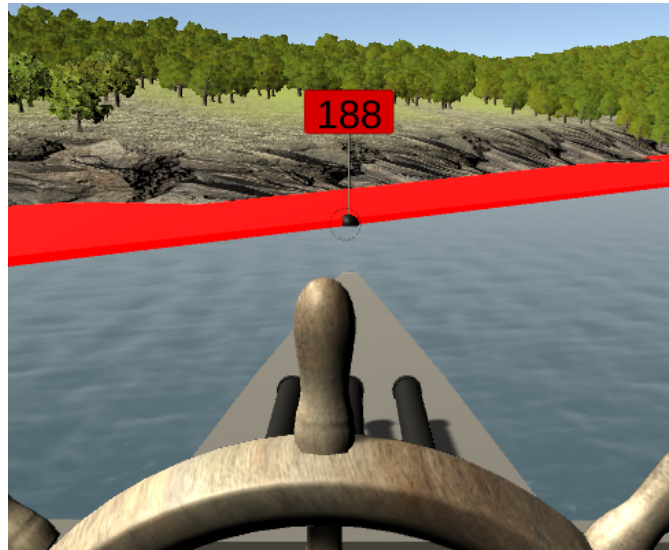


Figure 7.6: The Danger ARNA represents the area where the ship is in danger of running aground and should be avoided.

The Danger Area ARNA can reduce the cognitive load to make that assessment if fully trusted. Or, at the very least, it can confirm the assessment made by the NavO. The area between the LDL and the coast line is the Danger Area. The Danger Area ARNA displays that area as a red plane which follows the contour of the land and the planned LDL. An assumption is made that a red area in proximity to land would be associated with danger (especially contrasted to the yellow clearing area described later) instead of port. This would be similar to other ship's systems such as the ECPINS and the GPS, which shows alerts and dangers in red and warnings in yellow.

As seen in Figure 7.6, the visual overlay of the danger area allows the NavO to easily see where the dangers are located. In addition, the NavO is provided with a range to the dangers ahead, astern and abeam (both port and starboard) as text. The text positions are positioned at the intersection of the LDL with the lines directly ahead, astern, port and starboard of the ship.

When conducting pilotage, a NavO is always concerned about the availability of safe water. As a result of the Danger Area ARNA, the NavO can instantly know the amount of safe water available along with visually seeing the proximity to dangers.

## Real World Source of Information - Danger Area

In order to create the Danger Area ARNA, the LDL and the contour of land is required. Similar to the Track ARNA described previously, the LDL can be obtained via an export from the ECPINS system or through a direct interface. In this case, it would be a path of connected GPS positions. This would ensure that the information contained within the ECPINS system and the NavO's navigation notebook is consistent. To form the area, the LDL path can be combined with the path of the contour of the land. This contour can be obtained from the S57 chart loaded into the ARNA system by extracting the *LNDRGN* layer or the *LNDARE* layer [58]. In a similar fashion, the land contour information is extracted from the chart by the ECPINS system already and could be made part of the ECPINS export or via a developed ARNA-ECPINS interface.

Another avenue that could be explored is the possibility of dynamically calculating and generating the LDL. The pieces of information required to do this and the real world sources of information are:

1. A database of tide tables;
2. The ship's characteristics including the ship's draught and squat chart;
3. National Marine Electronics Association (NMEA) data from the ship's navigation system, including location, speed, and time [100]. These values would be used as an input for obtaining tide information from the tidal database and for obtaining the current squat value;
4. The available depth and breadth of water from the nautical chart required as inputs for the squat chart, obtained from the S57 chart loaded into the ARNA system or via an ARNA-ECPINS interface; and
5. The safety margin, which can be defaulted to 2m or made configurable;

### 7.4.3 Clearing Area

The Clearing Area ARNA is similar to the Danger Area ARNA in that it marks an area of interest to the NavO. The Clearing Area is the area between the danger area



and the point at which the ship can still turn 180 degrees away from the danger. That is, if outside of the clearing area, the NavO is assured that the he can direct the ship to be turned as much as possible without concern that the stern of the ship will run aground.

### **User Interaction - Clearing Area**

A NavO calculates clearing bearings, which are predetermined magnetic bearing lines from prominent points of land and navigation marks to indicate the extent of the clearing area. A track of a navigation passage can have as little as one clearing line or many depending on a number of factors including:

1. The proximity to danger, where the convention used in the RCN is to require clearing lines only at points where the ship is planned to be within 1nm of dangers in order to reduce the effort required to generate;
2. The availability of navigational marks ahead of the ship for use as reference for the clearing line;
3. The contour of the danger area in relation to the planned track, where clearing lines tend to follow the planned track of the ship; and
4. The length of the track, where a short track would have fewer clearing lines.

The NavO must negotiate the complexity of having too many clearing lines against needlessly limiting navigable water. That is, too many lines are of no value because the NavO could never reasonable be assured he was using the right bearing.

The Clearing Area ARNA is not impeded by the same restrictions imposed upon clearing lines. For example, proximity to danger, availability of navigation marks and length of track have no impact. Rather, the area is depicted as a yellow area lying on the water line adjacent to the red Danger Area ARNA. The size and shape of the area can be calculated irrespective of planned clearing lines and thus provide a more accurate representation of when the ship can safely turn. In addition, this area can be made dynamic by considering the turn radius and speed of the ship to indicate when the ship is running into danger.

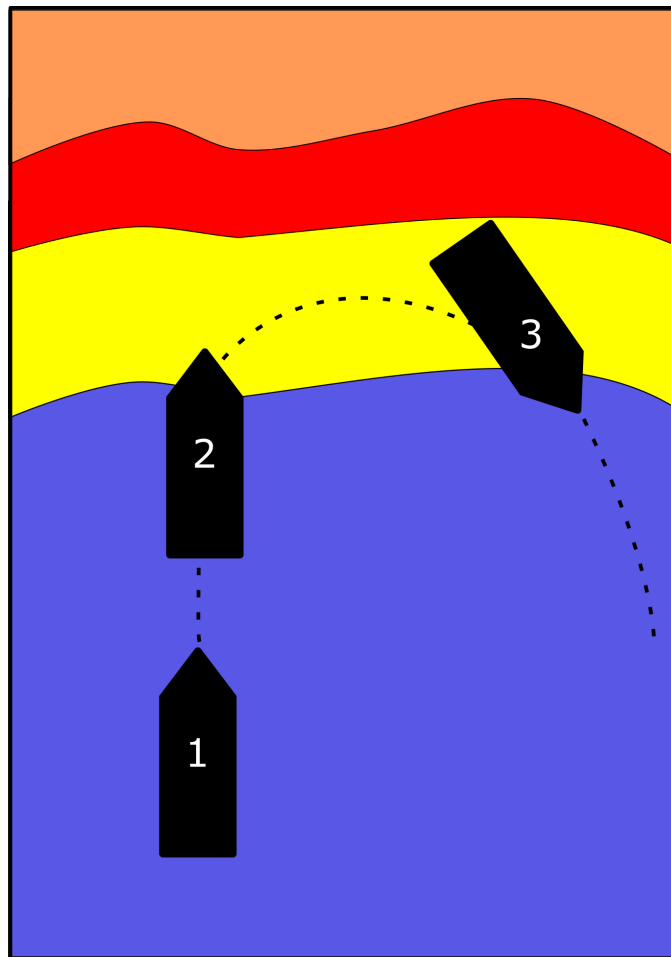


Figure 7.7: The Clearing Line Area (depicted in yellow) marks an area where the ship can still turn 180 degrees away from the danger area (shown in red). The diagram shows the ship (depicted in black) making a turn in positions marked as 1, 2, and 3. The Clearing Line Area is measured from the ship's polaris to the stern of the ship, such that upon completion of the turn the ship's stern remains outside of the danger area.

## Real World Source of Information - Clearing Area

In order to calculate the clearing area, the ARNA system requires:

1. The Danger Area ARNA, with requirements indicated previously;
2. The Ship's turning characteristics, which is part of the ship's navigation data sheet and can be loaded in as a priori information;
3. NMEA information as indicated previously, but with the addition of ship's heading (for dynamically updating the danger area).

As shown in Figure 7.7, the clearing line marks the point at which the ship can still commence a 180 turn and still clear the dangers. As a ship's turning diameter is influenced by the speed of the ship, the size and shape of the Clearing Area could be recalculated. The data for this calculation can be obtained using the ship's navigation data from its MK 49 ring-laser gyro navigator (RLGN) INS and Navigation Data Distribution System (NavDDS) [101]. That is to say, the ship's ability to clear the dangers is influenced by the speed of the ship and the angle at which the ship is proceeding in relation to the danger.

### 7.4.4 Passage Manager

When conducting a navigation passage, the NavO regularly has to recalculate the speed required and estimated time of arrival (ETA). This is normally done once per track. This is required in order to ensure that the ship arrives at the end of the navigation passage on time. The standard employed in the RCN is to achieve the arrival time within 2 minutes of the planned time. The speed required can be influenced by a number of factors, including the speed made good and the course made good of the ship. For example, if the ship is consistently manoeuvring to regain track, then the overall distance travelled would be greater than anticipated. If the ship is steaming into a tidal stream, then the ship would have to increase speed in order to compensate.

## User Interaction - Passage Manager

Without the Passage Manager ARNA, the process for calculating engine speed orders is done using multiple steps. These steps serve to determine the distance remaining in the navigation passage and what speed to order in order to maintain the speed plan. The speed plan is the planned speed made good throughout the passage. This is not normally the same speed throughout due to requirements to reduce speeds when appropriate such as when abiding by harbour regulations and wake restrictions.

The speed made good through the water is affected by the tidal set. Knowing the tidal set and the speed required, the NavO can make appropriate recommendations of what speed to order in order to maintain the required speed plan. The speed ordered is known as the “Speed Rung On” (SRO).

The first step to calculate the SRO is to accurately determine the ship’s current position. This is normally done by plotting a fix of the ship’s position, which is triangulating the ship’s position using some combination of bearing lines, radar ranges, and possibly depth soundings. This is known as fixing the ship’s position. GPS fixes can also be used, but are not normally used in Pilotage waters due to the frequent errors introduced by fouled GPS signals. *Of note, using GPS as a primary source of positioning for ARNAs would also be subject to this error. As such, the location of the ARNA placement should make use of the ship’s NavDDS which makes use of various sources to more accurately determine the ship’s position.*

Secondly, the NavO needs to determine the distance to go to the end of the navigation passage. To aid in this, in the planning stage, the NavO calculates the distance to go to the end of the passage at various points along the route. They then plot these distances as “Distance-to-go bubbles” on the chart and in the Navigation notebook. Knowing the current position and reviewing the recorded data in their notebook, the NavO is able to approximate the current distance to go and determine what the speed required is.

Thirdly, the NavO must calculate the current tidal set. This is done using a series of fixes. After the second fix, the NavO or designated Fixing Officer (FixO) can determine the tidal set by measuring the difference between the dead-reckoned position and the plotted position.

The Passage Manager ARNA alleviates the NavO and the FixO of needing to

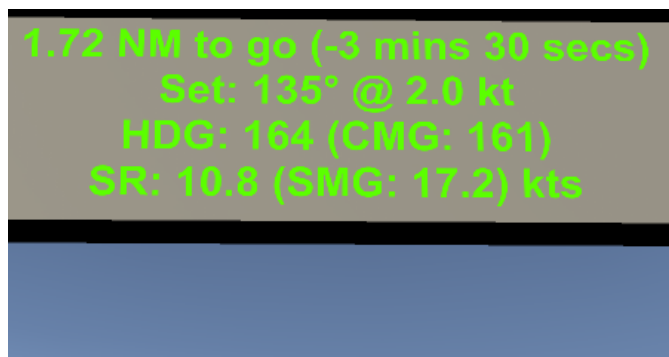


Figure 7.8: The Passage Manager provides the NavO with information on the distance to go to the end of the navigation passage, the current tidal set, the current speed made good and the speed required in order to arrive on time.

calculate this information. It provides real time information including the distance to go, ETA, tidal set, speed made good and speed required information. As per Figure 7.8, this information is provided as a HUD. Given this information, the NavO or OOW can easily determine the appropriate SRO and to manage the speed plan, and CMG to maintain track.

### **Real World Source of Information - Passage Manager**

The Passage Manager system requires the following pieces of information:

1. The planned tracks. The sources for this information was described previously when discussing the Track ARNA;
2. The ETA. This information will need to be configurable and the ARNA system should allow the user to input this value manually; and
3. NMEA information from the ship's NavDDS.

Using the planned tracks, the ARNA system can calculate the total distance to go. This is done by adding the distance to the next waypoint to the remaining distance from that waypoint, along the route, to the destination. In addition to providing the current position of the ship, the ship's NMEA information also provides an accurate time signal. After which, the speed required is simply a function of the distance and time remaining.



Figure 7.9: The Ship Avoidance ARNA provides a textual overlay in position with other vessels. The text is displayed upon a panel that remains oriented towards the observer. The text informs the NavO of the name of the vessel, current range, and CPA.

#### 7.4.5 Ship Avoidance

Shipping avoidance, including the arrangement of safe passage, is an essential component of Pilotage and is one of the major sources of operator overload. One crucial aspect of shipping avoidance is accurately identifying other vessels. This helps to correlate the visual picture with other contact avoidance systems such as automatic identification system (AIS) [102], navigation RADAR, and Marine Communications and Traffic Services (MCTS).

As seen in Figure 7.9, a Ship Avoidance ARNA was developed to provide the NavO with real-time shipping information. This information assists in identifying the vessel and determining if risk of collision exists.

#### User Interaction - Ship Avoidance

Without the use of the Ship Avoidance ARNA, the Navigator makes use of multiple techniques to identify other vessels, including:

1. Using a Vessel Traffic Service (VTS): stationed on the bridge are naval communicators [103]. They help to maintain the navigation picture by calling into a VTS, such as the Marine Communications and Traffic Services (MCTS) provided by the Canadian Coast Guard [104]. They call into VTS stations using a Very High frequency (VHF) radio at established checkpoints and gather traffic information from the VTS radio operator. This information is packaged into a

oral report and provided to the NavO. As an example report, they NavO may hear:

*“NavO, NavComm, MV ALICE is departing Bravo jetty at 0840. MV BOB is inbound at checkpoint 3. MV CHARLIE is outbound at checkpoint 5. MV DARRELL is fuelling at Echo jetty and requests a low wake. Diving operations are happening off Foxtrot jetty until 1100.”;*

Using their navigation notebook: the NavO can make use of recorded information in their notebook to correlate how the reported position of other vessels and visual sightings lie in relation to navigation marks;

2. Using AIS: the NavO may look at an AIS graphical plot, such as on the ECPINS system, and see icons representing where other ships are in relation to the navigation passage;
3. Using navigation RADAR: the NavO would make plots on the navigation RADAR and allow the ARPA system to provide information on movements of other ships;
4. Using the Operation’s Room: the Operation’s Room will have personnel manning RADARs and using cameras to help identify vessels. These reports will be provided to the NavO in block reports using an internal communication device.
5. Using Lookouts: the bridge will have multiple personnel acting as lookouts. The lookouts will report what they see to the OOW, who will then make a report to the NavO.
6. Visually: The NavO will look out the windows, take visual bearings and use binoculars to try and correlate the information received from block reports with the visual picture.

This information will come in at different times through a series of formal block reports that will require context switching and concentration by the NavO. This information needs to be processed in addition to maintaining the safe navigation of the ship. The NavO must anticipate how the current navigation plan will be

impacted and make prudent decisions to either change course and/or speed in a manner adhering to the COLREGS and available safe water.

With the Ship Avoidance ARNA, the NavO will be able to look at the contacts around him and immediately be able to correlate vessel identity via a textual overlay. As the information is received from other systems and through block reports, the NavO can confirm what is reported with what is seen thereby building confidence in the track picture.

In addition to identifying the other ships, the NavO must also appropriately avoid collision. Without the Ship Avoidance ARNA, the NavO relies upon multiple inputs for collision avoidance, including:

1. Visual bearings of the ship is the primary method in determining if risk of collision exists. If a vessel is closing on a steady bearing then there is a risk of collision. Whether a vessel is drawing left or drawing right, the rate of the bearing change, and proximity to the other vessel will also help to determine the risk of collision and the applicable COLREG situation.
2. RADAR ARPA: The RADAR report will provide a course, speed and CPA for the other vessel. This information is secondary to visual bearings as it can be slow to update and lack accuracy during course alterations.
3. Marine VHF radio [105]: The NavO can broadcast on appropriate VHF channels to contact the other ship and make passaging arrangements. This is one of the main reasons why appropriately identifying the other vessel is crucial.

With the Ship Avoidance ARNA, the CPA is provided to the NavO via the textual overlay. It is expected that the NavO will continue to verify the visual bearing as required by the COLREGS.

### **Real World Source of Information - Ship Avoidance**

Much of the information required for the textual overlay can be created using AIS. As discussed previously, the ARNA system is expected to have an interface with the NavDDS system. As such, the NavDDS system can provided AIS track information. The textual overlay can then be positioned based on AIS track's reported position



and masthead height. Alternatively, the ECPINS system has an AIS feed and could provide AIS track information via the ARNA-ECPINS interface.

The CPA can be obtained using different methods, including calculating it from NavDDS track information (including AIS and RADAR). This is a simple relative velocity problem that can be programmed into the ARNA system using linear algebra.

Additionally, the CPA can be calculated using computer vision. This would be a much more complex solution that would require determining the visual bearing of the other vessel and seeing if it is drawing left, right or closing on a steady bearing. This information could augment the NavDDS CPA solution calculated before or be used as a warning system that the CPA may be inaccurate. Likewise, the GPS position and information provided by the NavDDS system could be used as inputs to a computer vision solution, thereby assisting it on determining where to look for potential vessels.

<b>ARNA</b>	<b>Compliance with IMO e-Navigation Strategy</b>	<b>Relation to Literature Review Findings</b>
<b>Track</b>	The Track ARNA is consistent with existing navigation principles as it aligns with digital and paper representations of the planned course. It ensures the NavO remains the core decision maker. It augments rather than replaces existing navigation systems and is therefore adherent to system failure requirements. It facilitates bridge resource management.	The Track ARNA is consistent with current practices and uses colour to convey information. The Track ARNA uses size of distance-of-track panels to address depth perception issues.

<b>ARNA</b>	<b>Compliance with IMO e-Navigation Strategy</b>	<b>Relation to Literature Review Findings</b>
<b>Passage Manager</b>	The Passage Manager ARNA is consistent with existing navigation principles in that it provides information that is currently being calculated in the conduct of navigation passages. It ensures the NavO remains the core decision maker. It augments rather than replaces existing navigation systems and is therefore adherent to system failure requirements. It facilitates bridge resource management.	The Passage Manager ARNA is rendered inside of the bridge while other ARNAs are not. This helps to address depth perception issues. The information is contained within a small area which helps mitigate impacts of FOV constraints.

<b>ARNA</b>	<b>Compliance with IMO e-Navigation Strategy</b>	<b>Relation to Literature Review Findings</b>
<b>Collision Avoidance</b>	The Collision Avoidance ARNA is consistent with existing navigation principles in that it aligns with track data received from existing systems, like AIS and ARPA. It ensures the NavO remains the core decision maker. It augments rather than replaces existing navigation systems and is therefore adherent to system failure requirements. It facilitates bridge resource management.	The Collision Avoidance ARNA uses colour to help inform the NavO of risk of collision. The size of the panels changes based on range to the ship, thereby helping to address depth perception issues. The ARNA is occluded by the bridge stanchions, which also helps with depth perception.

<b>ARNA</b>	<b>Compliance with IMO e-Navigation Strategy</b>	<b>Relation to Literature Review Findings</b>
<b>Danger Area</b>	<p>The Danger Area ARNA is consistent with existing navigation principles as it represents clearing bearings and clearing depths already in use in navigation. It ensures the NavO remains the core decision maker. It augments rather than replaces existing navigation systems and is therefore adherent to system failure requirements. It facilitates bridge resource management.</p>	<p>The Danger Area ARNA uses colour to help inform the NavO of risk of grounding. It does not address FOV issues with regards to the red pland that is displayed and the impact of this will require further examination. It does address FOV issues with regards to presenting the distance panels in a small area. The distance panels also help with depth perception as they change size based on proximity as would real billboards.</p>

ARNA	Compliance with IMO e-Navigation Strategy	Relation to Literature Review Findings
<b>Clearing Area</b>	The Clearing Area ARNA is consistent with existing navigation principles in that it aligns with track data received from existing systems, like AIS and ARPA. It ensures the NavO remains the core decision maker. It augments rather than replaces existing navigation systems and is therefore adherent to system failure requirements. It facilitates bridge resource management.	The Clearing Area ARNA uses colour to help inform the NavO of reduction in ability to turn. It does not address FOV issues and the impact of this will require further examination.

