Emergent Display Technologies: Developing Use-Case Prototypes for Military Command Teams in Virtual Environments

Dr. James Karle, Tania Randall, Glenn Franck, and Don Coady

Defence Research and Development Canada – Atlantic Research Centre
Dartmouth, Nova Scotia, Canada
{james.karle, tania.randall, glenn.franck, don.coady}
@drdc-rddc.gc.ca

Abstract. The complex operational environments that military command teams are faced with demand the filtration and consumption of significant amounts of information, the volume of which is predicted to only increase in coming years. A number of emergent display technologies (EDT), including augmented reality (AR) and virtual reality (VR) systems, provide novel methods of organizing and presenting this information. These new technologies can be difficult to assess for their potential value to command teams, as they are often at varying levels of technological readiness, the application environments they are intended for are inaccessible, and/or the devices are impracticable to modify at the physical or software levels. Simulations of EDTs in virtual environments (VEs) provide a moderate to high-fidelity, low-cost, and easily implemented solution to these limitations. As such, we developed a process for the rapid generation and assessment of EDT related use-case prototypes in a VE. In addition, using this process, we identified novel solutions for current and predicted near-future challenges encountered by Royal Canadian Navy command teams as associated with the management and exploitation of information. The capabilities and limitations of using VEs in this manner are described when leveraging them as tools for rapid-prototyping.

Keywords: command, control, C2, augmented reality, virtual reality, emergent, displays, information, management, exploitation

1 Introduction

Naval command teams are today faced with complex operational environments. In the case of the Royal Canadian Navy (RCN), such operations involve some mixture of constabulary, diplomatic, and military duties [1]. During military duties alone, command teams must engage in offensive and defensive combat operations against modern forces and asymmetric threats in a variety of categories that include Above Water Warfare, Under Water Warfare, and Information Warfare [1] (IW; involving the management and exploitation of information in order to gain an advantage over an adversary). These categories of warfare are only made more complex as they involve command teams interacting at the unit-level, task-group level, and at the level of high command (e.g. Chief of Maritime Staff, Formation Commanders).

With so many types of operations, categories of warfare, and levels of command coming into play, efficient information management and exploitation are perennial problems for the RCN and other modern navies. Indeed, both afloat and ashore, data relevant to any operation and its related activities are gathered from a wide variety of sources. These include complex and multifaceted sources such as intelligence networks (human- and signals-based) and a host of sensors (e.g. RADAR, SONAR), down to the simplest of detection systems, the humble Mark 1 eye-ball (i.e. bridge crews on watch). The challenge faced by command teams is how to parse and exploit collected data to the maximal extent possible. Importantly, methods of exploiting information (to obtain information supremacy/dominance) are becoming increasingly varied, multifaceted, available, and practicable to implement, driven by advances in computers, communications, sensors, networks, and novel methods of exploiting the electromagnetic spectrum [2]. One such method of improving informational management and exploitation involves the use of emergent display technologies (EDTs). Though relatively nascent, they stand to be a disruptive force in the domains and environments (i.e. land, sea, air) relevant to the RCN and other navies, including the domain of IW.

The definition of what constitutes a disruptive technology varies by field but in our case a disruptive technology is best defined as any new or existing technology used in an innovative fashion that significantly alters established paradigms [3] (with our efforts concentrated in understanding on how RCN command teams can manage and exploit information in novel ways). EDTs encompass a variety of new technologies that alter the traditional approach to displaying and interacting with digital information, going beyond monitors (e.g. wall or stand-mounted liquid-crystal displays) and mouse/keyboard systems commonly found in military, civilian, and industrial settings. Virtual and augmented reality systems provide examples of EDTs that have the potential to be disruptive to how the RCN go about a wide-variety of tasks and are the focus of this paper.

Virtual reality (VR) and augment reality (AR) systems are computer technologies that commonly use head-mounted displays (HMDs) and other technologies to generate moderate to high-fidelity images, sounds, and other sensations that simulate or enhance a user's physical presence in a virtual or semi-virtual environment [4][5]. The two technologies differ in that VR subsumes a number of the user's senses entirely in the virtual environment (VE), largely cutting the user off from reality, while AR only adds/overlays virtual information to a real world environment [6]. For example, using a VR system, an ordinary seaman can be immersed in a virtual version of the frigate they will be assigned to, allowing them to be acclimated to the ship's layout and systems by moving themselves around the virtual ship and interacting with virtual objects. Once aboard that ship, in the real world, that same crew member could make use of an AR system that would guide him or her to various areas of the ship by providing virtual waypoints and directional arrows. This virtual information would be projected on a pair of what would appear to be heavy safety glasses or a visor.

