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# On the Necessity of Augmented Reality Technology in Surface Warfare Operations

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# ACRONYMS

| | |
|---|---|
| AR | Augmented Reality |
| ASTRID | Augmented Ship Transits for Improved Decision-making |
| BEMR | Battlespace Exploitation of Mixed Reality |
| CPA | Closest Point of Approach |
| Conn | Conning Officer |
| DARPA | Defense Advanced Research Projects Agency |
| DAVD | Divers Augmented Vision Display |
| FOV | Field of View |
| Helms | Helmsman |
| HMD | head-mounted display |
| IBS | integrated bridge system |
| JOOD | Junior Officer of the Deck JOOD |
| KARMA | Knowledge-based Augmented Reality for Maintenance Assistance |
| Lee Helms | Lee Helmsman |
| MARNAA | Marine Augmented Reality Navigational Assistance Application |
| NSWC PCD | Naval Surface Warfare Center – Panama City Division |
| NAVSEA | Naval Sea Systems Command |
| Nav | Navigator |
| OAF | omnidirectional attention funneling |
| ONR | Office of Naval Research |
| OOD | Officer of the Deck |
| SA | Situational Awareness |
| SWAVE | spherical wave-based guidance |
| SWO | Surface Warfare Officers |
| UI | user interface |

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# 1. INTRODUCTION

Surface Warfare Officers (SWOs) receive a constant influx of information from multiple sources to make split-second decisions when navigating a vessel from the bridge. An augmented reality (AR) head-mounted display (HMD) allows for sustained situational awareness (SA) of the task at hand by intuitively integrating necessary information as an image transposed onto the outside environment. By reducing cognitive load and increasing SA, AR technology proves to be a necessity in the ever more complicated domain of Surface Warfare Operations, as we shall see throughout the course of this paper.

## 1.1 MISHAPS AND THEIR CAUSES

In 2017, a series of four catastrophic maritime navigation incidents motivated a comprehensive review. While each incident was unique and complex, confusion or lack of situational awareness was a common thread (Davidson, 2017). The death of seventeen sailors in these incidents serves as a sobering motivation to consider what might be done to prevent a future tragedy such as these.

## 1.2 INFORMATION DISPLAY FOR IMPROVED SITUATIONAL AWARENESS

As Oh, Park, and Kwon at the Korea Research Institute of Ships and Ocean Engineering have determined, "Therefore, ships officers are requesting the efficient display of information on the bridge, and various navigational aids systems are being researched and developed using augmented reality technology as a means of displaying data… using HMD (Head-Mounted Display)… in order to enhance the target recognition speed of the navigator" (OH, Park and Kwon, 2016). We propose a similar modality to assist in the integration of information and allay confusion during navigation. What is augmented reality in the first place? The Center for Coastal and Ocean Mapping at the University of New Hampshire defines it as "the superimposition of digital information on top of a user's view of the real world" (Kokoszka, 2017). As Mark Livingston of the Naval Research Laboratory and others have said, "Performance requirements on cognitive tasks remain open for most AR systems. Which tasks are appropriate for investigation depends on the application, but certain core tasks are emerging in the literature: visual search, navigation (especially for outdoor, mobile AR), manipulation (especially for desktop AR), and situation awareness" (M. A. Livingston et al., 2005). Our report here will focus on the potentiality of AR applications to maritime navigation. But before we can understand how AR would be able to assist SWOs, we first have to understand what information the SWOs need to know and how officers communicate information in an ordinary bridge scenario.

## 1.3 AR AS A MITIGATION STRATEGY

Information is continuously exchanged between officers through various interfaces before, during, and after transit, as well as in the course of special maneuvers. Margaret Lutzhoft of the University of Linkoping in Sweden has described at great length how, "An integrated bridge system (IBS) is defined as a combination of systems which are interconnected in order to allow centralized access to sensor information or command control form workstations, with the aim of increasing safe and efficient ship's management by suitably qualified personnel" (Lutzhoft, 2004). This data can be centralized on a HMD employing AR technology. To understand the benefits of an AR HMD, let us take a look at a typical interaction on the ship bridge during transit. The major players on a ship's bridge are the Conning Officer (Conn), the Officer of the Deck (OOD), the Navigator (Nav), the Junior Officer of the Deck (JOOD), the Helmsman (Helms), and the Lee Helmsman (Lee Helms) (Barber, 2005). Like a GPS, the Nav gives verbal notifications as to whether the ship is tracking correctly, or if it needs a change of course. The OOD and the Conn then confirm this information. The Conn next relays this information to the Helms and the Lee Helms in the form of rudder and engine commands. The JOOD continuously monitors other contacts and will speak over the comms to the other vessels. The OOD moves about the bridge making sure that everything is running smoothly and is ultimately responsible for ensuring the ship navigates safely.