Table 7.1: ARNAs alignment with the IMO e-Navigation Strategy and Literature Review.

## 7.5 Implementation Summary

Developing a VR simulator allowed for the prototyping of ARNAs. The development of these ARNAs considered providing information in a consistent fashion in line with current navigation practices, as per Table ???. By viewing them as an observer on the bridge of a frigate via the Oculus Rift, adaptations and corrections could be made to best adhere to the visualization principles and observations discussed previously. This included the use of appropriate colours and visualizations that are in-line with current navigation practices (such as considering the current practice of using LDLs, Clearing Bearings and tracks to ensure safe passage). The validity and suggestions for improvements of these ARNAs is explored in the next chapter via a user study.

## Chapter 8

### User Study

#### 8.1 Introduction

A user study was conducted over a period of three weeks. The user study demonstrated ARNAs to professional mariners and obtained written and oral feedback. Eleven (n=11) participants participated in the study, with expertise including Bridge Watchkeepers, Fleet Navigating Officers, and Commanding Officers. Participants were mostly Officers of the Royal Canadian Navy (RCN), but participants also stemmed from the Royal Australian Navy (RAN) and private industry.

#### 8.2 User Study Overview

This user study was conducted remotely to ensure participant safety during the COVID-19 pandemic. Subject Matter Experts (SMEs) were solicited through email and social media. SMEs were defined as professional mariners who had at least one year of experience navigating ship's at sea and were familiar with the principles outlined in Bowditch. Those that responded indicating interest were provided with a consent form. Sample copies of the solicitation email and consent form are included as appendices of the Research Ethics Board Application Form (Appendix A).

A Microsoft Teams meeting was scheduled with those participants who agreed to the consent form. Immediately prior to the scheduled meeting, the participants were provided with a link to download the desktop application, that was designed for the testing and evaluation of the proposed ARNAs.

The participants were requested to download the application to their computer and share their screen with the researcher while using it. The application displayed each visualization in series to the user. The participant was first provided with a description of the ARNA and instructions on its use in Pilotage. Then, the ARNA was demonstrated using a ship simulation. During the ship simulation, the participant

could move the mouse around to view in first person the marine environment and ARNAs being demonstrated.

Finally, the desktop application gave control to the user to allow them to control the ship's movements using keyboard arrow keys. They were provided with directions to avoid collisions with other shipping vessels and to arrive at the destination on time. In particular, they were required to stay within 200 yards of the track, to remain outside of 100 yards from other ships, and to arrive at the destination within 30 seconds of the planned time. All participants were successful on their first try.

After the desktop application portion, the participants were provided with an online survey questionnaire to obtain feedback. A series of statements were provided about each visualization. Each participant indicated how much or how little they agree with the statement. For each visualization, the participant was provided with an opportunity to provide written feedback to the researchers. After completing these sections, the participant was provided an opportunity to provide written feedback on the use of ARNAs as whole. A detailed results report with comments is included (Appendix B).

### **8.3 User Study Summary of Results**

A summary of the results detailed in Annex B is provided below, including the addition of oral feedback provided during the conduct of the user study. Each ARNA is looked at in turn, with a summary of the feedback, observations made during the conduct of the simulation, and suggestions for improvement given by the participants. Finally, a general summary of the findings is provided in support of the user study hypothesis.

#### **8.3.1 Track ARNA SME Feedback**

The overwhelming consensus was that the Track ARNA was effective in determining if the ship was port or starboard of track and how far off track the ship was, with 10 out of 11 participants from the user study agreeing. One user indicated that “the visual feedback was unobtrusive, obvious, and provided an immediate and easy-to-understand measure of location relative to track.” Another user indicated that the ARNA is a “good tool to indicate where the ship is relative to its planned course.”

Additionally, the Track ARNA was said to do “its job very well” and to be “unobtrusive” and “obvious.”

Additionally, there was agreement that the Track ARNA helped to determine when the ship would need to alter for the next track, with 10 agreeing (9 strongly agreeing and 1 somewhat agreeing, and 1 strongly disagreeing). The consensus was that the track ARNA was not confusing and would improve safety, with 10 out of 11 participants agreeing. It was the general consensus that the Track ARNA was not distracting and that the colour choices were helpful (with 7 strongly disagreeing with it being distracting, 3 somewhat disagreeing, and 1 neither agreeing or disagreeing).

Oral feedback from the user study suggested that the display of the distance off track panel was the most important part of the Track ARNA. This was consistently met with approval and was noted by the participants, with 9 out of 11 participants making statements of approval of this feature about the Track ARNA. It was said that knowing how far off track with a glance would greatly assist the conduct of the navigation passage.

### **8.3.2 Track ARNA SME Observed Interaction**

All participants were able to quickly and effectively make use of the Track ARNA. They were observed looking towards the track to see how far off track they were, and to adjust the ship’s heading as necessary to stay within the 200 yards required. They commented on the location of the ship in relation to the the upcoming tracks and were able to quickly make decisions on which side of the track to steady up on to avoid upcoming collision situations.

User comments included statements such as, “I’m 2 cables from course alteration” and “I know that I’m 50 yards port of track.” When manoeuvring to avoid a risk of collision, one user said, “right now I’m steering off track which I’m good with because I’m still 5 cables from the destination.” This showed that the information was readily available, and the users were able to make immediate determinations of the navigation situation.



### 8.3.3 Track ARNA SME Suggestions

It was noted during the simulation that having the planned course displayed would be useful, and it was suggested that this could be added to the Passage Manager ARNA. Another suggestion was to change the colour scheme to highlight the track green when on track, and otherwise highlight it red. As the vast majority of participants agreed that the colour choices were very effective, this suggestion would need to be evaluated in a future user study.

One user suggested that cross-track corridors may be useful to augment the visualization. This would provide the navigator or bridge watchkeeper the ability to deviate from track to avoid obstacles without seeking permission from the Captain. They stated:

Other options for assisting in coastal or ocean navigation would be a user-driven manoeuvring area (cross-track corridor) where mates and bridge watchkeepers would be expected to navigate the ship, avoid obstacles and other vessels; this area would be determined by the CO/master and/or navigator.

This may be beneficial if the system was used for bridge watchkeepers following their tracks prior to entering Pilotage situations. It may also be useful when in Pilotage, but further study would be required to determine if it would be distracting.

Although yards was expected to be used exclusively for distance panels, one user suggested that the unit of measure be added to the panel if units could be changed. He said:

If the units for the distance off-track are changeable, then add units to the distance off track to ensure there is no ambiguity.

This would introduce an ability to switch units from yards to nautical miles when the distance off track exceeds 2000 yards. This mechanism is readily applied in other systems in use on ship, such as with the ECPINS system.

### 8.3.4 Passage Manager ARNA SME Feedback

The overwhelming consensus from the user study was that the Passage Manager ARNA was effective in providing pertinent navigation information and was useful

in the conduct of a navigation passage. All participants agreed that the Passage Manager ARNA was useful in the conduct of navigation, with 10 strongly agreeing and 1 somewhat agreeing. All participants strongly agreed that the Passage Manager ARNA was effective in providing the distance to go and speed made good. 9 strongly agreed that the Passage Manager ARNA was effective in providing the speed required, with the other 2 somewhat agreeing. 10 strongly agreed that it was effective in providing the estimate time of arrival, with the other 1 participant somewhat agreeing.

Additionally, it was suggested that the Passage Manager ARNA would “greatly assist with heads up navigation”. Additionally, another user expressed approval of the Passage Manager ARNA by saying:

This is vital information that every navigator is constantly checking. Having it to hand instantly while maintaining a heads up perspective is invaluable and can only increase safety.

Of note, one participant said that some of the terms (such as CMG or SMG) may have recently changed in the Navy. However, when other participants were asked this question it was unable to be corroborated. As such, additional feedback is suggested from the end user to ensure that the current vernacular is used for the HMI.

One participant said the Passage Manager ARNA was “an excellent and obvious tool to make passage navigation safer, especially in close waters.” This feedback helps to support the assertion that ARNAs could improve maritime safety.

### **8.3.5 Passage Manager SME Observed Interaction**

Users were seen to glance quickly to the Passage Manager before adjusting speed, which suggests that the information was useful in making these decisions. The changes in speed were uniformly determined to be correct and to easily adapt to the tidal set. Some participants verbally stated that they were stemming a tide before increasing their speed, indicating that the ARNA was providing the information in way that was easily digested by the participants.

### 8.3.6 Passage Manager SME Suggestions

Comments were generally related to the placement of the ARNA and to the information that was presented within. For example, it was suggested that also displaying the planned course and course to steer would be helpful in maintaining the track:

In addition, for mates/watchkeepers, a notation of the ship's planned track, and course to steer (CTS) would assist in executing their portions of a passage.

One participant suggested that the Passage Manager ARNA might be better below the line of sight rather than above it. As such, it is suggested that the placement should be made configurable. One user suggested that adding in the distance off track to the Passage Manager may also be useful. Additionally, it was suggested that the wheel over location should be dynamic, updating its location to make use of real-time tidal data and the ship's kinematics and the ship's turning data.

### 8.3.7 Collision Avoidance ARNA SME Feedback

The overwhelming consensus from the user study was that the Collision Avoidance ARNA was effective in providing pertinent collision avoidance information and was useful in determining if a risk of collision existed. All participants strongly agreed that it was effective in providing the closest point of approach of other ships and that the use of colours (white, yellow, and red) helped to prioritize which ships required monitoring. The Collision Avoidance ARNA was generally assessed as not being confusing and that it would improve safety, with 9 strongly disagreeing with the statement "The Collision Avoidance ARNA is confusing." The general consensus was that the Collision Avoidance ARNA would not distract the navigator in the conduct of the passage, with 7 strongly disagreeing with it being distracting, 2 somewhat disagreeing and 2 somewhat agreeing. It was indicated that the use of colours and the option to be able to fade out the display was highly effective.

It was also suggested that the Collision Avoidance ARNA would assist with heads up navigation, with one participant saying:

Many navigators end up standing in front of the radar, staring down. This can negatively affect their perception of their surroundings. The Collision

Avoidance ARNA removes this scenario and improves safety and allows the navigator to stay more alert and able to monitor several vessels at once.

### **8.3.8 Collision Avoidance ARNA SME Observed Interaction**

The Collision Avoidance ARNA shows panels above each ship. This ARNA uses the colour to indicate risk of collision. The distances of which a panel will show white, yellow, or red are configurable. In the simulation, white indicated ships with a CPA greater than 200 yards, while yellow indicate that the CPA was within 200 yards but greater than 100 yards. The panels showed red when the CPA was expected to be less than 100 yards. In general, white would indicate a safe situation with no risk of collision, while yellow would indicate that the NavO should exercise caution due to a closer CPA. The panel shows red to indicate a risk of collision.

The participants were noted manoeuvring the ship in succession until the red panel turned yellow. They spent much less time looking at ships that had white panels, and focussed significant amounts of their attention towards ships that had red panels. Once the red panel turned to yellow, they normally made sounds of relief or expressed satisfaction in the situation.

### **8.3.9 Collision Avoidance ARNA SME Suggestions**

Oral and written feedback suggested that some participants would want more information, such as the bearing and time to CPA, while others did not. One user suggested that more information was necessary and went so far as suggesting that it should mimic the information available from the track sensors. Another user directly contradicted this statement by saying:

Right now it is fairly good - I know the speed, range, and range to CPA  
- I don't want it to look exactly like a radar screen to show where the relative would be, and its good to see that everything is fairly dynamic when you are manoeuvring.

One suggestion made was that the panels could show more information only when requested by the user, such as with selection - this may be an approach that is able

to meet both objectives, where clutter is reduced but additional information could be made available upon request. Selection is currently envisioned as a combination of gaze and a button click. The current selection on these panels makes the panel transparent. As such, to add this additional capability, more research would be needed to determine the appropriate selection mechanism. For example, more than one button could allow this, but it may impact cognitive load. It is expected that dwell selection would not be appropriate in this case as the information and follow-on action is time sensitive.

Additional configuration suggestions were made, including the ability to only display track information for ships that are of concern or risk of collision, or to control the distance settings, or even the colours in use. As such, any implementation would have to allow for customization. The ARNA should be configurable based on the best practices of the industry in use, and at the discretion of the Commanding Officer or Navigator. In particular, as suggested by multiple participants, the ability to reduce the clutter would be especially important in areas with high traffic density. It was suggested that this could be done either using a distance from ownship filter, and/or limiting which ship's Collision Avoidance ARNA to display based on CPA.

Another user suggested that panels that had been set to transparent should automatically be set back to opaque if the risk level increases (i.e. transitioning from white to yellow, or yellow to red). This would help draw the attention of the user back to the risk, and is highly encouraged to be added to this visualization:

Regarding the toggling of visibility, the contact information should reappear if the risk category increases due to changing circumstances, not sure if this is incorporated. For example, if a white note is hidden and the contact changes course to increase collision risk, it should reappear as yellow or red requiring it be hidden again to remove it. -It would be good if hovering over or focusing on a distant contact information callout caused it to pop up larger temporarily allowing for increased readability of information for distant contacts and early planning.

Finally, another user suggested that displaying the other ship's course would be beneficial in order to determine their aspect. They suggested that being able to select

the panels of vessels at far ranges to increase its size would be beneficial, in order to read the text being displayed.

### **8.3.10 Danger ARNA SME Feedback**

The overwhelming consensus from the user study was that the Danger ARNA was very effective in providing the area marked by dangers, would improve safety, and was useful. All participants strongly agreed that the Danger ARNA would improve safety. There was unanimous consensus that displaying the range to the danger area was useful, in all directions. There was strong consensus that red was an effective colour choice for the Danger ARNA, with 10 strongly agreeing that red was an appropriate colour. That said, one participant expressed concern about the choice of also using red with the Track ARNA to indicate when starboard of track:

As red is already used in the navigational track, I worry about the confusion between navigation and danger. Perhaps an orange for the danger area? Or no colours for the navigational track, but have the port or starboard side of the line turn to grey when off course?

There was less consensus on whether or not the Danger ARNA would distract the navigator, but results tended towards it not being distracting, with only one participant suggesting otherwise (7 strongly disagreed with it being distracting, 2 somewhat disagreeing, 1 neither agreeing nor disagreeing, and 1 somewhat agreeing). Some believed that blanking out the entire area would possibly impact visibility of shipping in those areas:

The trial run does not show how other contacts interact with the Danger ARNA (as in how visible they are) it is possible that blanking out the whole area, instead of a dashed line or other identifier, would limit visibility in those areas.

As such, future work could implement visualizing the Danger ARNA as a red dashed line in order to gather more user feedback on the preferences between the two. The ship simulation could be reused to obtain this feedback by adding additional shipping vessels operating inside the danger area.

### **8.3.11 Danger ARNA SME Observed Interaction**

During the ship simulation, it was observed that users were able to quickly make decisions about where to manoeuvre the ship in relation to the dangers and the track when avoiding collision. They seemed to uniformly middle the distance between the track and the clearing area, thereby keeping a safe distance from the dangers.

### **8.3.12 Danger ARNA SME Suggestions**

One of the most often received comments about the Danger Area was the concern about it blanking out an entire area. It was suggested by multiple users that this area could either be made transparent by clicking on it, or be visualized with a dashed line instead.

Additionally, it was repeatedly noted that the closest point to dangers should also be shown. One user indicated “the only thing I considered to be missing was the closest distant to the LDL.” Another user corroborated this when they said:

One potential option would be a dynamic danger range to the closest danger zone, which would augment the beam/ahead ranges.

Also, it was suggested by one user that this ARNA could be configured to only be displayed within a certain range of the dangers to cut down on the visual clutter:

Recommendations for this Danger ARNA would be a user-programmable range at which the Danger ARNA would not display (such as if there are no dangers with X miles of the ship)

### **8.3.13 Clearing Area ARNA SME Feedback**

The consensus from the user study was that the Clearing Area ARNA was effective in providing the area marked by clearing bearings and/or clearing depths, would improve safety, and was useful. All participants strongly agreed that yellow was an appropriate colour for the Clearing Area ARNA. Likewise, all of the participants agreed that the Clearing Area ARNA would improve safety, with 9 strongly agreeing and 2 somewhat agreeing. Also, all of participants agreed that the Clearing Area ARNA was effective in visualizing clearing bearings and/or clearing depths, with 10

strongly agreeing and 1 somewhat agreeing. When asked if the Clearing Area ARNA was effective in alerting the navigator to monitor the proximity of the ship's stern to dangers when altering course, all of the participants agreed (10 strongly agreed and 1 somewhat agreed). Also, all of the participants disagreed with the clearing area ARNA being confusing, with 8 strongly disagreeing and 3 somewhat disagreeing.

There was no consensus on whether or not the Clearing Area ARNA would distract the navigator, but results tended towards it not being distracting, with 8 indicating that they disagreed with it being distracting, 1 neither agreeing or disagreeing, and 2 agreeing.

#### **8.3.14 Clearing Area ARNA SME Observed Interaction**

As stated above when discussing the Danger ARNA, it was observed that users were able to quickly make decisions about where to manoeuvre the ship in relation to the track and the Clearing Area ARNA. They tended to point the ship's head between the track and the Clearing Area ARNA, even before obtaining their distance off track. It is assumed that the user's first inclination was to ensure the ship's safety when adapting to collision situations, before conforming to the off track distance requirements artificially imposed by the user study. In any regard, it seemed that the Clearing Area ARNA allowed them to effectively assess safe water quickly when altering to avoid collision.

#### **8.3.15 Clearing Area ARNA SME Suggestions**

It was suggested that ranges to the Clearing Area ARNA, similar to those shown for the Danger ARNA, would also be helpful. This would help identify how much water they had remaining before their ability to turn was reduced. It was also suggested that displaying more information, rather than just the range to the Danger ARNA would be beneficial. In one panel, the user could be shown the ranges to the Danger ARNA and the Clearing Area ARNA. It was also suggested that displaying the amount of time the NavO could remain on their current course before entering the Clearing Area ARNA would be useful. This was so the operators could "immediately know how long they are able to stand-on based on their current speed."

Additionally, it was suggested that the NavO should be able to reduce the area



to less than 180 degrees of turn. It was noted that this was the “gold standard,” but there may be a need to reduce this to allow navigable water.

The clearing area ARNA provides the navigator or watchkeepers a visual indication of where they must take action to avoid grounding the ship. At present this is based on a 180 degree turn away from dangers (most useful if approaching a hazard from ahead). Recommendations may be to allow the user/navigator to dynamically alter the clearing area, and reduce if less drastic alterations away from dangers are planned. This recommendation would be of most benefit in pilotage, harbour, river and canal transits where the distance from land or underwater hazards may fill the screen with the clearing area.

In doing so, operator training would be required to identify that the Clearing Area is an area in which the ship is in danger of grounding astern when turning, and as such, caution needs to be taken in monitoring the stern when altering. Additionally, navigation briefs before a planned navigation passage would need to indicate the amount of turn possible. This would be similar to how Clearing Bearings are currently reduced and briefed in the RCN.

#### **8.4 SME General Comments and Feedback**

Question 45 in the survey report (Annex B) provides all additional written feedback about the ARNAs presented in general. Feedback included recommendations on how this work could be used practically. Interestingly, the feedback provided additional suggestions of the use of this tool. This included suggestions that it would be useful in a training environment as it is an improvement over existing training aids:

Overall, this is an improvement in the training environment as it clearly demonstrates the fundamental navigation safety and passage requirements. In a real world application, it would be of great use to watchkeepers and Navigators by ensuring that they are able to maintain a continuous watch outside of the platform. It would remove almost all requirement to look at screens internal to the platform. For a follow up, I would be quite keen

to know how it would work during night, to avoid reducing glare or bright lights. Overall a great tool with huge potential for remote operation of vessels on top of its intended use as a Navigator/Watch Keepers aide.