Neither VR nor AR technologies are new. However, in the past, VR and AR systems were largely niche technologies, too nascent to be of value beyond limited specialist populations (due to their weight, lack of portability, and often extreme cost). However, in recent years, technologies associated with VR and AR have seen significant advancements, especially in terms of light, affordable, and moderate to high-fidelity HMDs, making them more capable and practicable for broad application. In their current instantiations, systems associated with VR and AR provide new methods through which to interact with information. What remains unclear is whether or not they offer the RCN practical and compelling alternatives to traditional methods of displaying, manipulating, and exploiting information.

The research upon which this paper is based was an early exploration, aiming to provide initial answers to several questions:

1. Do AR and/or VR systems offer the RCN (command teams in particular) practical and compelling alternatives to traditional methods of displaying, manipulating, and exploiting information?
2. Can a VR system act as a reasonable platform for demonstrating the capability of a new technology to disrupt RCN operations?
3. Can VR technologies well-serve research and development (R&D) personnel as methods for rapid prototyping and high-level concept development?

In short, we sought to understand how RCN/Navy/Military audiences (focusing on command teams) could make use of AR and/or VR technologies to address their current problems, to prepare for predicted problems (near and mid future), and/or to enhance performance of personnel in a variety of settings. We were further interested in the capabilities of VR-based systems to act as platforms to prototype new technologies for use in navy contexts.

2 Methodology

2.1 Pilot Project

In order to begin to answer the above questions, we carried out some initial pilot work with subject-matter experts (SMEs), comprised of junior and senior officers from the RCN with experience both afloat and ashore. After we spent some time becoming acquainted with the technology spaces for both VR and AR, it was apparent that the Oculus Rift DK2 [7] was the most mature of available VR technologies and was selected for further assessment. With respect to AR technologies, the Microsoft HoloLens [8] system was selected. During these early stages of research, with respect to portable, head-mounted VR and AR systems like the Oculus Rift and HoloLens, there were no software applications that had been developed for use in military settings that were readily available. As such, we used demonstrations of civilian applications of VR and AR to establish the capabilities of each technology for our SMEs. We followed this with a presentation that expanded on how these civilian applications might be abstracted and developed to meet RCN needs, using simple 2D story-boards to demonstrate various applications for the technologies. SMEs were then asked to elaborate on our military use-case concepts and to put forward any of their own ideas. We carried out this process several times with small groups (3-5 individuals) of SMEs. Finally, it should be noted that we focused the majority of our attention on how command teams and bridge crews could make use of the technologies while afloat, as their use by shore-based teams falls outside of the scope of our current project. More importantly, in the two hours we had with each group to demonstrate the technologies and receive feedback from our SMEs, it was impossible to also comprehensively explore and assess shore-based use-cases for their capability to serve RCN needs.

An initial finding from the pilot work that immediately stood out and would go on to direct much of our efforts with respect to the research this report is based upon was that nearly all SMEs, while intrigued by the VR technologies, unanimously agreed AR would be more useful in terms of potentially improving their ability to complete tasks in various operational settings. Remembering that we were questioning these SMEs about the use of these technologies while afloat, they had two primary concerns with VR HMDs. Firstly, in the case of VR systems, the nature of an HMD is that it entirely occludes vision. Most destroyer and frigate class vessels are naturally unstable platforms in moderate to heavy seas and, as such, a crew member must be able to see where the nearest handhold is at all times in order to avoid injury. On ship, the saying is that crew members must always have one hand for themselves and one for the ship. Furthermore, during operations, command teams need to be able to see one another to quickly convey information. Indeed, bridge crews must always be able to see clearly out of the bridge windows to spot threats to the ship and other hazards. There are work arounds for this concern. Pass-through technologies use a separate external, forward mounted camera on the HMD to allow the user to see some of what is in their forward visual field while immersed in VR. Unfortunately, the field of view that these cameras provide can be limited. Also, the experience of perceiving an entirely virtual world and then switching to the real world can be jarring and uncomfortable for the user. When immersed in a purely VE, external video of the real world feels unnatural and unwieldly to some users. The second major concern that the SMEs had with head-mounted VR was the fact that many reported experiencing a series of deleterious side-effects including eye-strain, nausea, headache, sweating, disorientation, a sense of cognitive clouding, vertigo, and ataxia-like symptoms (i.e. difficulties with coordination of voluntary movements). These effects closely match the description of symptoms for cybersickness [9][10], which has been linked to motion and simulator sickness, though it has been argued that it is its own unique type of sickness [11]. Motion sickness is already a concern aboard ship and while research still needs to be completed, it is possible that cybersickness caused by a VR system would interact with motion sickness brought about by the movement of the ship through 6 degrees of freedom. While we feel that VR systems likely have manifold and worthwhile applications to facilitate and enhance performance of RCN personnel, it is likely they will be of most value ashore, especially with respect to their use as platforms for training, as well as the enhancement of planning processes and virtual interactions between command teams in remote locations. Armed with this knowledge, we focused our efforts on understanding how AR systems could be of value to RCN command and bridge teams.