As one might already be able to detect, AR has the potential to revolutionize many maritime operational tasks by more effectively displaying information, allowing for smoother context-switching. For instance, being able to check course heading at a cursory glance across the bridge panorama leaves the Nav unencumbered to follow new commands issued by the OOD. Research conducted at Renssaeler Polytechnic Institute has revealed that “officers wearing immersive AR technology can receive real-time weather, visibility, and vessel speed restriction information for a particular transit in advance of the transit or in real-time, and have that information linked to the bridge’s existing decision support and integrated bridge systems” (Gabrowski, 2014). Additionally, more ubiquitous information sharing across the chain of command enables more efficient communications to allow for more informed decisions by commanding officers and leadership. If all the officers can see the same closest points of approach (CPA) simultaneously through their headsets, they will be better equipped to communicate on deck to chart the course forward. Lastly, AR lets sailors quite literally see the unseen by projecting over the regular landscape the images of contacts and other obstructions in the water that are otherwise totally invisible to the naked eye under cover of night or fog (Morgère, 2015). Context-switching, communication, and see-through vision are all assets to AR technology in surface warfare operations.

## 1.4 FOREIGN AND DOMESTIC RESEARCH PRECEDENTS

While AR maritime navigation has yet to be perfected entirely for the military domain, recent research provides more than enough precedent for our current project.

# 2. UNITED STATES NAVY

By way of introduction to the state of the art, we will explore some of the concurrent studies being conducted in the US Navy. As Van Orden et al. have explained, "Space and Naval Warfare Systems Center Pacific has established the Battlespace Exploitation of Mixed Reality (BEMR) lab to demonstrate the art of the possible for applying AR and VR technologies to Navy-relevant areas of interest such as training, maintenance, and new user interfaces for a variety of operational environments" (Van Orden et al., 2018). As Kokoszka et al. have stated, "Augmented reality has been a research topic for over two decades, and Navy-funded research has driven many of the advances in the field over that time…" (Kokoszka, 2017). His team used Microsoft HoloLens "to allow mariners to look at their paper nautical charts and see all modifications that need to be rectified and their respective locations on their paper charts" (Kokoszka et al., 2018). While we use MagicLeap rather than HoloLens, and project images onto the panoramic ocean view rather than the paper charts, the principle of using AR to enhance the ship-driving experience remains the same.

Not only the Surface Warfare community but also the Diving community has taken an interest in the navigational potential of AR technology, further justifying Navy sponsorship of our designs. According to the Underwater Systems Development Branch, "Under a project sponsored by the Office of Naval Research (ONR) and Naval Sea Systems Command (NAVSEA), the Naval Surface Warfare Center – Panama City Division (NSWC PCD) has developed a prototype see-through head-up display system for a US Navy diving helmet – the Divers Augmented Vision Display (DAVD)" (Gallagher et al., 2017). While their prototype applies to underwater maneuvers rather than surface warfare evolutions, the same principles of AR technology apply: "The virtual images can be critical information and sensor data including sonar images, ship husbandry and underwater construction schematics, enhanced navigation displays, augmented reality, and text messages" (Gallagher et al., 2017). Although the challenges posed above and below the surface of the water prove to be different, AR technology could help both ship-drivers and divers alike reckon with their surroundings in a manner that most minimizes the inherent risks to mission operations.

## 2.1 EASTERN

However, we need not only turn to military sources to discover military solutions. The private sector has also worked hard to apply AR technology to maritime navigation. For instance, the Department of Maritime Systems Engineering at Tokyo University has developed a system "which displays the sea route on the surface of the sea by using augmented reality so that the navigator may grasp the ship's position from the sea route easily" (Okazaki et al., 2017). Not only Japan but also Korea has worked on AR technology's applications to maritime navigation, as the Korean Research Institute of Ships and Ocean Engineering has concluded, "Recently, in order to address the problem of navigation equipment, such a high complexity and inefficient information provision, augmented reality (AR) technology has been introduced to the navigation equipment for supporting decision making of officers" (Jang et al., 2017).