Regarding usefulness at sea, it was suggested that these visualization could be useful in replacing all other navigation screens at sea (ECPINS, RADAR, etc.) and would benefit heads-up navigation. It was suggested that this would be beneficial to both large and small ships. And, additionally, it was suggested that ARNA would provide the information most often requested by the Captain instantly:

As a Captain, ranges to dangers is probably the most often question I ask my Navigator. The ability to instantly provide them without having to reference another piece of equipment or have to calculate it with mental math would certainly improve situational awareness.

Some feedback suggested improvements to the fidelity of the simulation, including adding sound effects and the ability to make passing arrangements. Others suggested it would be useful to expand visualizations to include those that could be used at night.

Directly supporting the idea that ARNAs would increase heads up time and improve safety, and one user indicated:

I can envision this technology of benefit to watchkeepers, mates, navigators and masters, in order to enable personnel to spend more of their bridge rhythm time looking out the windows rather than their navigation systems; the data provided virtually would also allow for better assessments of risk of collision. One potential would be for harbour pilots to leverage this system to facilitate harbour entrances and departures. Overall, I have nil concerns with the ARNAs presented, and feel this system would improve maritime safety.

## 8.5 Data Collection and Analysis

When conducting the one-on-one sessions with the participants, Microsoft Teams was used. The participants shared their computer screen with the researcher along

with their audio. Once consent was given, the embedded Screen Recording feature of Microsoft Teams was enabled to record the video and audio data of the session.

During the video sharing session, notes were made of where the user had oriented their view. Due to the nature of the visualizations being geographically distinct from each other, this helped identify which visualizations were being used at a given time. This also helped to validate that the user could retrieve the information they needed quickly due to the short period time needed to engage with a visualization.

Additionally, the participant was encouraged to talk through their thought-process. Oral comments were recorded and noted by the researcher. This also helped identify that the user was able to obtain the information needed as they often relayed that information to the researcher. Also, they orally identified what information was important to them and why they were making alterations of the ship's heading or speed.

Upon completion of the user-driven portion of the study, the user was asked to conduct an Opinio survey without the researcher. When the participant was done, a detailed report was generated by the Opinio software that collected the responses as well as the associated statistical information.

## 8.6 Limitations

The conduct of this research user study has limitations that impact the conclusions that can be made. Some of these limitations may require future work to overcome in order to be able to make firm conclusions. Some of the limitations involve ecological validity, the potential of confirmation bias, observer-expectancy effect, and a lack of a control condition or comparative condition.

Regarding ecological validity, the ideal presentation of the ARNAs in the desktop simulation is significantly removed from the quality of visualizations capable of being displayed using current technology. For example, the desktop simulation displayed the visualizations with complete FOV. The impacts of a limited FOV should be evaluated and considered in future work. Additionally, the desktop simulation did not address impacts on light intensity. This would have impacts on depth perception and occlusion, as well as impacting the usefulness of ARNAs for night-time scenarios.

One way ecological validity issues was addressed is by creating ARNAs such that

aspects could be viewed even with a limited FOV. For example, the Passage Manager ARNA and the distance panels in the Track, Danger Area, and Clearing Area ARNAs could be viewed in their entirety even with a limited FOV. The visualizations that would be most impacted would be the Clearing Area and Danger Area planes, as they span a large area.

Another limitation is the impacts of confirmation bias. As the researcher was familiar with the conduct of navigation and designed the ARNAs to meet the expected need, there is likely a tendency to seek out support of the assumptions made. For example, when making subjective observations about where the participant was directing their attention, it is possible the researcher focused on those moments where the attention was directed towards ARNAs more than times when it was directed elsewhere. Likewise, it is possible that the researcher focused more on oral feedback that supported existing ideas while tending to ignore other feedback. One way this was countered was by using video and audio recordings of the user study. This allowed for the session to be replayed and for the extraction of the oral comments. It also allowed for verification and confirmation of noted observations.

Taking this a step further, another limitation is the potential for observer-expectancy effect to have impacted the feedback received. An effort was made to not influence the feedback by remaining quiet during the simulation and asking the user to openly talk about what they were thinking and doing. That said, sometimes the participants engaged the researcher in dialogue and this could lead to an observer-expectancy effect impacting the feedback to align with the cognitive bias of the researcher.

Another limitation of the user study was the lack of a control condition or comparative condition. As the desktop simulation evaluated the participant conducting a navigation passage, it would be useful to see how well the participant could conduct the passage void of any ARNA. This would not have been possible without traditional navigation aids, such as ECPINS, RADAR, lookouts, a ship's polaris, and access to navigation charts. As this was not feasible within the confines of the desktop simulation, no baseline was established. One avenue to address this would be to collaborate with an entity that has a bridge simulator for navigator training. This would require integration of the ARNAs into the existing visuals of the bridge simulator, but it would allow comparison of traditional navigation methods against navigating with

the use of ARNAs.

Finally, it's worth noting that there are differences in VR and AR presentations that limit the usefulness of VR as a test tool for AR visualizations. For example, depth perception was not an issue with the AR visualizations presented as they were rendered using the same lighting conditions and cameras as the 3D models representing real world objects. Importing the AR device simulator prototyped described earlier may be a way of addressing this issue. Other known problems in AR, such as with latency, registration issues, and occlusion are easy to ignore in a VR implementation. It would be beneficial to consider simulating these effects in order to increase the fidelity of the simulation. It is important to not occlude vital bridge equipment with AR overlays, so ensuring a culling mask is accurately applied would be crucial.

## **8.7 Summary**

In summary, the user study provides support to the hypothesis that ARNAs would improve maritime safety and assist in the conduct of navigation. All participants provided positive feedback, with some expressing hopefulness that the work would someday make it into production. It was observed that the ARNAs could be used completely void of any additional information to keep the ship safe in a simulated environment. The participants were able to effectively navigate the passage, avoid other shipping, and arrive on time without needing to consult any additional tools.

## Chapter 9

### Conclusion

#### 9.1 Introduction

In this thesis we looked at how AR can be used to assist coastal water navigation and improve maritime safety. It was determined that despite the current AR device limitations, AR visualizations can still be created and pre-validated using other mechanisms such as VR and desktop simulations. We leveraged existing work in the field, current navigation aids and tools, and the IMO e-Navigation Strategy to form the basis of our approach.

We examined the sources of information readily available on a ship to ensure that the visualizations being proposed were feasible. Additionally, in the creation of a ship simulation, we showed how existing data could also be used to more readily generate realistic VR environments. This was shown to have benefits in creating a navigation passage planning tool, where the NavO could simulate driving their planned navigation passage before entering the area.

Finally, we conducted a user study where we presented our proposed ARNAs to subject matter experts for feedback. The user study confirmed the hypothesis that ARNAs would assist in the conduct of coastal water navigation and would improve maritime safety. As such, it is suggested that ARNAs would be an excellent complement to e-Navigation systems. Additionally, based on user feedback and the ability to visualize real world locations in situ, it is also suggested that this technology could be useful to assist in training of Navigators and to assist in visualizing and planning navigation passages.

#### 9.2 Future Work

The user study participants provided excellent feedback on the ARNAs proposed and possible uses of the technology. Additional user engagement is suggested to evaluate

some suggestions for improvements to ARNAs and some of the other avenues for how this technology could be deployed.

One avenue for future work is to create alternate implementations of the ARNAs based on feedback and then conduct another user study. Examples of alternate implementations include having opacity control of the Danger Area and Clearing Area ARNAs. That user study would present both options in sequence and ask the users to rate and compare the variants. Also, if the COVID-19 pandemic continues to ease, it may be possible to conduct a user study using VR systems as originally planned.

Another avenue for future work would be to explore porting the ship simulator and VR terrain generation into a NavO navigation passage planning tool. Such a tool is envisioned to allow a NavO to import updated S-57 navigation charts, a database of terrain data, and the Navigator's planned passage from an ECPINS. The NavO could then use a desktop simulation or VR headset to conduct the Navigation passage with various scenarios (fog, rain, heavy shipping, strong tidal set, etc.). It is expected that this tool would allow for better preparation and improve maritime safety. It is also envisioned that video files from the simulation could be exported and selectively used in Navigation Briefs to the bridge team. This would allow the whole team to visualize and prepare their responses accordingly.

Another potential use case for this technology is in Navigator training. As proposed by users, the ARNAs were an effective tool in visualizing concepts of navigation. It was suggested that this would allow Navigator trainees to better understand the concepts being taught. As such, it may be useful to obtain feedback from navigator training schools for potential collaboration.

The ARNAs fuse multiple sources of data together in ways that can be beneficial to navigation through mediums other than AR. Future user studies or prototypes could look at the benefits of the ARNAs in other mediums, such as displaying on fixed screens mounted on the bridge, on hand held devices/screens or on a laptops. Such implementations should be evaluated via user study in order to determine any potential value, such as reduction of cognitive load and/or improvements to maritime safety.

### 9.3 Closing

Improvements to maritime safety can help save lives and reduce damage to property. It is suggested that ARNAs can improve maritime safety by providing navigation information in real time in an effective manner while allowing the NavO/Captain to continue to be the core decision maker. Although several participants of the user study were enthusiastic about ARNAs completely replacing other navigation methods, due consideration to the measured implementation requirement of the IMO e-Navigation strategy must be given.

Continued advancements in AR OST devices means that ARNAs are a feasible future addition to navigation at sea. But, as this thesis indicates, much work in this field can continue in the interim. User feedback suggests there are many potential avenues for this research. Those avenues, such as a planning or training aid, are feasible with current hardware.



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# Appendices

## Appendix A

### Research Ethics Board Application



**DALHOUSIE  
UNIVERSITY**

# RESEARCH ETHICS BOARDS APPLICATION FORM

## Prospective Research

This form should only be used if new data will be collected. For research involving only secondary use of existing information (such as health records, student records, survey data or biological materials), use the *REB Application Form – Secondary Use of Information for Research*.

This form should be completed using the [Guidance for Submitting an Application for Research Ethics Review](#).

### SECTION 1. ADMINISTRATIVE INFORMATION

[File No:

office only]

Indicate the preferred Research Ethics Board to review this research:

Health Sciences OR  Social Sciences and Humanities

<b>Project Title: Use of Augmented Reality for Coastal Water Navigation</b>
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1.1 Research team information				
Lead researcher (at Dalhousie)	Name	Randy Herritt		
	Email (@dal)	<a href="mailto:rn851080@dal.ca">rn851080@dal.ca</a>	Phone	(902) 817-2048
	Banner #	B00423833	Academic Unit	Comp Sci
Co-investigator names, affiliations, and email addresses	Dr. Stephen Brooks, sbrooks@cs.dal.ca			
Contact person for this submission (if not lead researcher)	Name			
	Email		Phone	
Study start date	May 3, 2021	Study end date	May 7, 2021	

1.2 For student submissions (including medical residents and postdoctoral fellows)			
Degree program	Masters of Computer Science		
Supervisor name and department	Dr. Stephen Brooks		
Supervisor Email (@dal)	<a href="mailto:sbrooks@cs.dal.ca">sbrooks@cs.dal.ca</a>	Phone	
Department/unit ethics review (if applicable). <b>Undergraduate minimal risk research only.</b>			
Attestation: <input type="checkbox"/> I am responsible for the unit-level research ethics review of this project and it has been approved.			
Authorizing name:			
Date:			

1.3 Other reviews		
Other ethics review (if any) for this research	Where?	
	Status?	
Scholarly/scientific peer review (if any)		
Is this a variation on, or extension of, a previously approved Dal REB submission?	<input type="checkbox"/> No <input type="checkbox"/> Yes Dal REB file # _____	
<b>If yes</b> , describe which components of the current submission are the same as the previously approved submission (list section numbers), and which components are different from the previously approved submission (list section numbers). You may also use highlighting to clearly indicate revised text.		

1.4 Funding		[X] Not Applicable
Funding (list on consent form)	Agency	
	Award Number	
	Institution where funds are/will be held	<input type="checkbox"/> Dalhousie University <input type="checkbox"/> Other: _____

<b>1.5 Attestation(s).</b> The appropriate boxes <i>must</i> be checked for the submission to be accepted by the REB		
<p><input checked="" type="checkbox"/> I am the <b>lead researcher</b> (at Dalhousie) named in section 1.1. I agree to conduct this research following the principles of the Tri-Council Policy Statement <i>Ethical Conduct for Research Involving Humans</i> (<a href="#">TCPS</a>) and consistent with the University <a href="#">Policy on the Ethical Conduct of Research Involving Humans</a>.</p> <p>I have completed the TCPS Course on Research Ethics (<a href="#">CORE</a>) online tutorial.</p> <p><input checked="" type="checkbox"/> Yes    <input type="checkbox"/> No</p> <p>For Supervisors (of student / learner research projects):</p> <p><input checked="" type="checkbox"/> I am the <b>supervisor</b> named in section 1.2. I have reviewed this submission, including the scholarly merit of the research, and believe it is sound and appropriate. I take responsibility for ensuring this research is conducted following the principles of the <a href="#">TCPS</a> and University <a href="#">Policy</a>.</p> <p>I have completed the TCPS Course on Research Ethics (<a href="#">CORE</a>) online tutorial.</p> <p><input checked="" type="checkbox"/> Yes    <input type="checkbox"/> No</p>		

## SECTION 2. PROJECT DESCRIPTION

<b>2.1 Lay summary</b>
<p>2.1.1 In <b>plain language</b>, describe the rationale, purpose, study population and methods to be used. Include a summary of background information or literature to contextualize the study. What new knowledge, or public or scientific benefit is anticipated? [maximum 500 words]</p> <p>Coastal water navigation is the process of directing a ship's movements when in close proximity to land and other shipping. It is a very complex tasks that requires a Navigator to combine and process information from multiple sources. While interacting with these information systems, the Navigator is unable to look out the ship's windows. Any time spent not looking out the windows increases the risk of a maritime incident (running aground or colliding with other shipping). Additionally, the large amount of information can cause delays in making assessments that also increases risk.</p> <p>Augmented Reality (AR) provides a way for computers to process multiple sources of data and then visualize the information obtained. This presents an opportunity to visualize navigation information in ways that may assist a Navigator in the conduct of coastal water navigation. The information can be presented via optical see through devices which would allow the</p>

Navigator to remain looking out the ship's windows. This has the potential to improve maritime safety and decrease risk of groundings and collisions.

The purpose of this study is to simulate the presentation of navigation information visualizations to ship's navigators for appraisal to gain insight into how AR can be used to used as a tool for coastal water navigation.

This user study will be conducted remotely to respect COVID-19 social distancing requirements. The participants and the researchers will not be collocated. Instead, distributed desktop applications, screen share and voice communication software (Microsoft Teams) will be used. A desktop application will be provided that presents a virtualized maritime environment. A set of proposed AR visualizations will be presented to the Navigator. After a tutorial session for each visualization, the Navigator will attempt to safely navigate the virtual ship using mouse and keyboard controls. The participants will be provided a questionnaire asking for feedback on the visualizations.

This is a pilot study.

This is a fully developed study.

2.1.2 Phased review. If a phased review is being requested, describe why this is appropriate for this study, and which phase(s) are included for approval in this application. Refer to the [guidance document](#) before requesting a phased review.

Not applicable

## 2.2 Research question

State the research question(s) or research objective(s).

The research objective will be to gain feedback from subject matter experts on the feasibility of using AR for the conduct of coastal water navigation and to identify how the proposed visualizations could be improved to best suit user need.

## 2.3 Recruitment

2.3.1 Identify the study population. Describe and justify any inclusion / exclusion criteria. Also describe how many participants are needed and how this was determined.

The study population will be professional navigators with at least 1 year of navigation experience. The preference will be given to those navigators familiar with the navigation principles outlined in Bowditch's American Practical Navigator (Bowditch) because the visualizations were developed with consideration for these navigation practices. We want navigators who have at least 1 year experience to ensure they the appropriate amount of expertise to adequately judge the visualizations being presented.

As the principles outlined in Bowditch are in use by professional Navies of the world, naval officers from the Royal Canadian Navy (RCN) and Royal Australian Navy (RAN) Officers will be recruited. A secondary population of consideration is commercial mariners. As such, recruits may include coast guard navigators or professional mariners operating for private companies.

2.3.2 Describe recruitment plans and append recruitment instruments. Describe who will be doing the recruitment and what actions they will take, including any screening procedures.

Recruitment will be done by the primary researcher. The primary method for recruitment will be to contact professional mariners directly via email or phone call and to follow up on any referrals. LinkedIn and referrals will be used to identify professional mariners.

2.3.3 If you require permission, cooperation, or participation from a community, organization or company to recruit your participants, describe the agreement obtained from the relevant group(s). Attach correspondence indicating their cooperation and/or support (required). Describe any other community consent or support needed to conduct this research. (If the research involves Indigenous communities complete section 2.11).

[x] Not applicable

## 2.4 Informed consent process

2.4.1 Describe the informed consent process:

A) How, when and by whom will the study information be conveyed to prospective participants? How will the researcher ensure prospective participants are fully informed?

Prospective participants will receive a copy of the consent form (Appendix A) via email (Appendix B) after they indicated an interest in participating in the study. They will be instructed to read the consent form before giving consent. The email will also indicate to prospective participants that they can ask clarifying questions regarding the study or the form itself.

B) Describe how consent will be documented (e.g. written signature, audio-recorded, etc).

Consent will be recorded via a web survey (hosted at surveys.dal.ca).

Participants who opt not to provide consent and not to participant will receive a "Thank you" message and will not be able to proceed.

[X] Append copies of all consent information that will be used (e.g. written consent document, oral consent script, assent document/script, etc).

*Note: If the research will involve third party consent (with or without participant assent), and/or ongoing consent, ensure these are described above.*



2.4.2 Discuss how participants will be given the opportunity to withdraw their participation (and/or their data) and any time (or content) limitations on this. If participants will not have opportunity to withdraw their participation and/or their data explain why.

Participants are informed in the consent form and that they can withdraw from the study at any time.

Participants can opt to withdraw their data from the study up to 2 weeks after the interview. If a participant opts to withdraw from the study, their questionnaire will be securely erased.

2.4.3 If an alteration/exception to the requirement to seek prior informed consent is sought, address the criteria in TCPS article [3.7A](#). If the alteration involves deception or nondisclosure, also complete section 2.4.4.

Not applicable

2.4.4 Describe and justify any use of deception or nondisclosure and explain how participants will be debriefed.

Not applicable

## 2.5 Methods, data collection and analysis

2.5.1

A) Where will the research be conducted?

Research will be conducted remotely using Microsoft Teams. Participants will be able to participate in the study at their homes.

B) What will participants be asked to do?

The Participant will be asked download and install an application onto their computer. Images of the software in use is included in Appendix C. The software application will be pre-scanned with anti-virus software. They will be asked to share their screen using Microsoft Teams while running the application. As illustrated in Appendix C, the participant will use the desktop application to learn more about each ARNA. The application will provide a description of each ARNA followed by a guided tour with prompts to direct the user to view different aspects of the visualization. They will then answer questions to rate the visualizations (Appendix D). They will be given a task to control the virtual ship to avoid collision with other ships, avoid running aground, and to arrive at a destination within 30 seconds of a estimated time of arrival. They will then be asked follow on questions on how they used the visualizations through the task (Appendix D).

C) What data will be collected using what research instruments? *(Note that privacy and confidentiality of data will be covered in section 2.6)*

The following data will be collected:

- answers to the questionnaire questions (Appendix D) will be collected using Opinio at <https://surveys.dal.ca/opinio/admin/folder.do>
- video and audio recording of screenshare session will be collected using Microsoft Teams and Open Broadcaster Software (OBS).

D) How much of the participant's time will participation in the study require?

Approximately 2 hour will be required. The guided ARNA presentations and user driven portion of the application have prograded duration of approximately 1 hour. Another hour is anticipated for completion of questionnaire questions.

Append copies of all research instruments (questionnaires, focus group questions, standardized measures, etc)

This is a clinical trial (physical or mental health intervention) – ensure section 2.12 is completed

2.5.2 Briefly describe the data analysis plan. Indicate how the proposed data analyses address the study's primary objectives or research questions.

After using the desktop application, the participant will be asked to complete the questionnaire (Appendix D). The questionnaire will ask how much they agree with the statements about each ARNA (Strongly Disagree/Somewhat Agree/Neither Agree nor disagree/Somewhat agree/Strongly agree). The interview results will be tabulated to provide a scoring for each question. Scoring will be conducted by assigning the following numbers to each checkbox:

- Strongly Disagree = -2
- Somewhat Disagree = -1
- Neither agree nor disagree = 0
- Somewhat agree = +1
- Strongly Agree = +2

In some cases, where the statement is negative towards the ARNA, then the scoring will be reversed. For example, "The Track ARNA is confusing" would consider "Strongly Disagree" as +2 instead of -2.