2.2 Current Project

When considering how AR systems could be applied to the RCN, we were immediately faced with two significant problems. First, unique to our setting, there were no readily available applications of AR directly targeted at the domains and environments within which the RCN operate. As such, our lab would have to develop scratch built prototypes/use-cases of our own that had the capacity to address current or predicted near future problems of the RCN. In order to generate meaningful use-cases for the RCN, we developed a user-centric iterative process comprised of five stages (see Figure 1), described in more detail below. The second difficulty with which we were faced involved the AR system. While we selected the most mature of the portable HMD-based AR systems currently available to researchers and developers, as a technology it is still quite new and somewhat immature and comes with a series of attendant problems. Building prototypes of wearable AR systems or developing applications for AR systems can be difficult and costly (both in terms of temporal and financial resources), as it requires the use of a number of devices, systems, and/or software that are at varying levels of technological readiness [12]. Indeed, due to their immaturity, AR devices can be impracticable to modify at the physical or software levels, which serves both to increase the cost and decrease the speed of research. Finally, the application environments for which our AR HMD use-cases are intended (e.g. bridge of a frigate-class warship or operations compartment of a submarine) can be difficult or impossible to access on a consistent basis. In order to receive the most precise and meaningful feedback from SMEs on the value of a use-case to address current and predicted near future problems of the RCN, it is important that AR technologies are demonstrated in environments that exactly match or, at least, closely approximate the operational environments faced by the SMEs.

In order to circumvent the above difficulties, we made use of a VE (with a virtual reality system [7] acting as the platform of presentation and interaction) to generate moderate to high-fidelity replications of the operational environments (e.g. bridge of a Halifax-class Frigate) faced by RCN command teams, in which we simulated each of our proposed AR use-cases. As will be described in section 3.1, this approach gave us full control over when and how use-cases and other environmental variables were presented to the SMEs (a feature that will become increasingly important as we move into more rigorous empirical testing in the future). For example, we were quickly able to demonstrate the likely effectiveness, for contact localization purposes, of AR-based virtual tags that were anchored to real world objects by changing the visual conditions in our VE, from a clear day to heavy fog to night operations. As conditions worsened, virtual tags played an increasing role in rapid and successful contact localization. This level of control is something that digital systems excel at and because VR systems are completely self-contained, we gain a significant amount of control over the testing environment at very little cost while still approximating the real world setting of interest. This is at odds with assessing AR in applied settings, which is expensive in terms of time and money, and laboratory settings, which can lack ecological validity by varying significantly from the real world. Something similar to this type of virtual prototyping has shown promise as a means to support human factors/ergonomics evaluation when designing complex systems targeted at end-users, though the focus of the research differed from ours in that it sought to determine whether AR or VR acted as a better platform for this process [13]. The VR system was demonstrated to be more suitable than the AR system in terms of several types of assessment, such as visibility, reach, and the use of tools [13]. This study provided us with some support that our approach of using a VE to perform high-level concept development and initial design work on AR use-cases for the RCN would be fruitful.