## 2.2 WESTERN

In a very similar approach to our own, researchers at the Institute of Information Technology in Germany have developed "a graphical user interface design based on Smart Glasses to support pilots in harbor maneuvers" (Ostendorp et al., 2015). The Department of Computer Engineering at the University of Victoria in Canada seeks "to provide a captain with a real-time augmented reality system that will centralize most of the relevant information about the vessel and its environment, thus relieving the effort of obtaining this data in real-time, as well as greatly reducing the risk for human error in the process of switching between media" (Wisernig et al., 2015). On a similar note, a collaboration between French researchers has achieved "a real-life outdoor Marine Augmented Reality Navigational Assistance Application (MARNAA) that alleviates cognitive load issues/orientation between electronic navigational and bridge view for vessels and recreational boats" (Morgère et al., 2014). As Morgère et al. have cited elsewhere, "In the maritime domain, current augmented reality systems are made to limit accidents… more precisely collisions and groundings" (Morgère et al., 2015). Most saliently in fact, "An early study sponsored by the US Defense Advanced Research Projects Agency (DARPA) focused on examining the impact that Augmented Reality (AR) has on an operator's cognitive capabilities under high workload conditions… Results indicated that Augmented Reality provided a 342% improvement in operator ability to handle multiple tasks while precisely navigating a vessel" (Benton et al., 2008). This singular reduction in cognitive load for the intensive task of shipboard navigation through high-traffic channels under inclement conditions constitutes the rationale behind AR technology in the martial maritime domain.

# 3. INTRODUCTION

Imagination alone limits the examples that come to mind for AR, whether in the private sector or the public sector. A few principles must be borne in mind when designing an effective AR application, which we shall elucidate in the following sections.

## 3.1 COMMERCIAL EXAMPLES

The gaming world has commercialized recent applications of AR for public entertainment in the gaming world. Entertainment venues have also experimented with AR to enhance viewer experience. Private industry is looking into AR applications to navigation. Likewise, holographic examples offer the possibility of virtual meetings to put people across continents in the same room together.

## 3.2 MANAGING COGNITIVE LOAD

However, military applications have focused on using AR to improve efficiency and lower long-term costs while supporting mission-critical objectives. Although positive in many respects, determining the proper amount of information to display in the system setup without overloading cognitive function has become a key point for user interface (UI) design testing (Gabrowski M., Rowen A. & Rancy J., 2018). In order to achieve this balance and reduce cognitive workload, we must take into account many factors when implementing AR to display visual information.

## 3.3 IDENTIFICATION OF KEY PRINCIPLES

Here, we address the primary issues that arise when utilizing a HMD in a routine ship-handling scenario.

### 3.3.1 Depth

First, AR is plagued by problems with how to best portray *occlusion*, which conveys *depth* perception of virtual images whose line of sight has been obstructed behind real-world objects in the external environment. How AR displays information proves critical to the functionality of the system, especially to a navigational system, lest the operator become even more disoriented than before. Relative depth of virtual objects can be hard to accurately project, especially when the objects are occluded. For instance, if a virtual course heading occludes the sailor’s view of a real buoy, a misperception of depth could result in a collision.

### 3.3.2 Attention guidance

Second, *attention guidance* techniques can help the operator filter visual information by order of importance, but they run the risk of ignoring secondary and tertiary tasks in the process. Principles of visual saliency – especially color, light, and motion – prioritize information flow by what appears to be most paramount in any given instance. As Kalkofen et al. have pointed out, “Salient regions can be understood as the regions in an image, which are most likely to attract the viewer’s gaze” (Kalkofen et al., 2011).

### 3.3.3 Technical implementation

Third, the *technical implementation* must accurately convey depth via attention guidance in order for the AR HMD to be instrumental in shipboard navigation. We must carefully consider optic effects, as well as hardware and software constraints, must be carefully considered to actualize the plan in a fleet scenario. After examining these three elements as they pertain to maritime AR, we conclude with a brief discussion of our own maritime design based on the literature review of the state of the art presented here. The following sections demonstrate the current limitations of AR to explore how our design takes these limitations into consideration, and in some cases, circumvents them entirely to make for a safer shiphandling experience for all aboard a naval vessel.