Participant responses will be compared and aggregated. Positive averaged scores for each ARNA will support the hypothesis that augmented reality can be used to assist in coastal water navigation. Positive average responses for each question related to improving safety will support the assertion that AR can be used to improve maritime safety.

Participants feedback is also requested in written form. This feedback, in addition to comments made by the user during the screenshare, will be used as suggestions for future work.

2.5.3 Describe any compensation that will be given to participants and how this will be handled for participants who do not complete the study. Discuss any expenses participants are likely to incur and whether/how these will be reimbursed.

The participants will not be compensated.

## 2.6 Privacy and confidentiality

### 2.6.1

A) Describe who will have knowledge of participants' identities.

Only the PI will know the relationship between participant's name and unique participant IDs.

B) Describe the level of identifiability of the study data (anonymous, anonymized, de-identified/coded, identifying) (see [TCPS Chapter 5A – types of information](#) for definitions).

Data from this study will be associated to participants IDs (Coded Information).

C) Specify which members of the research team (or others) will have access to participants' data and for what purpose.

The results from the interview questions might be used in presentations, publication and defenses.

D) Describe measures to ensure privacy and confidentiality of study documents and participant data during the data collection and analysis phase. *[Note that plans for long term storage will be covered in 2.6.2]*

- Address: handling of documents/data during data collection; transportation or transfer of documents/data; storage of documents/data (during the study).
- If a key-code will be maintained, describe how it will be kept secure.
- For electronic data, describe electronic data security measures, including file encryption and/or password protection [as applicable](#).
- For hard copy documents, describe physical security measures (specify location).

We will use Opinio (Dal Surveys) for the questionnaire. The questionnaire will include multiple choice answers and written responses to questions. Personal information from the questionnaire will be stripped to a separate file. Data will always refer to Participant ID.

This research involves personal health records (ensure section 2.13 is completed)

2.6.2 Describe plans for data retention and long-term storage (i.e. how long data will be retained, in what form and where). Will the data eventually be destroyed or irreversibly anonymized? If so, what procedures will be used for this? Discuss any plans for future use of the data or materials beyond the study currently being reviewed.

Survey responses will be stored on Opinio on the Dalhousie Servers. Recorded audio and video from the screenshare will be stored on a secure encrypted server at the Faculty of Computer Science, Dalhousie University. The data will be retained for three years and after this span of time all of the electronic data will be deleted permanently from the system. Only the researchers listed in the consent form will have access to the data collected in this study.

This research will be deposited in a data repository (ensure section 2.14 is completed)

### 2.6.3

Describe if/how participant confidentiality will be protected when research results are reported:

A) For quantitative results - In what form will study data be disseminated?

- Only aggregate data will be presented
- Individual de-identified, anonymized or anonymous data will be presented
- Other. If "other", briefly describe dissemination plans with regard to identifiability of data.
- Not applicable, only qualitative data will be presented

B) For qualitative results - Will identifiable data be used in research presentations/publications? If participants will be quoted, address consent for this and indicate whether quotes will be identifiable or attributed.

- Not applicable, only quantitative data will be presented

Participants are given the option to allow or not researchers to use quotes when disseminating results in the consent form. These quotes would be collected from the written questions in the questionnaire (Appendix D) and from the recorded audio capture during the user study. We will use participant IDs for quotes.

2.6.4 Address any limits on confidentiality, such as a legal duty to report abuse or neglect of a [child](#) or [adult in need of protection](#), and how these will be handled. Ensure these are clear in the consent documents. (See the [guidance document](#) for more information on legal duties and professional codes of ethics).

- Not applicable

2.6.5 Will any information that may reasonably be expected to identify an individual (alone or in combination with other available information) be accessible outside Canada? And/or, will you be using any electronic tool (e.g. survey company, software, data repository) to help you collect, manage, store, share, or analyze personally identifiable data that makes the data accessible from outside Canada?

- No
- Yes. If yes, refer to the University [Policy for the Protection of Personal Information from Access Outside Canada](#), and describe how you comply with the policy (such as securing participant consent and/or securing approval from the Vice President Research and Innovation).

## 2.7 Risk and benefit analysis

2.7.1 Discuss what risks or discomforts are anticipated for participants, how likely risks are and how risks will be mitigated. Address any particular ethical vulnerability of your study population. Risks to privacy from use of identifying information should be addressed. If applicable, address third party or community risk. (If the research involves Indigenous communities also complete section 2.11)

There are no anticipated physical risks associated with participation beyond those associated with everyday computer use. There may be some mild confusion for participants in that they will be using a new software application for the first time. We do not anticipate that this will exceed the usual levels of concentration or confusion commonly experienced when someone uses new software for the first time.

2.7.2 Identify any direct benefits of participation to participants (other than compensation), and any indirect benefits of the study (e.g. contribution to new knowledge).

Participating in the study might benefit participants in the long term. Results from the study might be used to create new navigation tools which could be used by the participants.

## **2.8 Provision of results to participants and dissemination plans.**

2.8.1 The TCPS encourages researchers to share study results with participants in appropriate formats. Describe your plans to share study results with participants and discuss the process and format.

Participants are given the chance, when completing the consent part of the questionnaire, to add their e-mail address to receive the results of this researcher when after it has been accepted for publication.

Those participants that provided their email addresses for this purpose will receive a summary of the findings after the results are published.

2.8.2 If applicable, describe how participants will be informed of any material incidental findings – a discovery about a participant made in the course of research (screening or data collection) that is outside the objectives of the study, that has implications for participant welfare (health, psychological or social). See [TCPS Article 3.4](#) for more information.

[ X ] Not applicable

2.8.3 Describe plans for dissemination of the research findings (e.g. conference presentations, journal articles, public lectures etc.).

Results from this study will be used for the lead researcher's MCS thesis and possibly for publication in Computer Science journals or conferences.

--

<b>2.9 Research Team</b>
--------------------------

<p>2.9.1 Describe the role and duties of all research team members (including students, RA's and supervisors) in relation to the overall study.</p> <p>Dr. Brooks is a faculty member in Computer Science. He will provide oversight during the study trials and will take part in analysis after the event. Investigator Randy Herritt has developed the study design under the direction of Dr. Brooks. This study is an integral part of his MCS Thesis.</p>
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<p>2.9.2 Briefly identify any previous experience or special qualifications represented on the team relevant to the proposed study (e.g. professional or clinical expertise, research methods, experience with the study population, statistics expertise, etc.).</p> <p>Dr. Brooks has previous experience designing and executing user studies in the data visualization field. Investigator Randy Herritt does not have experience in conducting user studies.</p>
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<b>2.10 Conflict of interest</b>
----------------------------------

<p>Describe whether any dual role or conflict of interest exists for any member of the research team in relation to potential study participants (e.g. TA, fellow student, teaching or clinical relationship), and/or study sponsors, and how this will be handled.</p> <p><input checked="" type="checkbox"/> Not applicable</p>
---

<b>2.11 Research involving Indigenous peoples</b>
---

<p>Consult TCPS <a href="#">Articles 9.1 and 9.2</a> in determining whether this section is applicable to your research.</p> <p><input checked="" type="checkbox"/> Not applicable – go to 2.12</p>
---

2.11.1 If the proposed research is expected to involve people who are Indigenous, describe the plan for community engagement (per TCPS Articles [9.1 and 9.2](#)). If community engagement is not sought, explain why the research does not require it, referencing TCPS article 9.2.

2.11.2 State whether ethical approval has been or will be sought from [Mi'kmaw Ethics Watch](#) and if not, why the research does not fall under their purview. If the research falls under the purview of other Indigenous ethics groups, state whether ethical approval has been or will be sought.

2.11.3 Describe plans for returning results to the community and any intellectual property rights agreements negotiated with the community with regard to data ownership (see also 2.11.4 if applicable). Append applicable research agreements.

2.11.4 Does this research incorporate OCAP (Ownership, Control, Access, and Possession) principles as described in TCPS [Article 9.8](#)?

Yes. Explain how.

No. Explain why not.

## **2.12 Clinical trials**

Not applicable – go to 2.13

2.12.1 Will the proposed clinical trial be registered?

No. Explain why not.

Yes. Indicate where it was/will be registered and provide the registration number.

2.12.2 If a novel intervention or treatment is being examined, describe standard treatment or intervention, to indicate a situation of clinical equipoise exists (TCPS [Chapter 11](#)). If placebo is used with a control group rather than standard treatment, please justify.

2.12.3 Clearly identify the known effects of any product or device under investigation, approved uses, safety information and possible contraindications. Indicate how the proposed study use differs from approved uses.

Not applicable

2.12.4 Discuss any plans for blinding/randomization.

2.12.5 What plans are in place for safety monitoring and reporting of new information to participants, the REB, other team members, sponsors, and the clinical trial registry (refer to TCPS [Articles 11.6, 11.7, 11.8](#))? These should address plans for removing participants for safety reasons, and early stopping/unblinding/amendment of the trial. What risks may arise for participants through early trial closure, and how will these be addressed? Are there any options for continued access to interventions shown to be beneficial?

### **2.13 Use of personal health information**

Not applicable

2.13.1 Research using health information may be subject to Nova Scotia's [Personal Health Information Act](#). Describe the personal health information ([definition explained in the guidance document](#)) required and the information sources, and explain why the research cannot reasonably be accomplished without the use of that information. Describe how the personal health information will be used, and in the most de-identified form possible.

2.13.2 Will there be any linking of separate health data sets as part of this research?

No

Yes

If yes:

A) Why is the linkage necessary?

B) Describe how the linkage will be conducted (it is helpful to append a flow diagram)

C) Does that linkage increase the identifiability of the participants?

2.13.3 Describe reasonably foreseeable risks to privacy due to the use of personal health information and how these will be mitigated.



## 2.14 Data Repositories

Not applicable

2.14.1 Identify and describe the data repository in which the research data will be deposited. What is its focus, who are its target users, who can access deposited data and under what circumstances? For how long will the data be kept in the repository?

2.14.2 Describe the data set to be released to the repository. If there is personal and/or sensitive information in the data, describe how you will prepare the data for submission to the repository and mitigate risks to privacy. Identify all fields that will be included in the final data set (include as an appendix).

2.14.3 Is agreeing to have one's data deposited a requirement for participation in the study? If yes, provide a justification. If no, indicate how participants can opt in or out.

## SECTION 3. APPENDICES

**Appendices Checklist.** Append all relevant material to this application in the order they will be used. This may include:

- List of References
- Permission letters (e.g. Indigenous Band Council, School Board, Director of a long-term care facility)
- Research agreements (required for research involving Indigenous communities)
- Support/cooperation correspondence
- Recruitment documents (posters, oral scripts, online postings, invitations to participate, etc.)
- Screening documents
- Consent/assent documents or scripts
- Research instruments (questionnaires, interview or focus group questions, etc.)
- Debriefing forms
- List of data fields included in data repository

## **Consent Form Templates**

Sample consent forms are provided on the [Research Ethics website](#) and may be used in conjunction with the information in the [Guidance](#) document to help you develop your consent form.

**A.1 Consent Form**



## CONSENT FORM

**Project title:** Use of Augmented Reality for Coastal Water Navigation

**Lead researcher:** Randy Herritt, Dalhousie University, [randy.herritt@dal.ca](mailto:randy.herritt@dal.ca), (902) 817-2048

### **Other researchers**

Dr. Stephen Brooks, [sbrooks@cs.dal.ca](mailto:sbrooks@cs.dal.ca)

**Funding provided by:** NIL

### **Introduction**

We invite you to take part in a research study being conducted by Randy Herritt, who is a student at Dalhousie University. Choosing whether or not to take part in this research is entirely your choice. There will be no impact to you if you decide not to participate in the research. The information below tells you about what is involved in the research, what you will be asked to do and about any benefit, risk, inconvenience or discomfort that you might experience.

You should discuss any questions you have about this study with Randy Herritt or Dr. Stephen Brooks. Please ask as many questions as you like. If you have questions later, please contact Randy Herritt.

### **Purpose and Outline of the Research Study**

The aim of this study is to get feedback on the use of augmented reality visualizations for assistance to coastal water navigation. The application simulates the user being on the bridge of a ship while displaying simulated AR visualizations within a desktop application.

The application has sections for each visualization. Each section of the application has an associated description section that explains the visualization's purpose followed by a tutorial. The user can look around the scene by using the computer mouse similar to being in a first-person video game. In these sections, control of the ship is automated.

The final section combines the visualizations together in a simulated navigation passage. The user has control of the ship using the keyboard arrow keys. The user is asked to use the visualizations to maintain track and avoid collision with other ships.

The user is provided with a questionnaire to evaluate each visualization and to provide general feedback.

### **Who Can Take Part in the Research Study**

You may participate in this study if you are a professional mariner with at least 1 year of navigation experience, have access to a Window's computer running Windows 10, have an internet connection, and have a microphone connected to the computer.

Mariners familiar with the navigation principles outlined in Bowditch's American Practical Navigator (Bowditch) are preferred.

### **What You Will Be Asked to Do**

If you decide to participate in this research, you will be asked to download and run a desktop application to a window's computer. You will be asked to connect to a meeting with an audio connection. You will be asked to close all other applications besides the downloaded software and the communication software itself. You will be requested to share your desktop screen with the researcher.

You will be asked to select and view each sections description and carry out the tutorial. Upon completion of the tutorial, you will be asked to control the simulated ship using the mouse and keyboard arrow keys to carry out a simulated navigation passage using the AR visualizations.

### **Possible Benefits, Risks and Discomforts**

Benefits: Participating in the study might not benefit you directly, but we might learn things that will benefit others.

Risks: The risks associated with this study are minimal; there are no known risks for participating in this research beyond being bored or fatigued, or confused by using a new piece of software. You will be offered breaks between activities to reduce these risks.

During the user study, you will be asked to share your screen and audio with the researchers. Your screen and audio will be recorded.

### **Compensation / Reimbursement**

Participants are not being compensated for their participation in this study.

### **How your information will be protected:**

Your participation in this research will be known only to members of the research team. At the beginning of the user study, you will be reminded that your screenshare and audio will be recorded.

The information that you provide to us, your audio, and your screenshare will be kept confidential. Only the research team at Dalhousie University will have access to this information. The people who work with us have an obligation to keep all research information confidential. All your identifying information (such as your name and contact information) will be securely stored separately from your research information. We will use a participant number (not your name) in our written and computer records so that the research information we have

about you contains no names. During the study, all electronic records will be kept secure in an encrypted file on the researcher's password-protected computer. No paper records will be kept.

We will describe and share our findings in the researcher's thesis and thesis's defense. We will only report group results and not individual results. This means that you will not be identified in any way in our reports.

We will not disclose any information about your participation except as required by law or our professional obligations. If you inform us about abuse or neglect of a child or an adult in need of protection, we are required by law to contact authorities. If we notice that you are at an immediate risk of harming yourself or other people, we are required by our professional code of ethics as social workers to seek assistance.

You can opt out in and out of having your quotes used as part of the disseminating results of this study. Quotes are collected from the questionnaire form in use. On the questionnaire form, you will be given an option to either allow or not allow excerpts from your written feedback to be quoted.

Once the study is over your personal information will be deleted from our data repositories. Stored information will contain the questionnaire responses and feedback but will be void of any personal identifying information. Despite these measures, I cannot guarantee your anonymity or predict how those who access the data will use them.

### **If You Decide to Stop Participating**

You are free to leave the study at any time. If you decide to stop participating during the study, you can decide whether you want any of the information that you have provided up to that point to be removed or if you will allow us to use that information. After participating in the study, you can decide for up to 1 week if you want us to remove your data. After that time, it will become impossible for us to remove it because it will already be anonymized.

### **How to Obtain Results**

We will provide you with a short description of group results when the study is finished. No individual results will be provided. You can obtain these results by providing your contact information at the time of participation.

### **Questions**

We are happy to talk with you about any questions or concerns you may have about your participation in this research study. Please contact Randy Herritt at 902-817-2048, [randy.herritt@dal.ca](mailto:randy.herritt@dal.ca) or Dr. Stephen Brooks at [sbrooks@dal.ca](mailto:sbrooks@dal.ca) at any time with questions, comments, or concerns about the research study (if you are calling long distance, please call collect).

If you have any ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-3423, or email: [ethics@dal.ca](mailto:ethics@dal.ca) (and reference REB file # 2021-5598).

**Signature**

Signatures will not be required as part of this informed consent process. Downloading and running the application is taken as implied consent.

## A.2 Sample Email



Good day Sir/Ma'am,

We are recruiting professional navigators for a Dalhousie University Master of Computer Science User Study. The User Study aims to get subject matter expert feedback on the feasibility of the use of Augmented Reality Navigation Aids (ARNAs) for coastal water navigation.

Currently, in order to obtain the navigation information required, Navigating Officers (NavOs) make use of bridge equipment. The time spent interacting with this equipment introduces risk, as it pulls their focus away from the bridge windows and the quickly changing marine environment. We suggest that Augmented Reality (AR) will offer a way to provide the information required while still allowing the navigator to maintain a proper and effective lookout. Additionally, we suggest that some of this information could be visualized in new ways that could improve maritime safety.

This user study will be done completely remotely to ensure participant safety during the COVID-19 pandemic. We created a Desktop Application that allows testing and evaluating these ARNAs. After an initial privacy check, the participant would be requested to download the application to their computer and share their screen with the researcher while using it.

The application displays each visualization in series to the user. The participant is provided with a description of how the ARNA is used. Then, the use of the ARNA is demonstrated using a ship simulation. During the ship simulation, the participant can move the mouse around to view in first person the marine environment and ARNAs being demonstrated. Finally, the desktop application gives control to the user to allow them to control the ship's movements using keyboard arrow keys. They are provided with directions to avoid collisions with other shipping and to arrive at the destination on time. It is expected to take less than 1 hour to complete the desktop application portion of the user study.

After the desktop application portion, the participant is provided with a questionnaire which asks for feedback on each proposed ARNA. A series of statements are provided about each visualization. The participant indicates how much or how little they agree with the statement. For each visualization, the participant is provided an opportunity to provide written feedback to the researchers. After completing these sections, the participant is provided an opportunity to provide written feedback on the use of ARNAs as a whole.

Participation in the study is completely voluntary and is not compensated. Meeting the following requirements are necessary for participation:

- You must be a current or former professional navigator with at least one year of experience in navigating ships at sea.
- You must have access to a Windows 10 Desktop Computer.
- You must have an internet connection
- You must be willing to share audio using either a computer microphone, such as a headset used for Skype communication, or a phone dialed into the meeting invite.
- You must be willing to download the application.
- You must be willing to share your screen with the researcher, including downloading any additional software required to do so (such as Skype).

Thank you for your consideration. If you are interested in participating, please contact the lead researcher at [randy.herritt@dal.ca](mailto:randy.herritt@dal.ca).