Other labs have sought to avoid some of the difficulties described above when working with AR systems by making use of VR technologies as platforms to simulate elements of AR. For example, Wafaa and colleagues [4] developed core, input, and interaction architectures to support incremental prototyping of augmented reality systems, based on a virtual reality system. They found that VR provided a low-cost, moderate-fidelity system for testing user interactions and spatial constraints in 3D environments. Alce and colleagues [12] sought to develop a wearable AR prototyping methodology, aimed at developing and assessing interaction in AR using a VE as the platform. Their findings were somewhat mixed. Participants were able to provide useful qualitative feedback, such as preferences for various interaction methods. Unfortunately, qualitative data was less reliable as subjects often experienced problems with the equipment (e.g. error prone tracking leading to poor performance) or became distracted from the experimental task due to their desire to just explore and enjoy the novel VR-based experience [12]. Ragan and colleagues [5] made use of a virtual environment as a platform for experimentation to understand AR and by doing so, were able to demonstrate that different types of AR-based registration errors[1] seem to disproportionately affect task performance. They suggested that VR can act effectively as a platform for experimentation, with the caveat that much more work was still needed [5].

Our approached varied from the previous work described above in a number of ways. Firstly, we were interested in the capacity of VEs to act as platforms for high-level concept development and initial design work for AR. Specifically, we used VEs to rapidly generate, assess, and then iterate upon AR-related use-cases to address current and near future problems faced by navy (RCN) command teams. Indeed, a key purpose of the current work was to understand if AR systems offer the RCN compelling alternatives to traditional methods of displaying, manipulating, and exploiting information. As well, with an emphasis on the RCN command teams, our research was more focused than previous work in terms of target audience and we were most interested in the potential applications of these new systems. Furthermore, we sought to determine whether or not VR (and associated VEs) could act as an effective platform for demonstrating the capabilities of disruptive technologies to a military audience. To foreshadow what will be discussed below, this approach to prototyping use-cases for military audiences was highly effective, in that it generated moderate to high-fidelity examples, at low temporal and financial, cost of how AR may be of use to solve problems faced by command teams and other personnel in the RCN. Importantly, use-cases presented in a VE elicited significant feedback from SMEs, well beyond what low

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[1] AR relies on the accurate registration of computer generated visual effects with the real world, which requires significant geometric precision between the displays, user's eyes, and objects in the real world. Sensor inaccuracies and the unavoidable delay (lag/latency) between sensor sampling and the process of updating the visual information presented by the HMD can lead to registration errors [20], which is the misalignment of virtual and real world items from the perspective of the user.

fidelity models of prototyping return (e.g. virtual mock-ups, brainstorming), while avoiding the often extreme expense of high-fidelity, purpose-built simulators. Based upon this feedback, as these AR technologies mature, they will likely act as disruptive technologies for the RCN and other navies, with respect to how they engage in and complete a variety of tasks.

2.3 Iterative Development Cycle

As mentioned above, there were no readily available applications of AR directly targeted at the domains and environments within which the RCN operate. In order to develop use-cases relevant to a military audience, we created an iterative development cycle, comprised of multiple stages (see Figure 1). In fact, the pilot work we completed can be thought of as early iterations. Each iteration was designed to bring us closer to developing an AR-oriented use-case that would be meaningful to RCN command teams, especially with respect to the efficient management and exploitation of information. If the SMEs could see some value in the use-case, it provided a critical first step in demonstrating that AR-based systems may provide compelling alternatives to traditional methods of displaying, manipulating, and exploiting information.