# 4. DEPTH

A good sense of depth perception proves integral to any shiphandling scenario. SWOs rely heavily on not only chart displays but also the orientation of the vessel based on their naked eye. The vast expanse of ocean across the horizon makes it difficult to assess the depth of virtual objects without the presence of anything else in the water to serve as a basis for comparison. AR can assist by overlaying virtual depth cues relative to the real environment of the maritime arena. First, we will go over the right ingredients to a successful AR projection. Then, we will examine the various pitfalls that can occur. Finally, we suggest a few solid remedies to the situation.

## 4.1 PRINCIPLES

Here it would be helpful to present a few general principles to better render the depth of virtual objects relative to the physical topography in maritime navigation.

### 4.1.1 Occlusion

First, the occlusion of opaque surfaces by virtual objects acts as an ordering cue. Thus, virtual circles targeting various vessels occlude each other based on their relative distance from one another. As Mark Livingston of the Naval Research Laboratory and others have shown, "In the development of AR (and VR) environments, we are interested in measuring the perception of distance, but we suffer from the classic problem that perception is an invisible cognitive state, and so we have to find something measurable which can be theoretically related to the perception of distance" (M. A. Livingston, Ai, Swan, & Smallman, 2009). Second, shadows help to convey relative position, especially if the virtual objects are to appear to be floating on the water. Third, the size of virtual objects should also appear relative as a function of distance, such that smaller objects appear to be farther away than larger objects (Durgin, Li, & Hajnal, 2010; Proffitt, Bhalla, Gossweiler, & Midgett, 1995). If the ship is far away, the circle targeting it is correspondingly smaller in size. The farther away virtual objects are supposed to appear, the less contrast they should have. Intuitively speaking, nearer objects should be seen more precisely than distant ones, which are to appear blurrier. Thus, the text/circle with contact information for a target ship will look smaller and blurrier than one up close. Hence, occlusion, shadow, and size all serve to make the virtual elements blend in more seamlessly with the environment to make for a safer transit for the SWO.

### 4.1.2 Motion, grid lines, and shapes

These are not the only principles to keep in mind, however. First, motion cues also provide important depth clues. Due to motion parallax in the real world, farther away objects appear to travel more slowly and less distantly than nearer objects, so the virtual projection should abide by the same cognitive effect (Furmanski, Azuma, & Daily, 2002). While relative size provides a strong sense of orientation in the marine environment, occlusion cues and motion parallax provide even more powerful visual cues than relative size does (M. A. Livingston, Ai, Swan, & Smallman, 2009). Second, parallel lines appear to cover a greater distance the farther they are from view. Simply adding ground plane grids gives an impression of both relative and absolute distance (Kalkofen, Sandor, White, & Schmalstieg, 2011a). In our case, we transpose chart lines over sea rather than land to endow the resulting image with the correct perspective. Third, shape is an important factor in accurate perspective. Depth perception is harder for round objects than sharp ones; thus, flat moving objects like ships can be far harder to detect than motionless cylindrical buoys, and floating objects like submarines appear differently than stationary ones such as lighthouses. (Tönnis, Klein, &

Klinker, 2008). Motion parallax, visual parallelism, and shape differentials can enhance or detract from the SWOs' user UI, depending upon how well they are integrated into the design.

### 4.1.3 Light

The maritime environment itself can pose difficulties to depth perception. First, outdoor versus indoor use of AR can affect perception in a variety of ways. Using AR in an outdoor environment is much more susceptible to changes in terms of the angle of lighting, specifically as to whether it is diffuse or direct. Outdoor AR users tend to overestimate depth, while indoor users tend to underestimate it. Therefore, employing linear perspective cues reduces depth errors, indoors or outdoors (M. A. Livingston, Ai, et al., 2009). Second, since our system will be utilized on a ship bridge in ever-fluctuating light conditions, how the level of luminance affects depth perception is of critical importance. Adjusting for rugged outdoor conditions involves careful visual composition, or else the naval officer will have trouble discerning what is real from what is virtual. Calibrating opacity and color intensity of virtual objects in a linear-decreasing fashion such that each object is less opaque than the one preceding it enables the operator to more accurately determine the location of the target object, but it does not enhance response time (M. A. Livingston et al., 2003). Third, research suggests that an opacity value .5 or lower causes perceptual problems for mariners. On the one hand, when virtual objects are too transparent, occlusion can no longer able to be used as a depth cue. On the other hand, when the virtual occlusion becomes too opaque, it actually appears to be behind the real object it occludes (Buchmann, Nilsen, & Billinghurst, 2005). External light sources, internal luminance, and level of transparency must all be finely calibrated, so that the officer's panorama remains unobstructed.