Thank you,

Randy Herritt

(902) 817-2048

Master of Computer Science Graduate Student

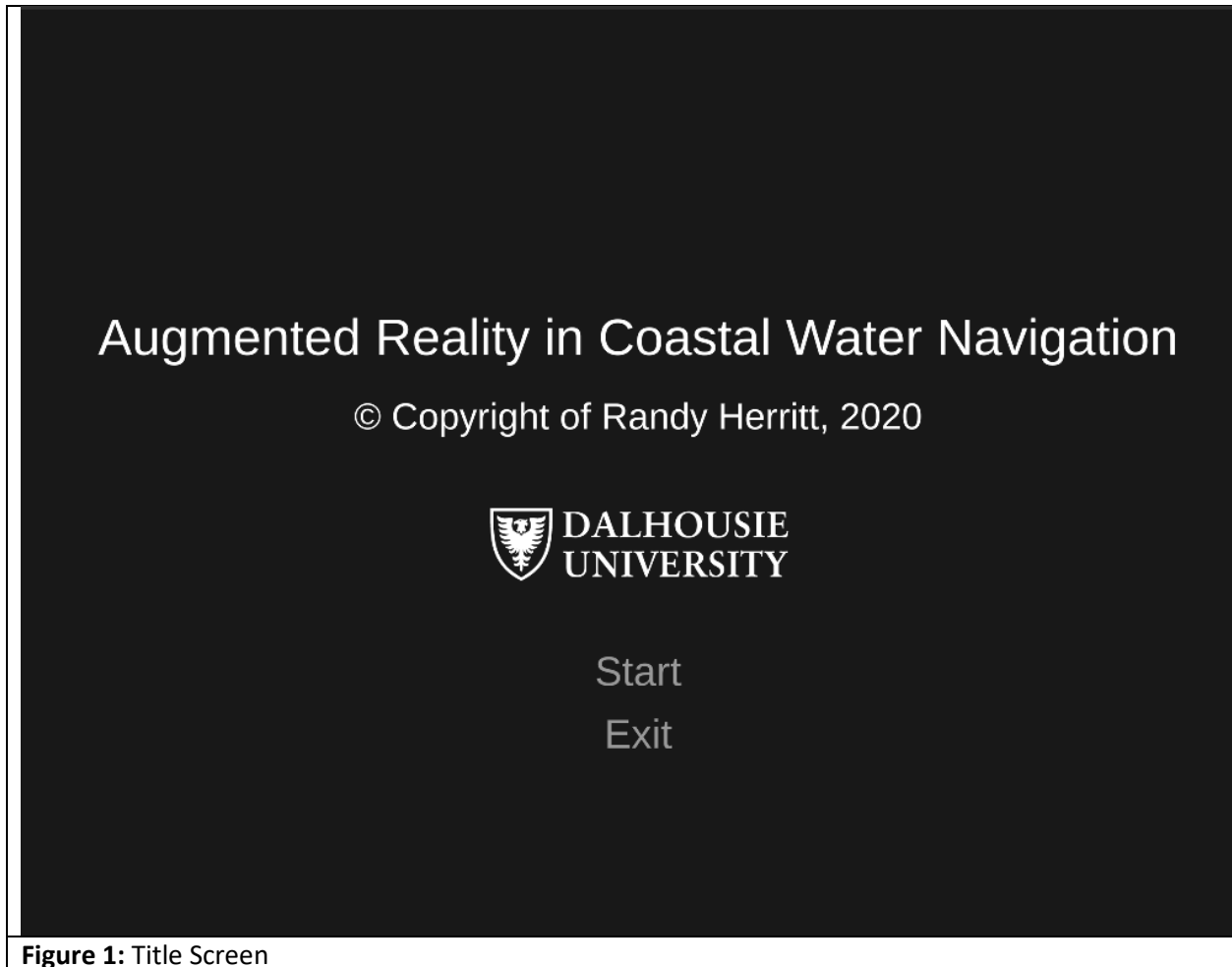
Dalhousie University

6299 South St, Halifax, NS B3H 4R2

### A.3 Application Screenshots

This document provides screenshots of the application for the Augmented Reality in Coastal Water Navigation User Study.

The application begins with a title screen, figure 1.



**Figure 1:** Title Screen

After clicking Start, the user is presented with an overview of the risks (figure 2).

## Risks/Privacy

< Back

The risks associated with this study are minimal; there are no known risks for participating in this research beyond being bored or fatigued, or confused by using a new piece of software. You will be offered breaks between activities to reduce these risks.

You will be asked to share your screen and audio. Your audio and screen will be recorded and used as part of this research. Your participation in this research will be known only to members of the research team.

Accept

Exit

**Figure 2:** Risks

After accepting the risks, the application transitions to the main menu (figure 3).

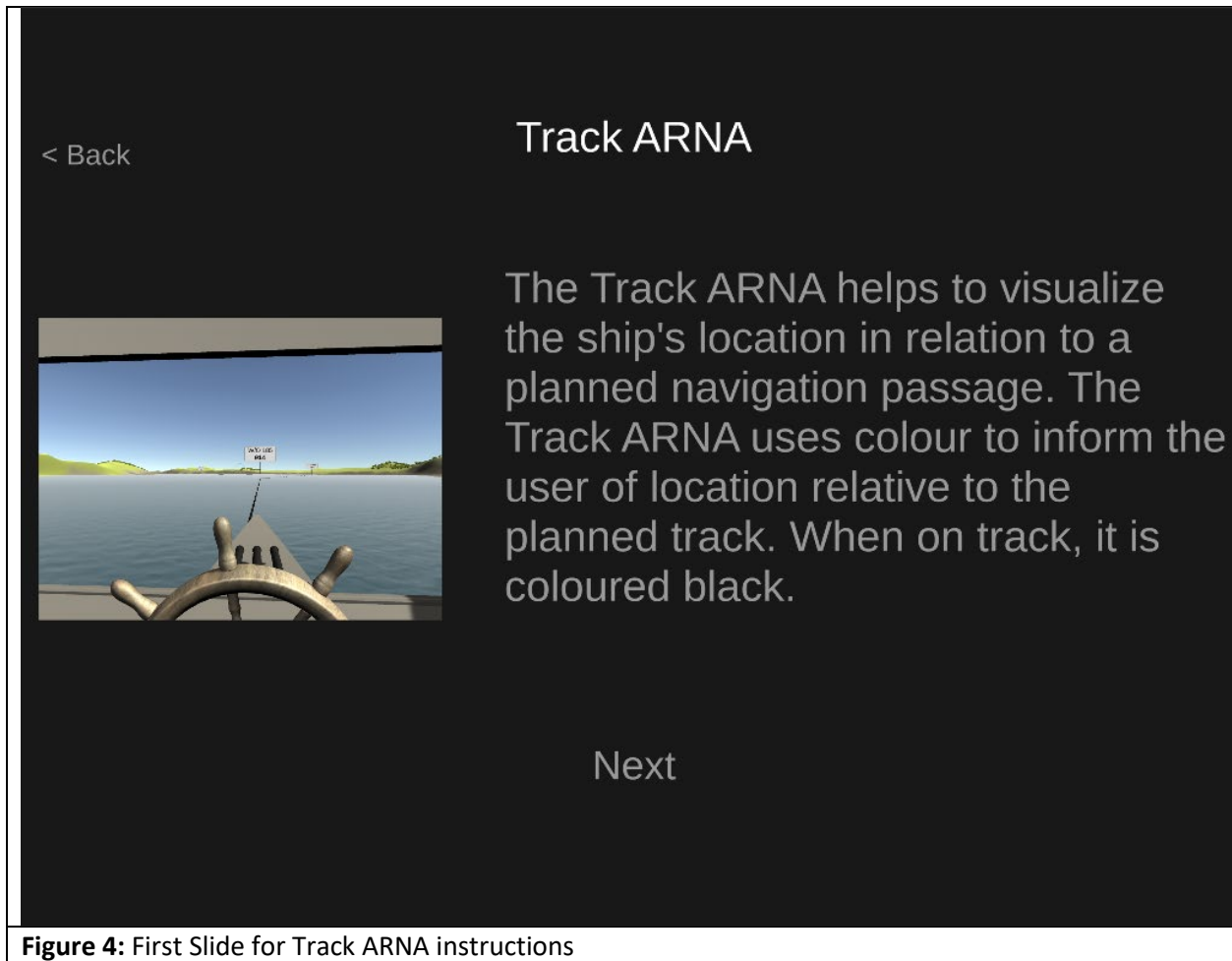
< Back

## Augmented Reality Navigation Aid (ARNA) Selection

Track ARNA  
Danger Area ARNA  
Clearing Area ARNA  
Ship Avoidance ARNA  
Passage Manager ARNA  
User Driven

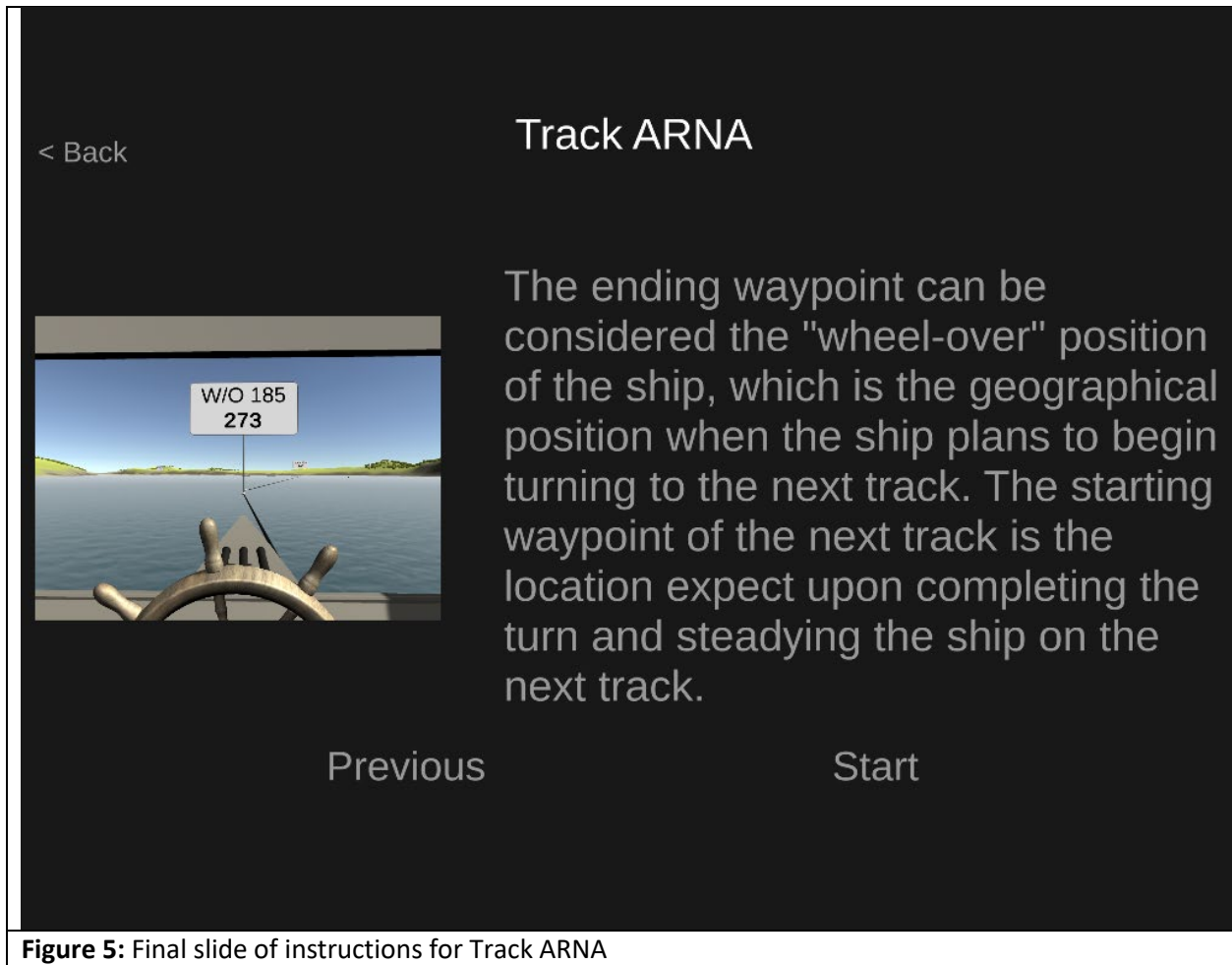
**Figure 3:** Main Menu

After selecting one of the options, the user is presented slides that show how the Augmented Reality Navigation Air (ARNA) works (figure 4).



**Figure 4:** First Slide for Track ARNA instructions

After clicking next through multiple slides, the last slide gives the option to start that portion of the user study (figure 5).



**Figure 5:** Final slide of instructions for Track ARNA

Upon clicking start, the scene transitions to a 3D visualization of being on the bridge of the ship (figure 6). The user is guided with prompts about the visualization in text form at the top of the screen to help them learn to use the visualization in situ.





As the user progresses through each visualization, more visualizations are added until the entire set being evaluated is presented. The user is then given controls to drive the ship to arrive at their destination and avoid other shipping (figure 7).



Figure 7: User controlled

## A.4 Questionnaire



DALHOUSIE  
UNIVERSITY

## QUESTIONNAIRE FORM

**Project title:** Use of Augmented Reality for Coastal Water Navigation

**Lead researcher:** Randy Herritt, Dalhousie University, [rn851080@dal.ca](mailto:rn851080@dal.ca), (902) 817-2048

### Other researchers

Dr. Stephen Brooks, [sbrooks@cs.dal.ca](mailto:sbrooks@cs.dal.ca)

**Funding provided by:** NIL

## Questions

1. Do you consent to the researchers quoting text you write in feedback sections below?

**Yes, I consent to my written feedback in this questionnaire being quoted anonymously.**

**No, I do not consent to my written feedback in this questionnaire being quoted.**

## Track ARNA

2. Select the degree to which you agree or disagree with each of the following statements:

- a. **The Track ARNA helps to determine if the ship is port or starboard of track.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

- b. **The Track ARNA helps to determine how far the ship is from track.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

- c. **The Track ARNA helps to determine if the ship is on track.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**d. The Track ARNA helps to determine the distance to wheel over.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**e. The Track ARNA is confusing.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**f. The Track ARNA would improve safety.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**g. The Track ARNA would distract the navigator in the conduct of the passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**h. The colour choices used for the Track ARNA visualization help to determine if you are port or starboard of track.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

3. Please provide any additional comments/feedback you wish the researchers to know about the Track ARNA.

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### Passage ARNA

4. Select the degree to which you agree or disagree with each of the following statements:

- a. **The Passage ARNA is effective in providing the speed required.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

- b. **The Passage ARNA is effective in providing the distance to go.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

- c. **The Passage ARNA is effective in providing the speed made good.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

- d. **The Passage ARNA is effective in providing the estimate time of arrival.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

e. **The information provided in the Passage ARNA is useful in the conduct of a navigation passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

f. **The Passage ARNA is confusing.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

g. **The Passage ARNA would improve safety.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

h. **The Passage ARNA would distract the navigator in the conduct of the passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

5. Please provide any additional comments/feedback you wish the researchers to know about the Passage ARNA.

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### **Collision Avoidance ARNA**

6. Select the degree to which you agree or disagree with each of the following statements:

a. **The Collision Avoidance ARNA is effective in providing the closest point of approach of other ships.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

b. **Being able to toggle the visibility of the Collision Avoidance ARNA is useful.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

c. **The Collision Avoidance ARNA provides information that is useful in determining if a risk of collision exists with other ships.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

d. **The Collision Avoidance ARNA's use of colours (white, yellow, and red) helps prioritize which ships require additional monitoring.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

e. **The Collision Avoidance ARNA is confusing.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--



**f. The Collision Avoidance ARNA would improve safety.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**g. The Collision Avoidance ARNA would distract the navigator in the conduct of the passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

7. Please provide any additional comments/feedback you wish the researchers to know about the Collision Avoidance ARNA.

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**Danger ARNA**

8. Select the degree to which you agree or disagree with each of the following statements:

**a. Red is an appropriate colour for the Danger ARNA.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**b. The Danger ARNA would improve safety.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**c. The Danger ARNA would distract the navigator in the conduct of the passage**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**d. The Danger ARNA is effective in showing the area marked by the limiting danger line.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**e. The information gained by the Danger ARNA is useful in the conduct of a navigation passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**f. The Danger ARNA is confusing.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**g. The range to the Danger ARNA ahead is useful to the navigator.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**h. The range to the Danger ARNA astern is useful to the navigator.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**i. The range to the Danger ARNA abeam is useful to the navigator.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

9. Please provide any additional comments/feedback you wish the researchers to know about the Danger ARNA.

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### Clearing Area ARNA

10. Select the degree to which you agree or disagree with each of the following statements:

a. **Yellow is an appropriate colour for the Clearing Area ARNA.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

b. **The Clearing Area ARNA would improve safety.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

c. **The Clearing Area ARNA effectively visualizes clearing bearings and/or clearing depths.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

d. **The Clearing Area ARNA is effective in alerting the navigator to monitor the proximity of the ship's stern to dangers when altering course.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**e. The Clearing Area ARNA is confusing.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

**f. The Clearing ARNA would distract the navigator in the conduct of the passage.**

Strongly disagree <input type="checkbox"/>	Somewhat disagree <input type="checkbox"/>	Neither agree nor disagree <input type="checkbox"/>	Somewhat agree <input type="checkbox"/>	Strongly agree <input type="checkbox"/>
---	---	--	--	--

11. Please provide any additional comments/feedback you wish the researchers to know about the Clearing Area ARNA.

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**General Feedback**

12. Please provide any additional comments/feedback you wish the researchers to know about the use of ARNAs for coastal water navigation.

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## Appendix B

### Detailed Survey Results with Comments

# Comment report

*Lists all the questions in the survey and displays all the free text responses to these questions, if applicable.*

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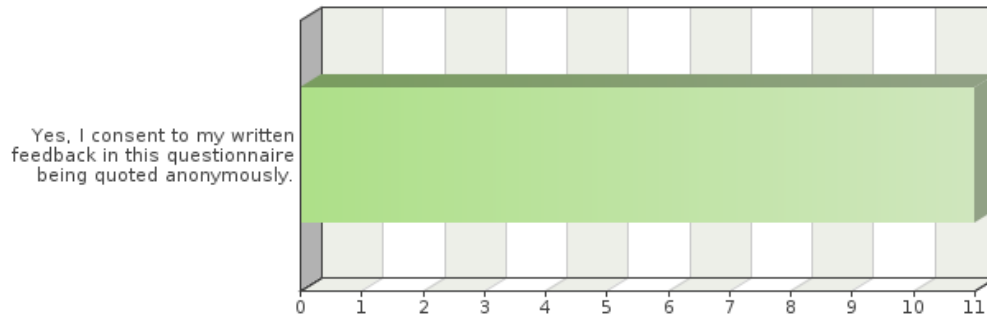
## Report info

<b>Report date:</b>	Saturday, July 17, 2021 2:41:51 PM ADT
<b>Start date:</b>	Thursday, June 17, 2021 9:23:00 PM ADT
<b>Stop date:</b>	Monday, July 19, 2021 9:23:00 PM ADT
<b>Stored responses:</b>	11
<b>Number of completed responses:</b>	11



## Question 1

Do you consent to the researchers quoting text you write in feedback sections below?



Frequency table

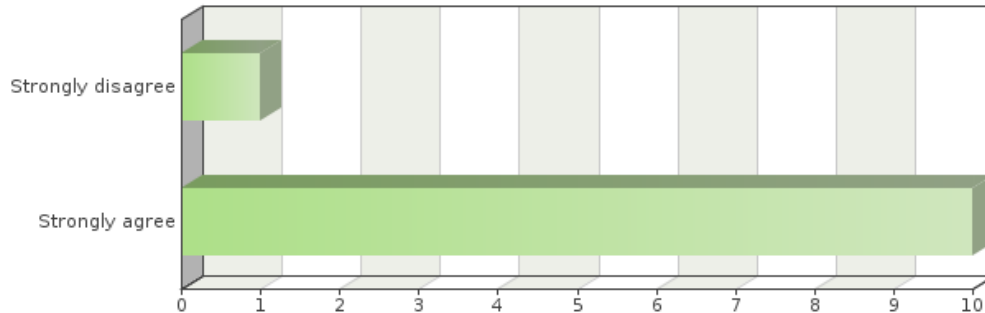
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Yes, I consent to my written feedback in this questionnaire being quoted anonymously.	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1	Minimum:	1	Variance:	0	
Median:	1	Maximum:	1	Std. deviation:	0	

Total answered: 11

## Question 2

Select the degree to which you agree or disagree with each of the following statements:

**The Track ARNA helps to determine if the ship is port or starboard of track.**



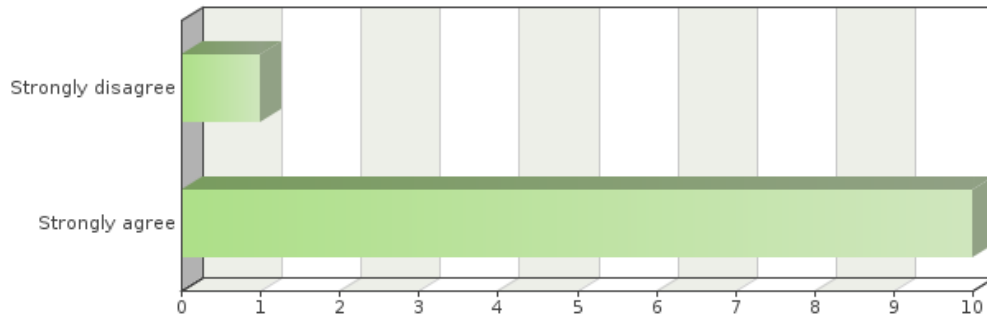
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.64	Minimum:	1	Variance:	1.45	
Median:	5	Maximum:	5	Std. deviation:	1.21	

**Total answered: 11**

### Question 3

The Track ARNA helps to determine how far the ship is from track.