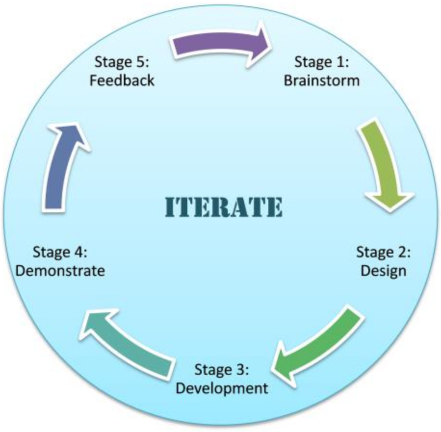

Fig. 1. Iterative Development Cycle

In Stage 1, we examined the material gathered during the pilot phase of this research (or from feedback obtained in Stage 5 from a previous iteration). Through a series of creativity exercises, we generated a series of use-cases that would address problems faced by RCN command teams and bridge crews or improved upon use-cases that had been previously demonstrated. These creativity exercises included brainstorming, bodystorming [14], and simple virtual mock-ups [15]. These mock-ups were low to moderate fidelity and non-interactive examples of AR use-cases created in the VR system (i.e. Oculus Rift). Once we had a series of what we felt were meaningful use-cases, we moved to Stage 2, where we designed the AR use-case for presentation in an interactive VE or laid out changes to existing use-cases that had received meaningful feedback from SMEs during previous iterative cycles. In Stage 3, we built each AR use-case in our VE (which made use of the Oculus Rift VR system as its platform) or implemented the changes defined in Stage 2 to existing use-cases. During Stage 4, we presented the now functional or updated use-cases to RCN SMEs. As in the pilot study, SMEs included junior and senior level officers from the RCN, with experience on Canadian naval vessels. We expanded the population to include non-commissioned members (e.g. leading seamen, petty officers, chief petty officers) who had experience on the bridge and/or in the operations room. These populations work integrally with command teams and their feedback provided another important view on how AR could disrupt RCN activities. During demonstrations, small groups of 4 to 8 individuals experienced each AR use-case through the VR HMD (i.e. they were immersed in the VE). The demonstration will be described in more detail below. Following the AR use-case demonstrations, we entered Stage 5 of our iterative cycle, the feedback section. SMEs were encouraged to discuss how the application of AR technologies, as seen in the demonstrated use-cases, could improve or degrade their ability to complete tasks and address problems that they currently face or predict that they will face in the near future. Much of the interview portion of this process was undirected but guided questions were also presented to the SMEs. A wide variety of questions were used to promote conversation amongst SME, a small sample of which included:

1. “Would you use <insert use-case>?” (e.g. Would you use the virtual displays?”)
2. “Do you feel the <insert use-case> is superior/the same/inferior to traditional methods of managing and exploiting information?”
3. “What areas of the ship would AR be most/least valuable and why?”
4. “How would the current instantiations of AR HMD technologies have to improve before you would regularly use them as opposed to traditional methods of managing and exploiting information?”

We asked SMEs to speak as freely and broadly as they liked regarding each use-case that they had experienced. These informal data will be used to constrain and direct future empirical work on the topic, which will seek to gather qualitative and quantitative data on the subject. For the moment, the data collected was then submitted back to Stage 1, beginning the cycle anew. With each iteration, we sought to further refine each use-case to more closely approximate real world situations faced by SMEs, thereby providing novel solutions to problems with which they are faced. As well, this iterative approach allowed us to gather increasingly valid data to address the research questions we laid out in the introduction of this paper. Finally, it should be noted that we were entertaining the "realm of the possible" during this research, attempting to identify meaningful applications for AR in a navy/RCN setting rather than being concerned with the various kinds of engineering that would be required to implement these ideas. We did, however, take into account limitations when reasonable. For example, wireless technologies are closely monitored and their use restricted aboard ships of many navies. Since many VR and AR systems take advantage of wireless methods of communication, this factored into how we presented the use-cases to our populations of interest.

2.4 Augmented Reality in Virtual Environments: Use-case Demonstrations

We generated, developed, and demonstrated a wide variety of AR use-cases for assessment by SMEs, too many to describe here. We will discuss a handful of use-cases that were presented in our VE. As with all prototyping procedures, some use-cases were abandoned due to disinterest or impracticability. Importantly, however, we were met with a strong interest from SMEs in the capabilities of AR technologies to manage and exploit information after our initial demonstrations.

Demonstrations (use-cases) of AR were presented in a VE via the use of a HMD VR system (Oculus Rift). The VE was a nearly one-to-one simulation of the bridge on a Halifax-class frigate, as seen in Figure 2. Users interacted with the system in several ways. To select an item to interact with, users moved their head to center their field of view on the object of interest. To aid this process, a red crosshairs could be activated. To input a command, after fixating on an item, users activated a button on a Wii Nunchuk controller [16]. For example, by centering their view on a virtual object, a user could then input a command with the press of a button in order to have a virtual screen provide more or less information. To increase interactivity with the system, a virtual menu was implemented (see right image in Fig. 2.) that allowed access to most of the demonstration features. This provided a very intuitive form of interfacing with the demonstrations, though in the future we hope to map input methods to those used in the real world implementations of AR (see below). Users could either physically walk around the simulated environment or use the joystick on the controller to drive their virtual avatar. Finally, it should be noted that we had full control over the system. As mentioned in Section 2.2, this control allowed us to demonstrate use-cases and their various features at will, guiding the user through the experience, as needed. This control proved a distinct advantage of simulating AR in a VE as it is more difficult to take remote control of an AR system.