## 4.2 PROBLEMS

While AR can offer major advantages to the naval officer, there are serious drawbacks to using this approach, which we will now discuss.

### 4.2.1 Visual obstruction

First, although providing virtual depth cues can be beneficial, it also has the potential to obstruct real-world objects from view.

### 4.2.2 Optical infinity

Second, as the interactive display approaches optical infinity, it becomes increasingly difficult to distinguish between the real world and the virtual world. Depth cues vary in their effectiveness by distance. The far field distance is defined as 30 meters to infinity, and as the distance increases, depth perception becomes increasingly compressed (Swan et al., 2006).

### 4.2.3 Poor legibility

Third, when Livingston et al. (2005) tested a search-and-rescue navigation task in an AR environment, results showed that details such as text layout and legibility clearly impeded the operator's performance; therefore, the legibility and text layout of virtual views superimposed over the real-world scenery are essential factors for navigating in a marine setting. Taken together, relative depth cues, optical infinity, and text legibility help the SWOs gauge distance through the display.

## 4.3 SOLUTIONS

Furthermore, AR has the potential not only to enhance what can already be seen with the naked eye but also to see what cannot otherwise be seen.

### 4.3.1 X-ray vision

First, this kind of "x-ray" vision can be very useful, if the information contained therein is presented in a user-friendly way. A fine line remains between giving the operator so much information that they become overwhelmed, and so little information that the operator has no sense of depth relationships. Thus, showing the sailors too many things that are invisible to the naked eye may end up doing more harm than good (M.A. Livingston et al., 2003).

### 4.3.2 Heuristic algorithms

Second, in order to limit the amount of visual stimuli displayed, algorithms can be implemented to weed out information that is extraneous to the naval officer's information needs. For example, only vessels within a designated CPA would be visibly labeled at any given time.

### 4.3.3 Mini-maps

Third, shallow waters are shown by shading a top-down mini-map, which is one example of a non-distracting way of visualizing invisible dangers. X-ray vision, heuristic algorithms, and mini-maps work in conjunction to make the display intuitive.

### 4.3.4 Virtual texturing

Using virtual holes projected on real objects to visually connect with virtually occluded objects enhances depth perception dramatically. First, the Knowledge-based Augmented Reality for Maintenance Assistance (KARMA) system represented virtual objects outside of the direct line of sight by means of dashed lines and partial transparency. To make it obvious that the 'ghosted' object is behind the real object, a virtual hole was placed in the center of the real object (Feiner, Macintyre, & Seligmann, 1993). When tested, a cutaway in the real object (or, virtual hole) significantly improved the ability for users to recognize virtual objects from real objects and thus improved their cognitive capacity to order objects by depth (Furmanski et al., 2002). This cutaway works by providing a visual context for the 3D relationship between real and virtual objects. Second, additional research has found that adding virtual textured background and virtual holes reduces perceptual depth errors associated with the presence of a visible real surface near a virtual object. (Ellis & Menges, 1998). Texture helps with depth cueing, as well as synthetic markings, such as hatch marks or stippling (Kalkofen, Sandor, White, & Schmalstieg, 2011b). Third, adjusting the look of the virtual objects such that they have color fills and wire frames around them has shown to help with speed and accuracy of locating a target object (M. A. Livingston et al., 2003). This speed and accuracy is crucial in a maritime environment when mission-critical decisions need to be made. Cutaways, virtual backgrounds, and wire-filled frames can help display information panels.

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# 5. ATTENTION GUIDANCE

One of the benefits of AR is that visual information can easily be manipulated to draw on attentional cues, which is a huge benefit to marine navigation. Several techniques have been developed to guide the operator's attention towards the target object. In the case of SWOs, this usually entails honing in on another boat on the horizon. As with depth/occlusion, several principles must be borne in mind when architecting an AR UI for the marine navigational HMD. First, the cueing used to detect targets as quickly as possible can be either explicit, or subtle. Second, directing lines and attention funneling serve to focus the operator's eyes upon objects of key interest by an explicit means. Third, the level of luminance produces contrast against the background environment so as to draw the gaze by a subtle means. We will explore cueing, direction, and luminosity throughout the course of the rest of this section to incorporate all of the above explicit and subtle elements into future interface design.