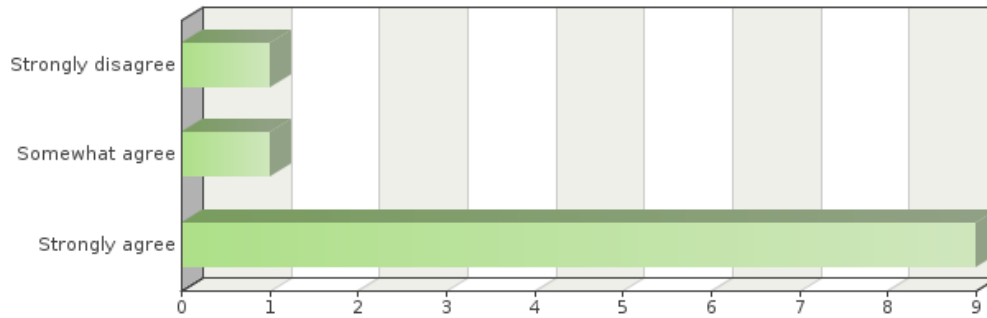
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.64	Minimum:	1	Variance:	1.45	
Median:	5	Maximum:	5	Std. deviation:	1.21	

Total answered: 11

## Question 4

The Track ARNA helps to determine if the ship is on track.



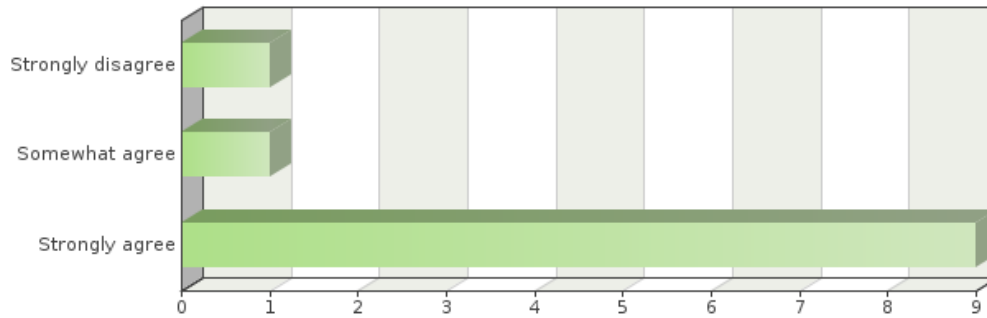
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	1	2	9.09%	18.18%	9.09%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.55	Minimum:	1	Variance:	1.47	
Median:	5	Maximum:	5	Std. deviation:	1.21	

Total answered: 11

## Question 5

The Track ARNA helps to determine the distance to wheel over.



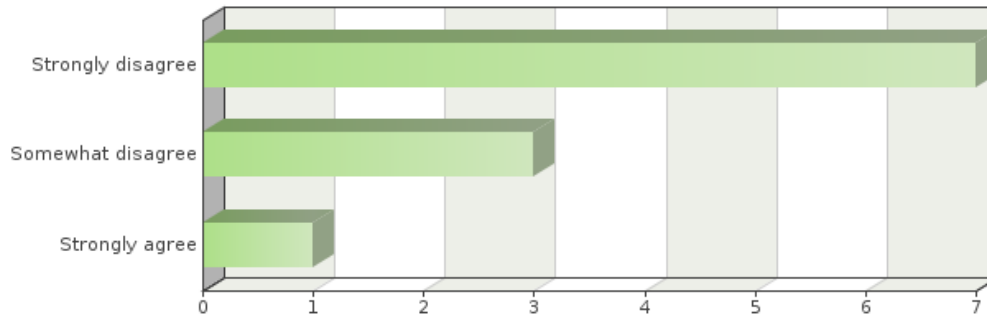
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	1	2	9.09%	18.18%	9.09%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.55	Minimum:	1	Variance:	1.47	
Median:	5	Maximum:	5	Std. deviation:	1.21	

Total answered: 11

## Question 6

The Track ARNA is confusing.



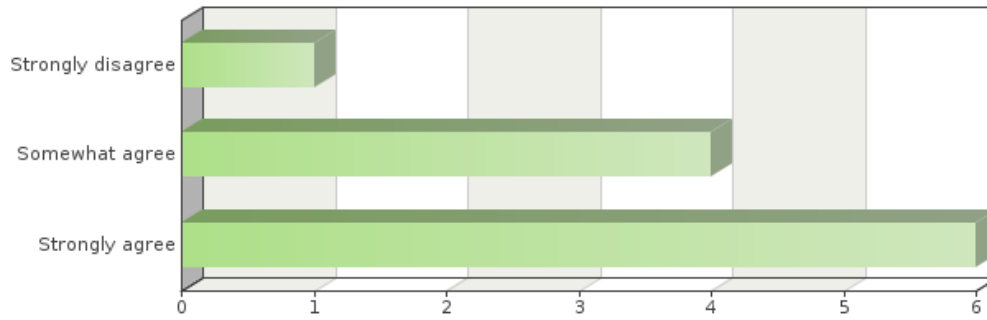
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	7	7	63.64%	63.64%	63.64%	63.64%
Somewhat disagree	3	10	27.27%	90.91%	27.27%	90.91%
Strongly agree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.64	Minimum:	1	Variance:	1.45	
Median:	1	Maximum:	5	Std. deviation:	1.21	

Total answered: 11

## Question 7

The Track ARNA would improve safety.



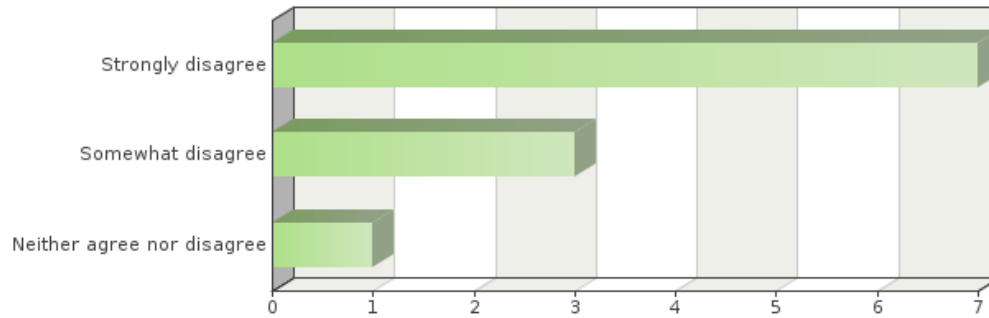
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	4	5	36.36%	45.45%	36.36%	45.45%
Strongly agree	6	11	54.55%	100%	54.55%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.27	Minimum:	1	Variance:	1.42	
Median:	5	Maximum:	5	Std. deviation:	1.19	

Total answered: 11

## Question 8

The Track ARNA would distract the navigator in the conduct of the passage.



Frequency table

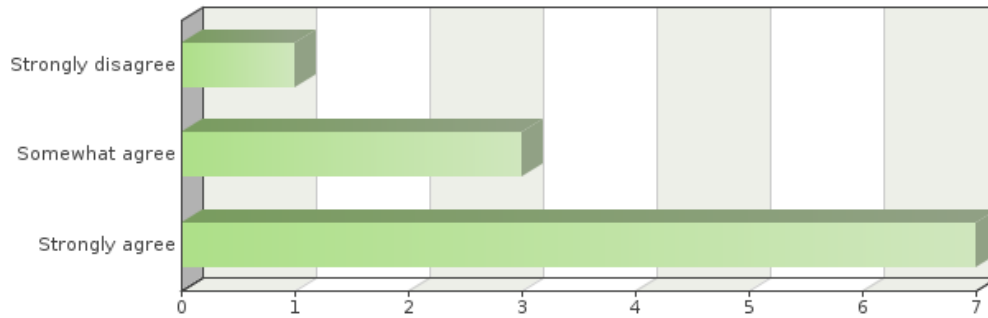
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	7	7	63.64%	63.64%	63.64%	63.64%
Somewhat disagree	3	10	27.27%	90.91%	27.27%	90.91%
Neither agree nor disagree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.45	Minimum:	1	Variance:	0.47	
Median:	1	Maximum:	3	Std. deviation:	0.69	

Total answered: 11



### Question 9

The colour choices used for the Track ARNA visualization help to determine if you are port or starboard of track.



Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	3	4	27.27%	36.36%	27.27%	36.36%
Strongly agree	7	11	63.64%	100%	63.64%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.36	Minimum:	1	Variance:	1.45	
Median:	5	Maximum:	5	Std. deviation:	1.21	

Total answered: 11

## Question 10

Please provide any additional comments/feedback you wish the researchers to know about the Track ARNA.

Text input

---

If the intent is to eliminate the requirement to look at internal equipment, perhaps a spot on the Passage ARNA should include current Planned Course

---

Given current practices, it would be helpful if the colour when on track was green and off track, regardless of p/s, was red

---

The Track ARNA does its job very well. The only thing I could think to add is some sort of highlight for when you are on track to provide the navigator a visual warm fuzzy, but it's hardly necessary.

---

The visual feedback was unobtrusive, obvious, and provided an immediate and easy-to-understand measure of location relative to track. This is an excellent visual aid that keeps your head out the window.

---

If the units for the distance off-track are changeable, then add units to the distance off track to ensure there is no ambiguity.

---

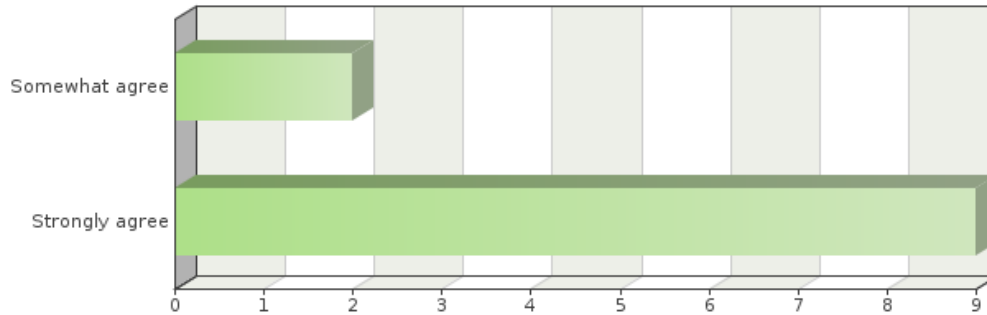
The track ARNA is a good tool to indicate where the ship is relative to its planned course. The indicators of off-track distance, and direction to steer, are intuitive and would assist in regaining track. Options for improving navigation, if this was the only ARNA selected for visualization, would be the bearing of the planned track. Other options for assisting in coastal or ocean navigation would be a user-driven maneuvering area (cross-track corridor) where mates and bridge watchkeepers would be expected to navigate the ship, avoid obstacles and other vessels; this area would be determined by the CO/master and/or navigator.

---

## Question 11

Select the degree to which you agree or disagree with each of the following statements:

**The Passage ARNA is effective in providing the speed required.**



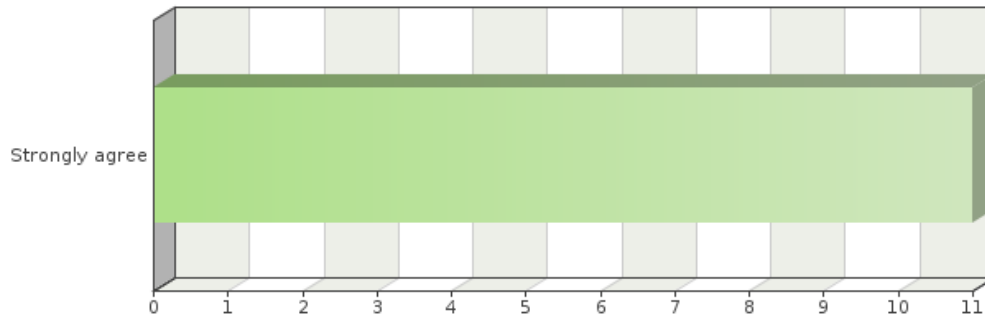
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	2	2	18.18%	18.18%	18.18%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	4	Variance:	0.16	
Median:	5	Maximum:	5	Std. deviation:	0.4	

**Total answered: 11**

## Question 12

The Passage ARNA is effective in providing the distance to go.



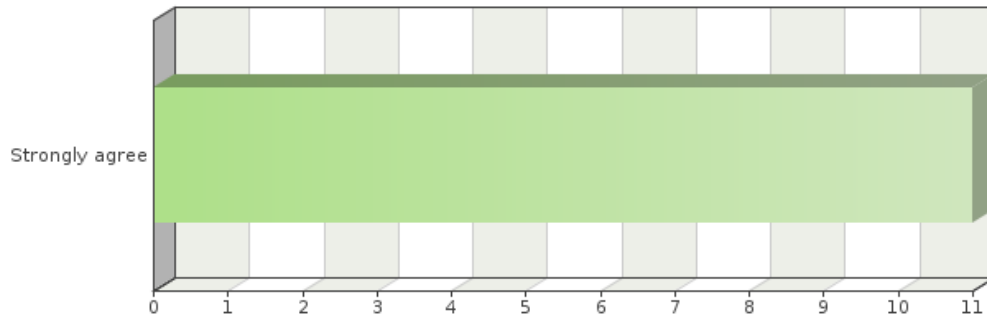
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

Total answered: 11

### Question 13

The Passage ARNA is effective in providing the speed made good.



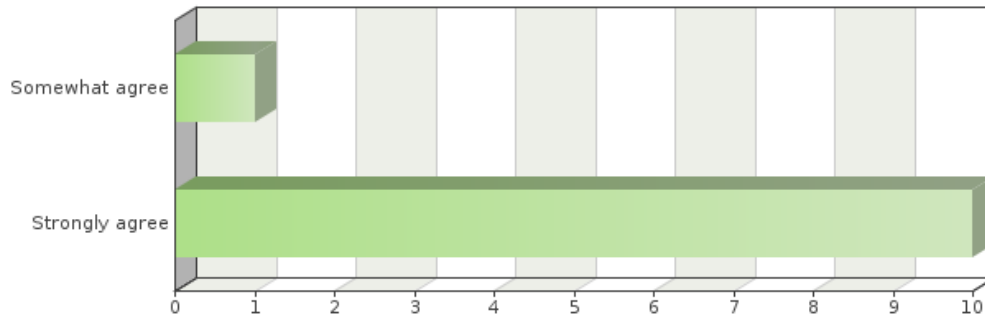
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

Total answered: 11

## Question 14

The Passage ARNA is effective in providing the estimate time of arrival.



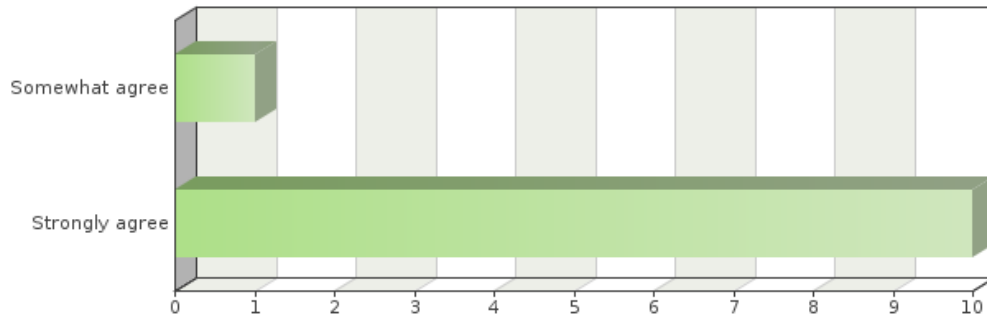
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.91	Minimum:	4	Variance:	0.09	
Median:	5	Maximum:	5	Std. deviation:	0.3	

Total answered: 11

### Question 15

The information provided in the Passage ARNA is useful in the conduct of a navigation passage.



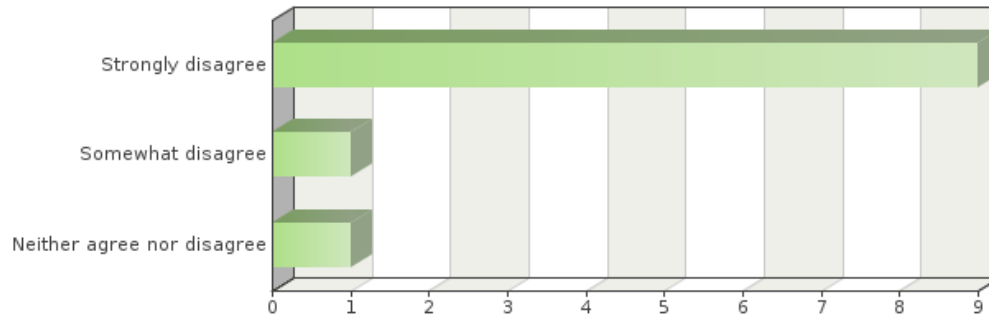
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.91	Minimum:	4	Variance:	0.09	
Median:	5	Maximum:	5	Std. deviation:	0.3	

Total answered: 11

## Question 16

The Passage ARNA is confusing.



Frequency table

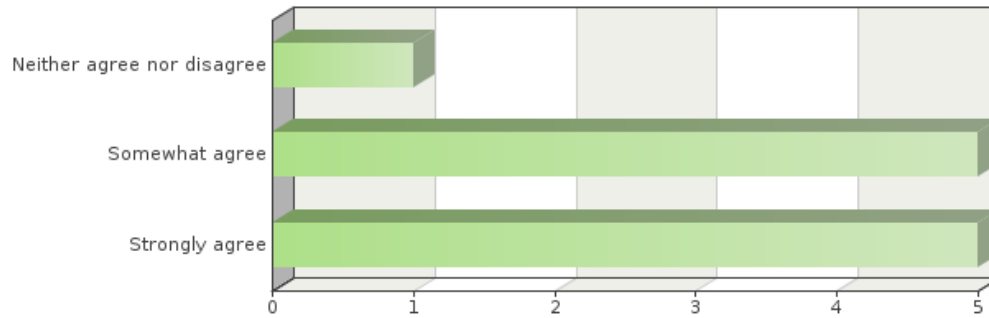
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	9	9	81.82%	81.82%	81.82%	81.82%
Somewhat disagree	1	10	9.09%	90.91%	9.09%	90.91%
Neither agree nor disagree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.27	Minimum:	1	Variance:	0.42	
Median:	1	Maximum:	3	Std. deviation:	0.65	

Total answered: 11



## Question 17

The Passage ARNA would improve safety.



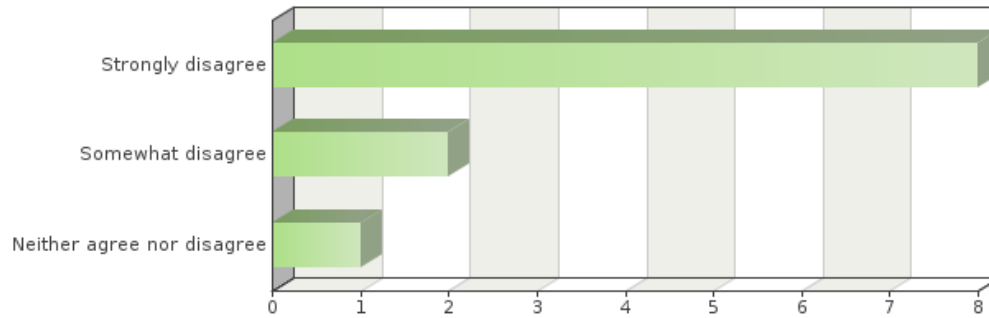
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Neither agree nor disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	5	6	45.45%	54.55%	45.45%	54.55%
Strongly agree	5	11	45.45%	100%	45.45%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.36	Minimum:	3	Variance:	0.45	
Median:	4	Maximum:	5	Std. deviation:	0.67	

Total answered: 11

## Question 18

The Passage ARNA would distract the navigator in the conduct of the passage.



Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	8	8	72.73%	72.73%	72.73%	72.73%
Somewhat disagree	2	10	18.18%	90.91%	18.18%	90.91%
Neither agree nor disagree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.36	Minimum:	1	Variance:	0.45	
Median:	1	Maximum:	3	Std. deviation:	0.67	

Total answered: 11

## Question 19

Please provide any additional comments/feedback you wish the researchers to know about the Passage ARNA.