Fig. 2. Overview of VR Bridge Environment & AR Menu System

Five of the use-cases that we developed are described below (refer to Fig. 2. and Fig. 3.), in order to provide readers with a sense of what SMEs positively responded to in terms of the use of AR in operational settings:

1. Virtual Polaris (VP): this is a system by which a user can quickly gain information at a glance regarding what direction he or she is facing and the relative bearing of contacts from their vessel (i.e. own-ship; see top of Fig. 3). Using expandable virtual panels, a user can call up increasingly detailed information about a contact, including the exact relative bearing, distance from own-ship, speed, course, and so on. Operational markers, waypoints, and other designators can also be added or removed from the VP. Furthermore, various filters and layers can be implemented by the user in order to control the flow of information. For example, while contacts are generally minimal in the North Atlantic, near the Strait of Hor-

muz, surface traffic increases significantly. At this point, a user may desire only to see hostile or friendly contacts or both, removing neutral shipping from the equation.

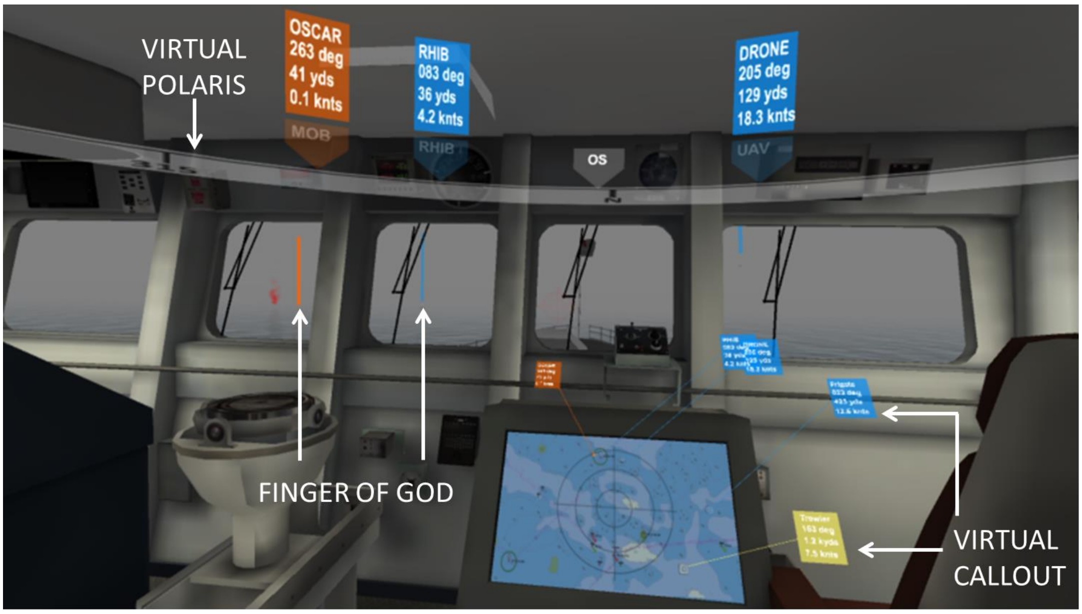

Fig. 3. Simulated AR Content For Visual and Screen Contacts

2. Finger of God: so named after the emission trails left by missiles launched from submarines that bring immediate (and often unwelcome) attention to their location, these are virtual pillars/tags of coloured light that attach to critical items outside of the user's vessel (see Figure 3; outside of bridge windows). They provide quick and efficient means of locating objects above and below the water, as well as on the surface (based on contact data available in the ship's combat management system), by cuing the user's attention to the object. For example, in a Man Overboard emergency, the crewmember in the water (Oscar) is often hard to visually perceive, especially in degraded weather conditions. Oscar can be quickly picked out by activating a Finger of God to mark his or her location in real-time (provided the crewmember is equipped with some kind of locator beacon).
3. Virtual Call-Outs: screen real-estate is often limited on the bridge, restricted to a handful of multi-function and RADAR displays. Virtual call-outs are similar to the panels describe above in the VP use-case (see Fig. 3; foreground, attached to monitor display). They differ in that they are anchored to information found on a real world display of interest. They provide extra information, at a glance, without the need to manually interface with the display. Virtual call-outs also provide further information without crowding what are often already information laden displays.
4. Transparent Displays: this is an example of AR that would not use a HMD but rather another AR technology (see right most image of Fig. 4.). Transparent displays act exactly as regular displays without occluding the information behind them. Most interesting to the RCN is that they allow two systems that must not interact directly (i.e. systems that must have a security or "air" gap) due to multi-classification conflicts to overlay information. For example, a RADAR or navigation display can have a command and control system overlaid to make the visual compiling of information more rapid and accurate. Currently, when systems cannot interact, users must estimate if a contact on one system is the same as on another system. Further, this information is available to all on the bridge, whereas, HMD AR systems cannot always share information (though, in the future, should wireless restrictions be eased aboard ship, networked HMD AR systems may be capable of achieving the above).
5. Virtual Displays: as mentioned under Virtual Call-Outs, screen real-estate is limited on the bridge. Virtual displays (Fig. 4., see left most image, top) mimic real world displays, presenting users with information from various systems on the bridge (including RADAR, ship status systems, navigation systems, etc.) but have the advantage of being mountable wherever the user desires. Further, these virtual displays can either be anchored to the user (thereby following them as the move around the bridge) or anchored to a point in space. As only the user can see these virtual displays, they not only provide immediate access to display information that, at times, can be physically on the other side of the bridge but also do not interfere with the ability of others to see out of the bridge windows. Moreover, physical displays must be set to a standard format to ensure ease of use by all bridge watch keepers. Virtual displays and their re-