## 5.1 CUEING

There exist two main types of cueing: explicit and subtle.

### 5.1.1 Explicit

First, explicit cueing is more blatant and can cause distracting visual clutter, which decreases search effectiveness and inhibits the likelihood of mission success (Lu, Duh, Feiner, & Zhao, 2014). Examples of explicit cueing are relatively straightforward. Tabs that list information to the side of an object of interest constitute an explicit cue, as do chart lines and attention funnels. Likewise, circles can circumscribe visual targets of interest. Furthermore, shaded boundaries indicate the presence of shallow waters.

### 5.1.2 Subtle

Second, subtle cueing is barely noticeable, as it is usually accomplished through adjusting opacity in a designated region. The larger the subtle cue, the easier it is to find the target; the higher the opacity level, the more effective it is in aiding users to find designated targets. Since no other opacity level was tested, it is unknown if an even higher opacity level would be more efficacious in aiding visual search, or not (Lu et al., 2014). Besides visual cues, audio cues can act as the initial cue leading to attention-directed scanning (Biocca et al., 2006). The small field of view (FOV) of most current AR systems means that operators must perform more scanning movements, particularly in the case of maritime environments, so it is imperative to use effective guiding techniques to eliminate the need for unnecessary scanning movements. Directing attention should be done in a way that minimizes visual clutter, as additional clutter increases search time and error, which could be catastrophic in a shipboard scenario (Lu et al., 2014). Thus, explicit and subtle cueing optimize the performance of the SWO in marine navigation.

## 5.2 EXPLICIT CUEING

Now that we have distinguished between explicit and subtle cueing, we can examine some explicit and subtle techniques to direct the operator's attention to important information, such as approaching points of contact.

### 5.2.1 Line guiding

Line guidance is the most intuitive route for explicit cues. First, Patrick Renner et. al found that directing the next action using a virtual line drawn from the center of the AR FOV to the target object, or in situ-line guiding, is the most effective method for attention guidance. Since this is a form of explicit cueing, it has the potential to cause visual clutter and distraction if the next AR target object in the FOV is not the primary task at hand.

### 5.2.2 Peripheral imagery

Second, the next fastest method to direct the user to an object or task is to have a peripheral image of the next object shown in the corner of the screen, but the virtual line method is likely the fastest, as it provides directional information (Patrick Renner & Pfeiffer, 2017). Both in situ guiding via chart lines as well as peripheral cues via a top-down mini-map corner display that can be toggled to for the navigation team's easy use.

### 5.2.3 Attention funneling

However, line-guiding is not the only explicit method of cueing. Another attention guiding technique is funneling. There are three main types of funneling that we will compare and contrast here: omnidirectional attention funneling (OAF), spherical wave-based guidance (SWAVE), and arrow-based guidance. First, instead of just one line curving in the correct direction, OAF creates a tunnel of rectangular frames to direct the operator. The shape of this funnel consists of three elements: 1) a boresight indicating the centered plane's FOV; 2) a series of frames that curve in the direction of the target; and last but not least, 3) a final frame consisting of red crosshairs marking the center of the target object. When the operator looks at the target object head-on, the funnel fades into one pane, so as to not add visual clutter (Biocca et al., 2006). This method can be used for objects not directly in the FOV, or objects occluded, which increases speed and accuracy while decreasing workload when compared to simply highlighting the target object (Biocca et al., 2006). However, this method of directing attention is much more explicit than a single virtual line drawing attention to the target. Although OAF minimizes workload, it monopolizes the operator's attention from focusing on any secondary tasks, which could be detrimental when driving a naval vessel through accident-prone waters. It also may be a case of diminishing returns, since OAF has yet to be compared with the direct line method. Although OAF has not yet been directly compared to a situ-line guiding technique in a maritime environment or otherwise, it has been compared to a variety of other techniques. Second, the SWAVE technique was compared to OAF. The SWAVE method guides the operator with depth information by means of a series of spheres. Spherical ring circumference is ordered in a directly proportional relationship with distance from the target. A layering of virtual spheres of progressively decreasing size circumscribes the real target object concentrically. Testing this original prototype against an optimized version that involved eye-tracking technology proved that eye-tracking improves depth perception with a reduction of head movement, so our naval vessels would do well to incorporate it to assist the SWOs on the bridge. While SWAVE is faster than OAF, SWAVE is designed for a smaller FOV than the typical shipboard scenario presents. Third, arrow-based guidance has been compared against SWAVE and OAF alike. While the arrow SWAVE method is a bit slower than the circle version, there is less visual obstruction across the maritime panorama to guide the attention, rating it higher amongst operators than OAF (Renner & Pfeiffer, 2017). Of the three methods described here, arrow-based guidance is the least obtrusive, with an arrow to represent the SWOs ship orientation along with an arrow to represent heading information. Circles also indicate other ships that can be drilled down on for contact information.