Text input

---

The inclusion of a Course Required (or Planned Course) would help maintain track.

---

This comment may be an artefact of using the ARNA on a laptop vice in a true augmented-vision setting, but personal preference would be to place this information below the line of sight, similar to how it would be on a car-dashboard.

---

Nil I think it would greatly assist heads up navigation.

---

This is vital information that every navigator is constantly checking. Having it to hand instantly while maintaining a heads up perspective is invaluable and can only increase safety.

---

An excellent and obvious tool to make passage navigation safer, especially in close waters.

---

The ability to have some of the information in a larger font or more contrasting colour compared to the other data would be useful. For example, Speed Made Good or Speed Required distinguished from Set or ETA.

---

Add in what the course is and the next track course

---

Nil

---

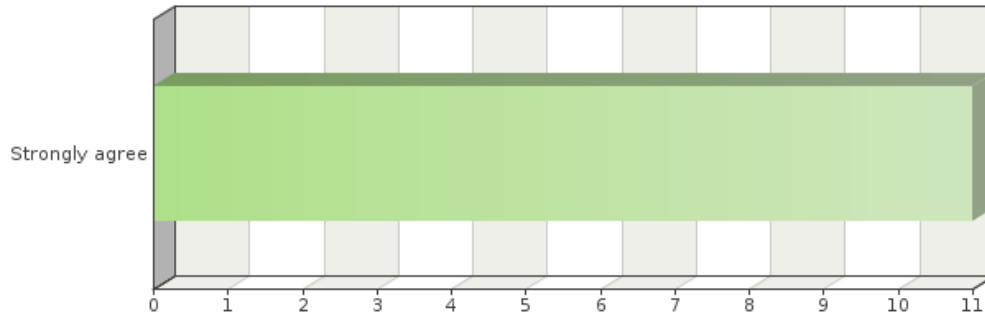
The passage ARNA is a good method of providing data to the navigator to conduct their transit/passage. If operating in this mode, a notification of off-track distance, co-located with the other heads-up navigation data, may be beneficial. In addition, for mates/watchkeepers, a notation of the ship's planned track, and course to steer (CTS) would assist in executing their portions of a passage. Additionally, the passage ARNA would benefit from using real-time data sourced from the ship's inertial navigation systems and ECPINS (for CMG and set) plus any external sources (from MCTS or tidal stations to more accurately gauge the ship's transit. Finally, the ability to dynamically update the course alteration/wheelover point, using the ship's maneuvering characteristics at its actual speed, influenced by actual conditions, and based on its actual position, would be beneficial.

---

## Question 20

Select the degree to which you agree or disagree with each of the following statements:

**The Collision Avoidance ARNA is effective in providing the closest point of approach of other ships.**



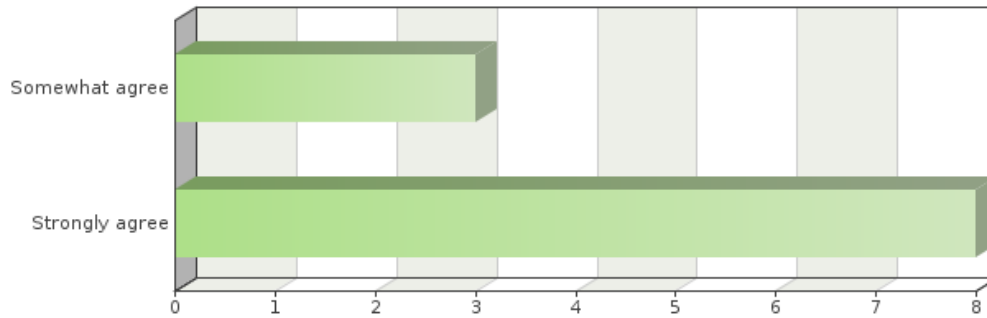
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

**Total answered: 11**

## Question 21

Being able to toggle the visibility of the Collision Avoidance ARNA is useful.



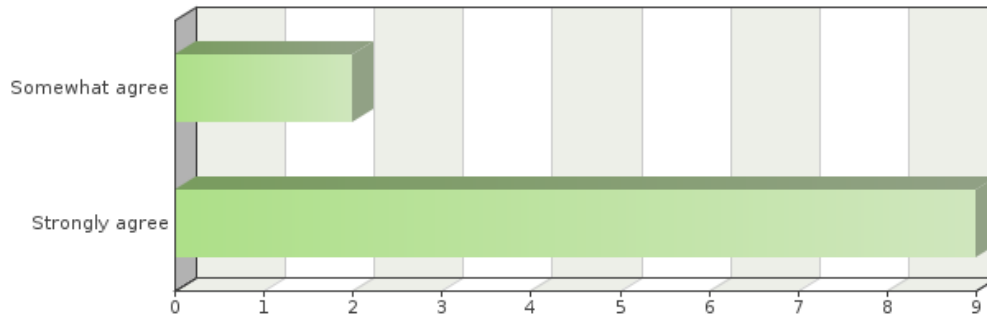
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	3	3	27.27%	27.27%	27.27%	27.27%
Strongly agree	8	11	72.73%	100%	72.73%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.73	Minimum:	4	Variance:	0.22	
Median:	5	Maximum:	5	Std. deviation:	0.47	

Total answered: 11

## Question 22

The Collision Avoidance ARNA provides information that is useful in determining if a risk of collision exists with other ships.



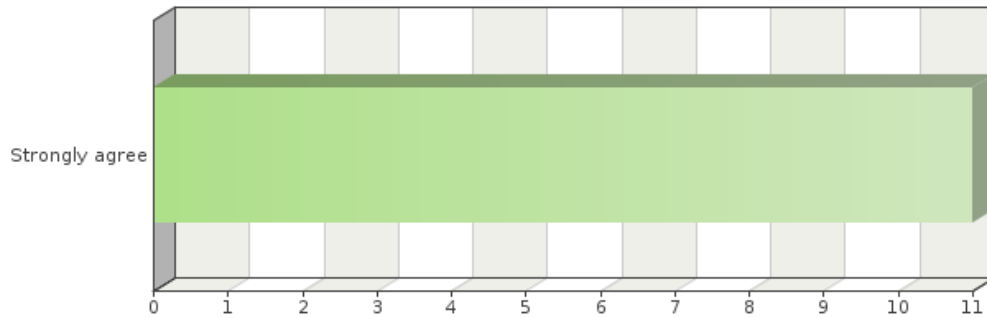
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	2	2	18.18%	18.18%	18.18%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	4	Variance:	0.16	
Median:	5	Maximum:	5	Std. deviation:	0.4	

Total answered: 11

### Question 23

The Collision Avoidance ARNA's use of colours (white, yellow, and red) helps prioritize which ships require additional monitoring.



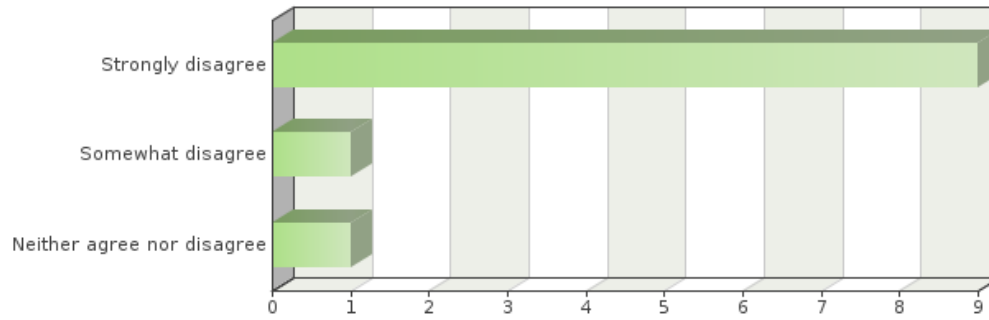
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

Total answered: 11

## Question 24

The Collision Avoidance ARNA is confusing.



Frequency table

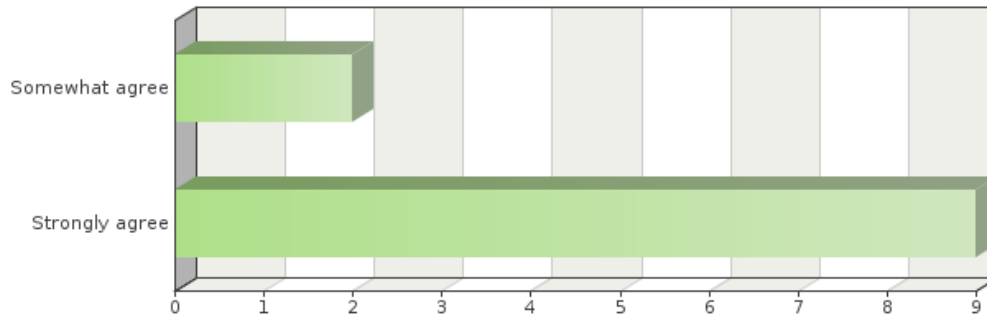
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	9	9	81.82%	81.82%	81.82%	81.82%
Somewhat disagree	1	10	9.09%	90.91%	9.09%	90.91%
Neither agree nor disagree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.27	Minimum:	1	Variance:	0.42	
Median:	1	Maximum:	3	Std. deviation:	0.65	

Total answered: 11



## Question 25

The Collision Avoidance ARNA would improve safety.



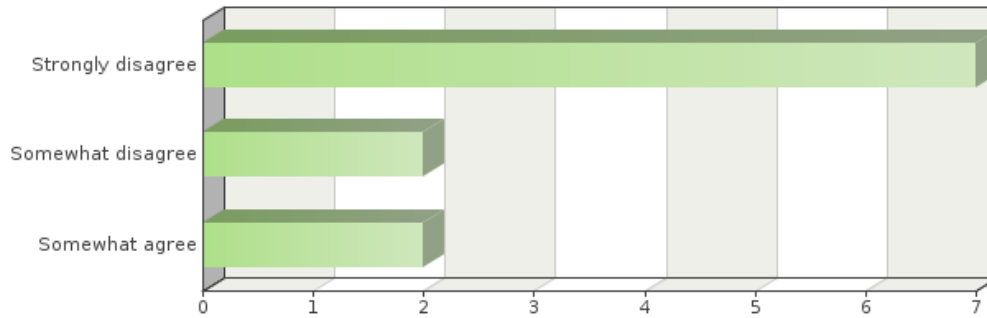
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	2	2	18.18%	18.18%	18.18%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	4	Variance:	0.16	
Median:	5	Maximum:	5	Std. deviation:	0.4	

Total answered: 11

## Question 26

The Collision Avoidance ARNA would distract the navigator in the conduct of the passage.



Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	7	7	63.64%	63.64%	63.64%	63.64%
Somewhat disagree	2	9	18.18%	81.82%	18.18%	81.82%
Somewhat agree	2	11	18.18%	100%	18.18%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.73	Minimum:	1	Variance:	1.42	
Median:	1	Maximum:	4	Std. deviation:	1.19	

Total answered: 11

## Question 27

Please provide any additional comments/feedback you wish the researchers to know about the Collision Avoidance ARNA.

Text input

---

If the default is set to automatically display all ships data then the scree would be crowded in a high traffic density area (such as Singapore Straits etc). If it can be configured to only display "Red" data automatically and allow the Nav/User to select the others, I believe that it would be of great use.

---

The colours and option to fade out are highly intuitive.

---

If the visibility of the ARNA is turned off, it should automatically return to opaque if it turns to Yellow or Red to immediately draw the operator's attention to a reduction in CPA. Otherwise the operator risks not noticing that change below the tripwire/treshold. As well, a Bearing to CPA would be beneficial to indicate where the CPA will occur (e.g. is it drawing left or right).

---

The colours for each CPA would have to be amendable based on CSO's.

---

Having vessel CMG and bearing to CPA would be useful. For example, in the scenario, I wasn't able to tell at first which direction the sail boat was heading (away or towards me). In addition, vessels at longer ranges was difficult to read the Collision Avoidance text, having the ability to zoom in would be useful or just clicking on the text to have it get larger would be great.

---

Many navigators end up standing in front of the radar, staring down. This can negatively affect their perception of their surroundings. The Collision Avoidance ARNA removes this scenario and improves safety and allows the navigator to stay more alert and able to monitor several vessels at once.

---

To my mind this is the biggest improvement to safety for a ships officer. The ease of prioritizing close contacts and the colour coding as the information changes would be a game changer and perhaps a literal life saver. Ships which you would perhaps have dismissed as no longer being a danger could alter course and change the situation; the changing colour is a very visual and dramatic demonstration of this. Perhaps when this is pitched (or sold, or whatever) the demo could include a ship which has an opening CPA and could be dismissed visually but then alters to become a danger to illustrate how visual the effect is

---

-Regarding the toggling of visibility, the contact information should reappear if the risk category increases due to changing circumstances, not sure if this is incorporated. For example, if a white note is hidden and the contact changes course to increase collision risk, it should reappear as yellow or red requiring it be hidden again to remove it. -It would be good if hovering over or focusing on a distant contact information callout caused it to pop up larger temporarily allowing for increased readability of information for distant contacts and early planning.

---

If the course of the contact is known it would be nice to have it placed on the ARNA display along with 3 or six min hash marks to allow the user to know where the contact will be in that time and what aspect the contact is

---

Recommend adding the ability to "pull up" an information box that integrates the AIS information (CMG, SMG, Turning Rate, Vessel Type and Info)

---

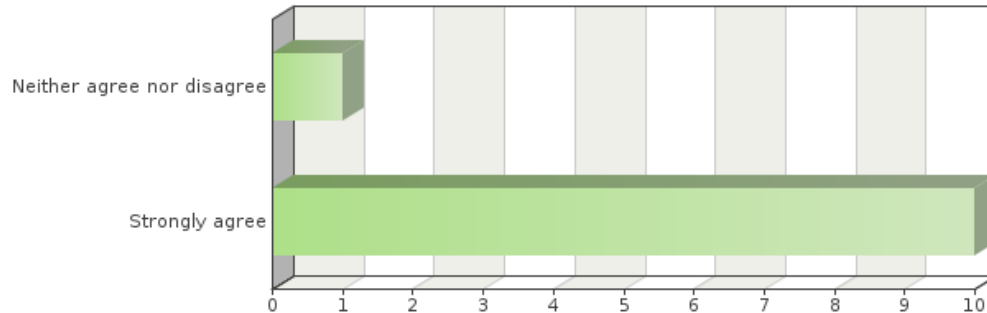
One potential item with the collision avoidance ARNA would be for the potential to overwhelm the navigator with information in congested waters. A recommended option would be to allow the ship to set a zone around the ship where the collision avoidance data would be displayed. This could take the form of either an absolute range from the ship (5nm bubble), or a targeted zone (3nm ahead, 2nm abeam and astern), or a zone specific area (to provide indications of vessels around a bend in the channel/river.

---

## Question 28

Select the degree to which you agree or disagree with each of the following statements:

**Red is an appropriate colour for the Danger ARNA.**



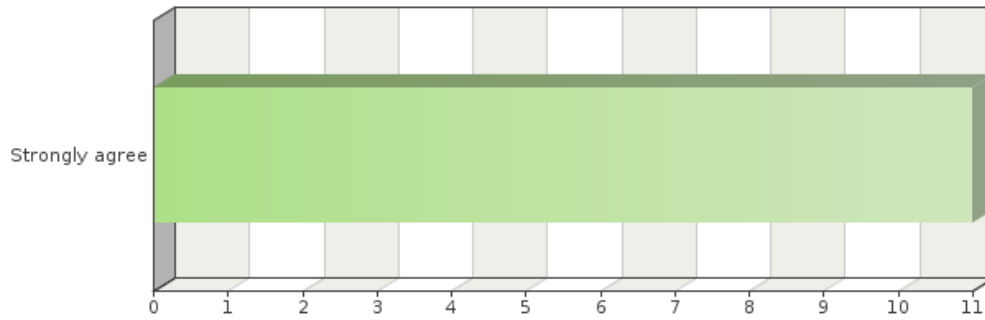
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Neither agree nor disagree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	3	Variance:	0.36	
Median:	5	Maximum:	5	Std. deviation:	0.6	

**Total answered: 11**

## Question 29

The Danger ARNA would improve safety.



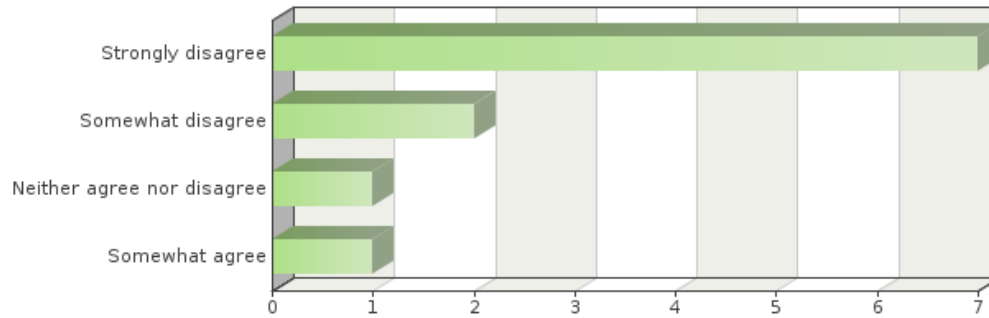
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

Total answered: 11

### Question 30

The Danger ARNA would distract the navigator in the conduct of the passage.



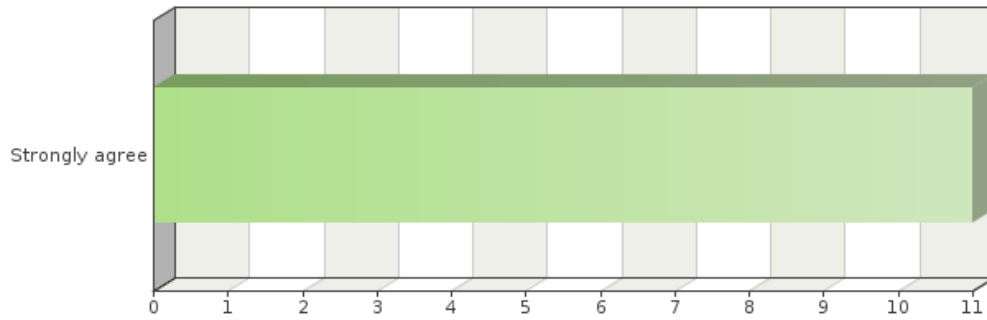
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	7	7	63.64%	63.64%	63.64%	63.64%
Somewhat disagree	2	9	18.18%	81.82%	18.18%	81.82%
Neither agree nor disagree	1	10	9.09%	90.91%	9.09%	90.91%
Somewhat agree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.64	Minimum:	1	Variance:	1.05	
Median:	1	Maximum:	4	Std. deviation:	1.03	

Total answered: 11

### Question 31

The Danger ARNA is effective in showing the area marked by the limiting danger line.



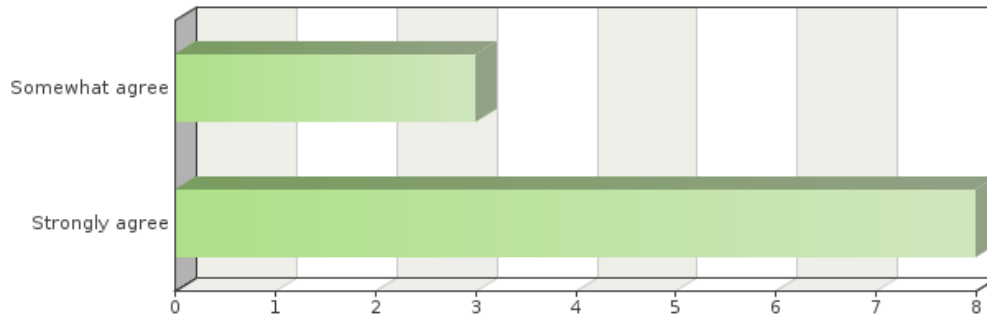
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

Total answered: 11

### Question 32

The information gained by the Danger ARNA is useful in the conduct of a navigation passage.