lated systems can be adjusted to suit the user's needs (i.e. personalized), which may have the effect of improving accuracy and reaction time during a variety of tasks when making use of the information that the systems offer (though research must be completed to assess this hypothesis in this context).

Fig. 4. Virtual Displays & Transparent (Overlaid) Display Content

3 Results and Discussion

3.1 Benefits of Simulating AR in VE for Prototyping Purposes

Simulating AR in a VE provides a series of distinct benefits as opposed to using more simple (e.g. brainstorming, bodystorming, mock-ups) or complex (e.g. high-fidelity 6 degree of freedom simulators) methods of prototyping when assessing EDTs for consumption by a military (navy/RCN) audience. The demonstrations/use-cases were highly immersive due the moderate to high-fidelity visual and auditory information that the VR system presented and because of the level of interactivity. For example, users were often seen to duck under overhanging objects (e.g. ceiling mounted but low hanging lamps or ducting) found in the virtual environment, despite knowing that these objects did not actually exist. Feedback from SMEs was also significantly more varied, targeted, and useful when using the AR in VE demonstrations. By being so immersed, SMEs were quickly able to point out strengths and weaknesses associated with the use of HMD AR systems in operational settings, something they struggled with in early iterations of the use-cases that were less immersive and non-interactive (e.g. simple virtual mock-ups). This result was analogous to what Aromaa and Väänänen [13] found in their work, where the VE elicited significantly more feedback than the AR system when assessing ergonomics for the purpose of designing complex systems targeted at end-users. They suggest this finding was possibly due to the lower technological readiness and poor usability of the AR system; it required an increased reliance on imagination and lacked natural interaction, which may have caused more frustration in the user [13]. This finding could also be due to the deeply immersive nature of VR and the ability of the current technology to fairly closely resemble real world environments, thus more readily eliciting natural and meaningful feedback.

Another benefit of note is that the use of a VE environment allows R&D teams the ability to demonstrate the prototypes in a close replica of the target context of interest (i.e. where the SMEs will use the system of interest). In our case, we simulated a bridge aboard a combat vessel (i.e. Halifax-class frigate) but we could have simulated any environment that RCN crewmembers might be faced with. This provides distinct advantages in terms of immersion and eliciting useful feedback (as mentioned above) but has a number of benefits for researchers. The use of VEs to simulate AR allows access to contexts that are normally difficult to gain short-term access to, much less the kind of repeated and long-term access needed to iterate on prototypes. Additionally, it can be quite dangerous to perform research in some military and industrial environments (e.g. a ship in extreme sea state). By using a VE as a platform for prototyping, risk to both researchers and SMEs is greatly reduced, so that all efforts can be focused on gathering detailed and meaningful data. Indeed, some the use-cases described in this report would be difficult and expensive to mock up in physical world contexts (e.g. overlaying transparent and traditional displays to combine information from systems that must be security gapped), something that was quickly and inexpensively accomplished in a VE. Indeed, the use of VE as platforms to do the kinds of prototyping described in this paper provides a cost effective means to go about research and development as changes to use-cases between iterations can be relatively quickly implemented by any individual fluent in computer programming. Finally, where research teams are concerned, VEs are highly controllable, allowing research teams nearly millisecond control over the presentation of stimuli, something that is often not available when using simple mock-ups or the real world settings in which this type of work would be completed. When attempting to assess empirical hypotheses, this type of control is often essential.