## 5.3 SUBTLE CUEING

However, explicit techniques are not the only ones at our disposal to guide the eye of the SWO. Subtle visual factors, such as color, luminosity, orientation, and motion, must be considered in order to attract the naval officer's gaze to the scenery surrounding him or her via virtual cues.

### 5.3.1 Saliency

First, salient regions must be preserved for the human eye to pick up on them through the change in luminosity over time as well as color opposition (Kalkofen et al., 2011b).

### 5.3.2 Size

Second, size configuration minimizes obtrusive labels in the SWO's FOV, but the presence of subtle motion in the form of blinking or circling can direct the operator's attention gently (Kruijff E., Orlosky J., Kishishita N. & et.al., 2018).

### 5.3.3 Transparency

Third, transparent rays can also be utilized as a cognitive anchor to direct naval officer's depth perception of occluded objects of interest, as some other researchers have demonstrated. These virtual cues could be programmed to change from green to red and bend with radial distortion to further alert sailors to potential hazards on the horizon. However, the efficacy of such an approach remains to be seen (Kalkofen et al., 2011b). Rays could potentially be projected over shallow water shoals and correspond with chart lines over the course. Saliency, size, and transparency could dramatically reduce the frequency of accidents underway.

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# 6. TECHNICAL IMPLEMENTATION

Having covered the foundations of depth and attention guidance in marine AR, we will now explore how technical implementation expedites mental processing for the naval officer operating in the maritime environment. Several principles must be borne in mind. First, the information presented must be classified as either registered, or unregistered. Virtual objects overlaid over real-world objects associated with them means that the virtual objects are registered, whereas free-floating virtual objects are unregistered. Second, how light stimulates the human retina must be considered. Third, the way in which the informational content is delivered – via window, wearable, glasses, etc. – comprises a key component in UI design. We will discuss these elements throughout the rest of this section.

## 6.1 VISUAL REGISTRATION

Let us take a look at the positives and negatives of registering information in the visual display. First, registered information garners a quicker cognitive reaction than unregistered information. As Haeuslschmid et al. have demonstrated, “A registered presentation makes use of the gestalt laws of connectedness, proximity and common fate… expected to reduce the driver’s cognitive and visual workload and reaction time” (Haeuslschmid, Shou, O’Donovan, Burnett, & Butz, 2016). This elementary principle of visual salience applies directly to the SWO, because markings virtually projected over neighboring vessels, buoys, and other obstructions provide an immense boon to shipboard navigation. Second, the visual clutter of registered information can slow the mental processing of the sailor to the point of defeating the purpose of having the navigational aid in the first place. Third, side-by-side layout tags pose a greater advantage instead of direct transposition over target objects (Khuong et al., 2014). Machine learning algorithms can filter information sources to declutter anything irrelevant based on eye-tracking the operator (White, Feiner, & Kopylec, 2006). Thus, in a highly demanding environment like marine navigation, crucial information should occupy the center of vision, whereas superfluous information should be relegated to the periphery (Haeuslschmid et al., 2016). Therefore, presenting the contact information of neighboring vessels when the officer presses the trigger button to unlock the window display (projected adjacently to the ship in question) registers information without clutter.

## 6.2 LIGHT STIMULATION

Without the photonic response, no AR HMD will function correctly.

### 6.2.1 Light

First, the way in which the human retina works in response to light stimuli influences the maritime display, such that graphical factors like resolution, color, and contrast should be optimized for perceptual acuity of fine detail (M. A. Livingston, Barrow, & Sibley, 2009).