Frequency table

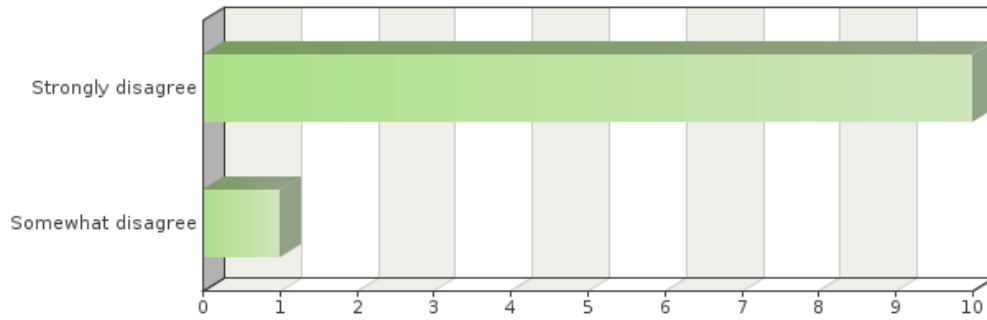
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	3	3	27.27%	27.27%	27.27%	27.27%
Strongly agree	8	11	72.73%	100%	72.73%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.73	Minimum:	4	Variance:	0.22	
Median:	5	Maximum:	5	Std. deviation:	0.47	

Total answered: 11



### Question 33

The Danger ARNA is confusing.



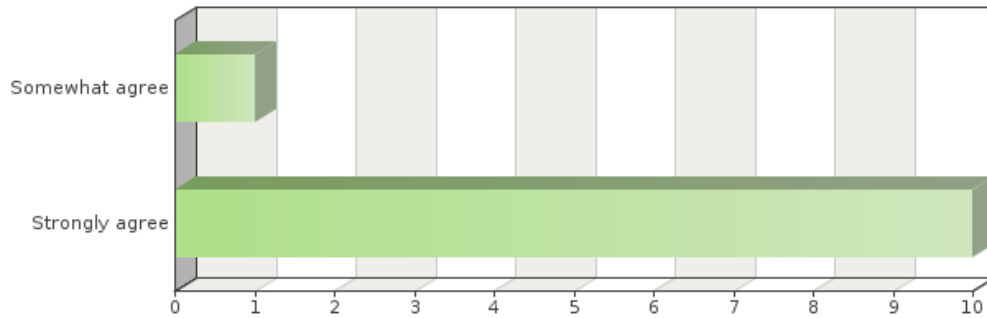
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	10	10	90.91%	90.91%	90.91%	90.91%
Somewhat disagree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.09	Minimum:	1	Variance:	0.09	
Median:	1	Maximum:	2	Std. deviation:	0.3	

Total answered: 11

### Question 34

The range to the Danger ARNA ahead is useful to the navigator.



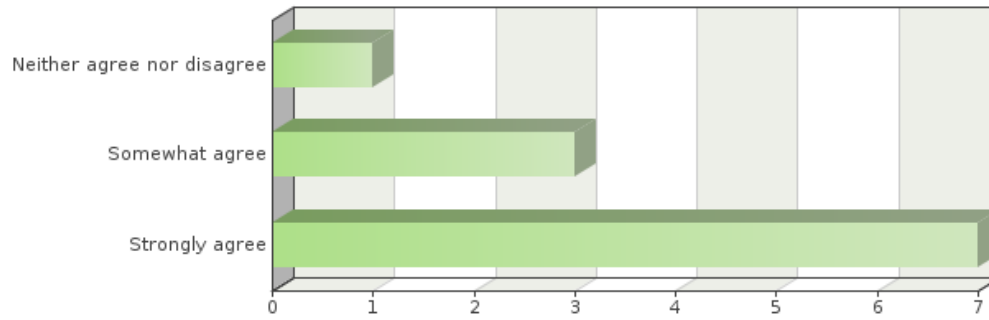
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.91	Minimum:	4	Variance:	0.09	
Median:	5	Maximum:	5	Std. deviation:	0.3	

Total answered: 11

### Question 35

The range to the Danger ARNA astern is useful to the navigator.



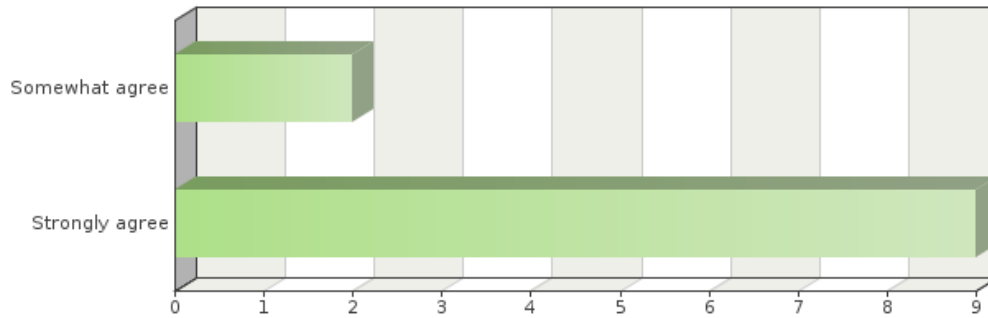
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Neither agree nor disagree	1	1	9.09%	9.09%	9.09%	9.09%
Somewhat agree	3	4	27.27%	36.36%	27.27%	36.36%
Strongly agree	7	11	63.64%	100%	63.64%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.55	Minimum:	3	Variance:	0.47	
Median:	5	Maximum:	5	Std. deviation:	0.69	

Total answered: 11

### Question 36

The range to the Danger ARNA abeam is useful to the navigator.



Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	2	2	18.18%	18.18%	18.18%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	4	Variance:	0.16	
Median:	5	Maximum:	5	Std. deviation:	0.4	

Total answered: 11

## Question 37

Please provide any additional comments/feedback you wish the researchers to know about the Danger ARNA.

Text input

---

The trial run does not show how other contacts interact with the Danger ARNA (as in how visible they are) it is possible that blanking out the whole area, instead of a dashed line or other identifier, would limit visibility in those areas.

---

As red is already used in the navigational track, I worry about the confusion between navigation and danger. Perhaps an orange for the danger area? Or no colours for the navigational track, but have the port or starboard side of the line turn to grey when off course?

---

The three ranges are all very useful. Ranges to the clearing areas would also be helpful, so that the operators can determine how far before their ability to turn away becomes reduced. Additionally, a "time of safe water" would be beneficial for the range ahead, so that operators can immediately know how long they are able to stand-on based on their current speed. Perhaps this could be all included in a single box: Range to Danger Area Ahead: XXX yds Range to Clearing Area Ahead: YYY yds Time of Safe Water: MM:SS

---

It is recommended that the danger line be dashed and that the transparency has the ability to be changed.

---

The only thing I considered to be missing was the closest distant to the LDL. Ahead is obviously important, but the closest point provides information I was thinking about and wasn't readily available. (This may be due to my inexperience in navigating, and it may not be something that is of real value)

---

Much like the track ARNA, adding the units to the distance would be useful.

---

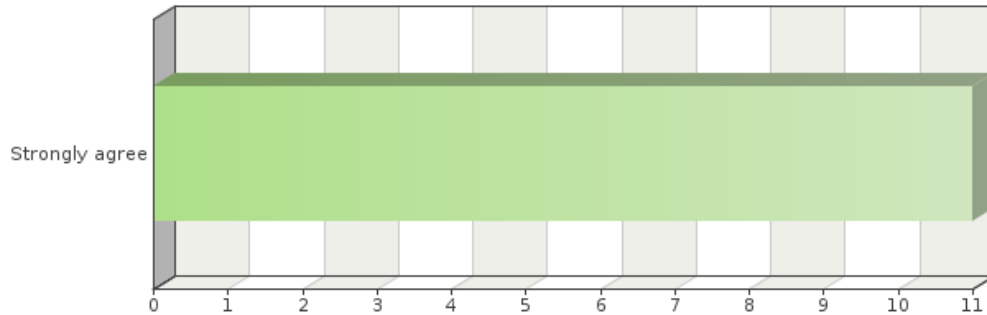
The Danger ARNA is good to indicate the absolute ranges to dangers around the ship. One potential option would be a dynamic danger range to the closest danger zone, which would augment the beam/ahead ranges. The astern danger range is useful in certain situations but is most useful if altering to avoid going aground. Recommendations for this Danger ARNA would be a user-programmable range at which the Danger ARNA would not display (such as if there are no dangers with X miles of the ship). Finally, a heads-up indication when a ship is approaching within a certain distance of a Danger ARNA is also recommended, as a prompt to watchkeepers/mates, navigators and masters/commanding officers (i.e. an indication that the ship has approached within XXX yards of a danger ahead, on its beam, or to a dynamic danger range).

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### Question 38

Select the degree to which you agree or disagree with each of the following statements:

**Yellow is an appropriate colour for the Clearing Area ARNA.**



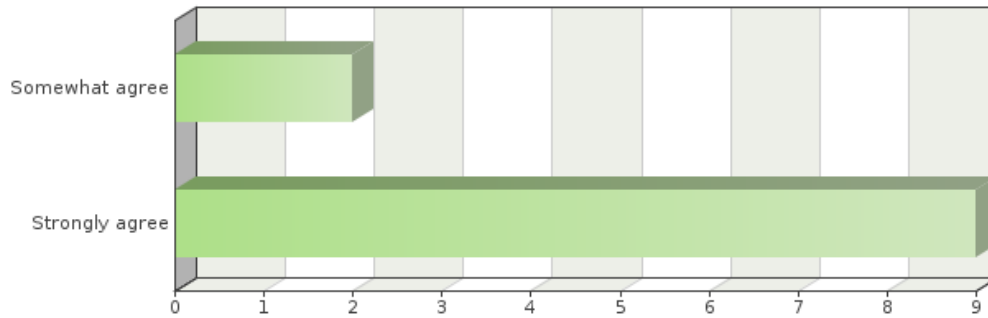
**Frequency table**

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly agree	11	11	100%	100%	100%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	5	Minimum:	5	Variance:	0	
Median:	5	Maximum:	5	Std. deviation:	0	

**Total answered: 11**

### Question 39

The Clearing Area ARNA would improve safety.



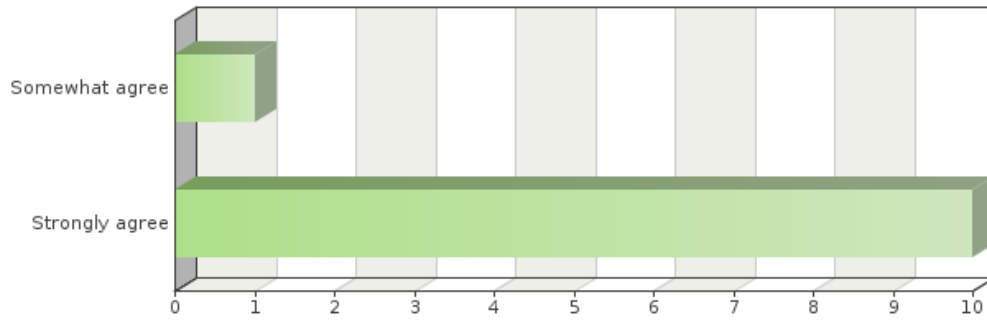
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	2	2	18.18%	18.18%	18.18%	18.18%
Strongly agree	9	11	81.82%	100%	81.82%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.82	Minimum:	4	Variance:	0.16	
Median:	5	Maximum:	5	Std. deviation:	0.4	

Total answered: 11

## Question 40

The Clearing Area ARNA effectively visualizes clearing bearings and/or clearing depths



Frequency table

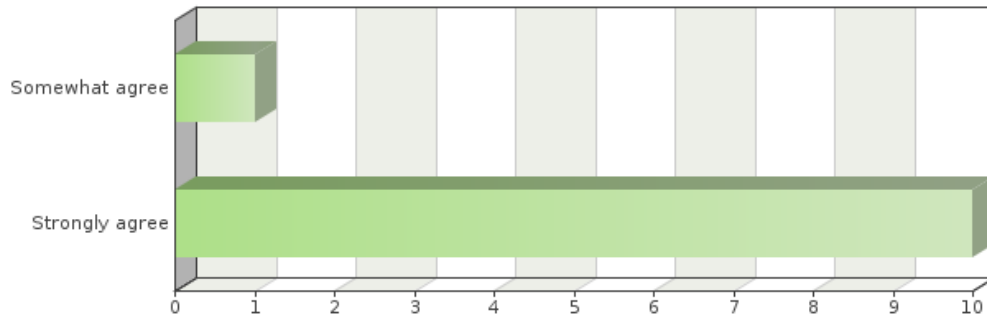
Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.91	Minimum:	4	Variance:	0.09	
Median:	5	Maximum:	5	Std. deviation:	0.3	

Total answered: 11



### Question 41

The Clearing Area ARNA is effective in alerting the navigator to monitor the proximity of the ship's stern to dangers when altering course.



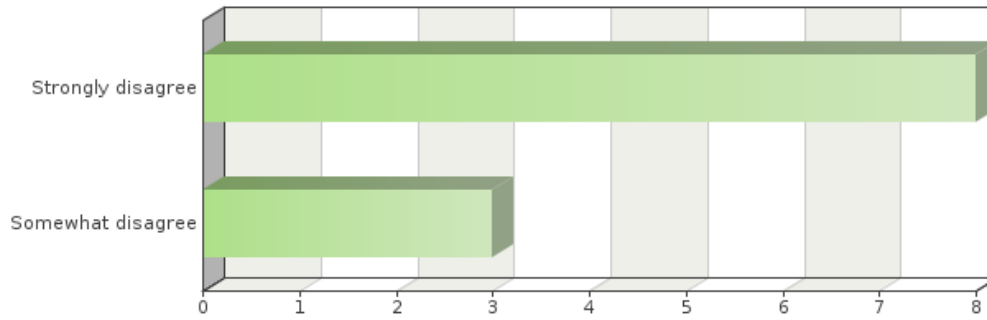
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Somewhat agree	1	1	9.09%	9.09%	9.09%	9.09%
Strongly agree	10	11	90.91%	100%	90.91%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	4.91	Minimum:	4	Variance:	0.09	
Median:	5	Maximum:	5	Std. deviation:	0.3	

Total answered: 11

## Question 42

The Clearing Area ARNA is confusing.



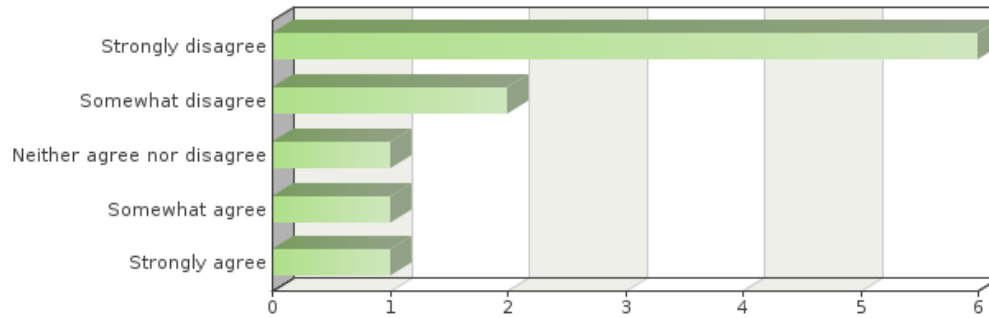
Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	8	8	72.73%	72.73%	72.73%	72.73%
Somewhat disagree	3	11	27.27%	100%	27.27%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	1.27	Minimum:	1	Variance:	0.22	
Median:	1	Maximum:	2	Std. deviation:	0.47	

Total answered: 11

### Question 43

The Clearing Area ARNA would distract the navigator in the conduct of the passage.



Frequency table

Choices	Absolute frequency	Cum. absolute frequency	Relative frequency	Cum. relative frequency	Adjusted relative frequency	Cum. adjusted relative frequency
Strongly disagree	6	6	54.55%	54.55%	54.55%	54.55%
Somewhat disagree	2	8	18.18%	72.73%	18.18%	72.73%
Neither agree nor disagree	1	9	9.09%	81.82%	9.09%	81.82%
Somewhat agree	1	10	9.09%	90.91%	9.09%	90.91%
Strongly agree	1	11	9.09%	100%	9.09%	100%
Sum:	11	-	100%	-	100%	-
Not answered:	0	-	0%	-	-	-
Average:	2	Minimum:	1	Variance:	2	
Median:	1	Maximum:	5	Std. deviation:	1.41	

Total answered: 11

## Question 44

Please provide any additional comments/feedback you wish the researchers to know about the Clearing Area ARNA.

Text input

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Similar to the Danger ARNA, blanking out the whole area may limit visibility inside the Clearing Area ARNA

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The yellow as a warning area was a natural choice for the colour.

---

See comments on Danger ARNA.

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As with the danger area, it is recommended that the area be dashed.

---

I really like this feature. When close to danger, an immediate piece of information telling you that you cannot simply come hard about would be invaluable.

---

having a clearing area that is not fixed to a 180 degree turn away from dangers would increase the utility of the ARNA

---

As the vessel turns away, if it integrated with the turning data from the ship may allow the program to make recommendations when entering the clearing area (ie) increase helm, decrease helm, steady ship's head, etc

---

The clearing area ARNA provides the navigator or watchkeepers a visual indication of where they must take action to avoid grounding the ship. At present this is based on a 180 degree turn away from dangers (most useful if approaching a hazard from ahead). Recommendations may be to allow the user/navigator to dynamically alter the clearing area, and reduce if less drastic alterations away from dangers are planned. This recommendation would be of most benefit in pilotage, harbour, river and canal transits where the distance from land or underwater hazards may fill the screen with the clearing area.

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## Question 45

Please provide any additional comments/feedback you wish the researchers to know about the ARNAs presented in general.

Text input

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Overall, this is an improvement in the training environment as it clearly demonstrates the fundamental navigation safety and passage requirements. In a real world application, it would be of great use to watchkeepers and Navigators by ensuring that they are able to maintain a continuous watch outside of the platform. It would remove almost all requirement to look at screens internal to the platform. For a follow up, I would be quite keen to know how it would work during night, to avoid reducing glare or bright lights. Overall a great tool with huge potential for remote operation of vessels on top of its intended use as a Navigator/Watch Keepers aide.

---

I could see use for this product in both large ships and small boats. Visual aids would greatly help the small boat navigator who has lots of navigational aids aboard the boat, but not necessarily the skills to use the aids. The ARNA visual representation is much more intuitive than a "plotter map" or radar.

---

Very interesting concept with a lot of potential. As a Captain, ranges to dangers is probably the most often question I ask my Navigator. The ability to instantly provide them without having to reference another piece of equipment or have to calculate it with mental math would certainly improve situational awareness.

---

I really like this idea. As discussed, training for those using would be very important to ensuring appropriate implementation and use. Great work and thanks for asking for me to participate. I'm merely a watchkeeper but was thankful to take part.

---

Having sounds would help make it more realistic, such as the sound of your engines, other vessels passing, radio signals, weather, etc... Also, having the ability to talk to other vessels would be great too. Understand that is difficult, unless someone is acting as control for the simulation, but perhaps you could have set texts that you could send to each vessel, that would provide a reply. For example, see you red to red, or request I pass astern or ahead of you, what clearance astern do you need for fishing vessels trawling, etc.. Otherwise, loved the simulation and found it very user friendly and visually everything was right there to help keep the ship safe.

---

This seems like an excellent tool. Rather than distracting the navigator with unnecessary information, it condenses multiple sources into an easily absorbable format, allowing a quicker response time to developments, instead of searching for vital information. In addition, it allows the navigator to remain "heads up" and focussed on their surroundings which is essential for proper and safe marine navigation.

---

Overall I found this to be an absolutely amazing piece of technology. It seems so obvious that it should exist that I am amazed that it has not yet been implemented! I wish you every success!

---

In general enabling any of the information placards to pop up or zoom when rolled over or focused on to allow for readability of more distant ones would be welcome. The absolute size is useful in visualizing distance to the data point in question, but once one has attracted attention no matter how distant, it should be possible to easily read it.

---

A tool used to give any seafarer more information regarding safety is an asset

---

Excellent tool for the Navigator/Pilot to execute a passage in a heads-up virtual world! Looks great and very user-friendly.

---

I can envision this technology of benefit to watchkeepers, mates, navigators and masters, in order to enable personnel to spend more of their bridge rhythm time looking out the windows rather than their navigation systems; the data provided virtually would also allow for better assessments of risk of collision. One potential would be for harbour pilots to leverage this system to facilitate harbour entrances and departures. Overall, I have nil concerns with the ARNAs presented, and feel this system would improve maritime safety.

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