### 6.2.2 Legibility

Second, how the eye perceives light influences how best to make information legible. Dark borders circumscribing targeted regions increases saliency (Kalkofen et al., 2011b), and fully-saturated green text is more legible than fully-saturated red text, whereas text displayed on a billboard background (as opposed to concrete, or brick) is easiest to read (Gabbard, Swan, & Mix, 2006).

### 6.2.3 Luminance

Third, higher contrast results in faster reaction times (M. A. Livingston, Barrow, et al., 2009). All of these factors – light, legibility, and luminance - prove integral to designing the safest and most secure shiphandling experience for the sailors. Filling arrows and text boxes in with grey and white tones balances the colors against the physical environment to optimal effect as they are the most visible on the spectrum.

## 6.3 DELIVERY OF INFORMATION

Various factors must be weighed in the virtual display.

### 6.3.1 Device

First, AR windows and headsets have both been bandied about as possible avenues to explore, and each option comes with its own advantages and disadvantages. Headsets can be obtrusive, as can window displays, but at least a headset can be individually tailored to the specific needs of the officer wearing it.

### 6.3.2 Brightness

Second, no matter what course is eventually settled upon, it is important to take into account the AR operator's vulnerability to visual impairments, especially given the exceptionally bright refraction of light from the surface of the ocean. Glare makes rings appear in the image. Furthermore, this luminosity varies wildly throughout the day in a shipboard situation, so the level of computing power must be able to accommodate a resolution of at least 720p for text legibility and clarity; "indeed the mobile system must provide information under luminosity variations from a shining sea to a dark night" (Morgère  et al., 2014, p. 7).

### 6.3.3 Darkness

Third, additional image processing of the FOV is required for fog and night conditions. Therefore, AR needs to be able to function properly in all complex and unfavorable sea conditions, if it is to act as a potent component in the navigational arsenal for sailors standing watch aboard the deck (Morgère, 2015). Thus, how the AR display is transmitted, the level of brightness, and the level of darkness must all be addressed for the best image to be produced.

# 7. CONCLUSION

What we have discussed in this paper is just the beginning of the applications of AR HMD to the military maritime domain. As we have seen, the primary way to achieve attentional saliency in the maritime navigational display is via occlusion and depth perception. Techniques for displaying occlusion comes with their own unique set of challenges.

## 7.1 LIGHT AND SHADOW

Changing light sources, multiple targets in motion, and incorrect calibration compose the most common culprits. However, these obstacles are not insurmountable. Color modulation, opacity, and transparency all possess potential to create an intuitive interactive display for the sailor at sea. Furthermore, an AR HMD worth its sea salt for the purposes of marine navigation must direct the attention of the SWOs explicitly and subtly as the situation demands.

## 7.2 SEEN AND UNSEEN

Explicit techniques like in-situ line guidance, arrow-based guidance, and attention funneling have their place in the pantheon of panoramic navigation. Information must be registered, and text must be luminous, with the information specifically tailored to the needs of the officer wearing the headset and the avoidance of cognitive overload kept at the forefront. The stimuli commonly seen by the officer in question should dictate the mode of presentation for that individual operator. The AR HUD must handle light, shadow, transparency, and opacity to convey depth and occlusion in a legible way. Furthermore, it should abide by the latest principles of visual saliency by means of arrow-guided attention funneling.

## 7.3 SCENARIOS

Finally, simulated testing of the experimental and control groups indicates that such a headset might be applied to a variety of maritime scenarios, including fuel replenishment, man-overboard, and high-traffic channel transit. By helping them to see the unseen, augmented reality leads the eyes of our sailors to safe harbor.

*The authors of this paper are developing a prototype system that employs many of the best practices of virtual information display as discussed in this paper. A close working relationship with the operational community including user-centered design and frequent at-sea testing aims to further optimize its effectiveness. This effort is called Augmented Ship Transits for Improved Decision-making (ASTRID).*

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Surface Warfare Officers (SWOs) receive a constant influx of information from multiple sources to make split-second decisions when navigating a vessel from the bridge. An augmented reality (AR) head-mounted display (HMD) allows for sustained situational awareness (SA) of the task at hand by intuitively integrating necessary information as an image transposed onto the outside environment. By reducing cognitive load and increasing SA, AR technology proves to be a necessity in the ever more complicated domain of Surface Warfare Operations, as we shall see throughout the course of this paper.

**15. SUBJECT TERMS**

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