With respect to our goal of using this platform as a means to demonstrate potentially disruptive technologies to command teams and other navy/military personnel, VEs provide several other benefits to those listed above. The most recent instantiations of VR (and AR) systems are extremely portable, requiring a headset, one or more small cameras, a laptop, and various cords. As a result, rather than forcing SMEs to take time out of their busy days to come to a laboratory, it is often possible to bring the laboratory to them. This also allows research to be completed in situ, a critical component of any applied project. Additionally, VR systems have a very small footprint, allowing demonstrations (and research) to occur in small to moderately-sized spaces. For example, when making use of a seated demonstration, periods of data collection only require enough space for a desk and two chairs (one for the subject/SME and one for the experimenter). A caveat should be noted here that if full range of motion is critical (that is, the freedom to walk as opposed to drive one's virtual avatar around the VE, which can be done from a seated position in the real world) for demonstration and data collection purposes, a much larger space that is free of obstacles is required for the safety of the user as their vision of the real world is entirely occluded.

3.2 Challenges of Simulating AR in VE for Prototyping Purposes

Using a VE to simulate AR proved an excellent platform for high-level concept development and demonstrating use-cases of AR for our target audience but there are limitations to this approach. For one, even though we were interested in the "realm of the possible" in the current work, it is easy to over-promise what AR is capable of achieving at its current state of technological readiness (portable AR-based HMDs are still a relatively immature technology). When using VR as the platform to create a VE, nearly any problem or situation that can be imagined can be simulated and nearly any solution can be proposed, which could lead to a false understanding of the strengths and limitations of AR technologies. A solid grounding in the current or predicted near future capabilities of AR technologies is essential to avoid this pitfall.

Additionally, while both VR and AR technologies share many characteristics, they have essential differences. For example, VR presents fully rendered 3D information to the viewer, while AR technologies overlay digital information on the real world. In terms of object occlusion (where one object appropriately obstructs the view of another), this effect is essentially gained for free in VR, as both the simulated "real world" (e.g. Bridge) and AR use-cases are computer generated. However, when using AR technologies in the real world, a 3D real-time scan of the surrounding environment is necessary in order for a real object to occlude a virtual object and vice versa. With respect to the current generation of AR technologies, these scan distances are often quite limited. In the case of the HoloLens, it is capable of scanning environmental elements in a 70-degree forward facing cone that are no closer than 0.8 meters and no farther than 3.1 meters [17]. AR systems also have significantly limited fields of view (where digital/virtual information can be represented) when compared against VR systems (approximately 40 degrees versus 90 degrees, respectively). Unless accounted for, this can lead to demonstrations in VR which inaccurately portray augmented virtual objects and information at eccentricities from center well beyond what current generation AR systems are capable of presenting. It is also important to remember that AR systems are meant to be used in a variety of settings. In brightly lit environments, virtual information can become unperceivable, as the sun far over-powers the displays/projectors. Since VR systems are entirely self-contained, this is not an issue that would immediately present itself when simulating AR in a VE.

While VR and AR systems have a variety of control systems in common, gestural interaction is not well shared. Both systems are capable of recognizing gestures as methods of input but VR systems are not currently well adapted to this process. More importantly, when using real world AR systems, you can use your hands for both physical tasks and for inputting information into the system. This is not easily achieved when simulating AR in a VE. Indeed, the user's hands are entirely occluded. In our experience, it was often the case that lab technicians had to help our SMEs find real world objects, like the keyboard or Wii Nunchuk [16]. Moreover, while there are applications that will generate virtual one-to-one representations of the user's hands, without the addition of pass-through technology to visualize the real world, they have little value to the simulation experience. Unfortunately, pass-through technology would undermine the AR simulation by decreasing the immersion level of the user and occluding the use-case demonstrations.

Another major impediment to using VR to simulate AR is a variety of physical discomforts that are unique to VR HMDs. The display portion of a VR HMD is situated just a few centimeters in front of the user's eyes. This means that despite the visual simulation presenting information and objects as if they were at varying distance from the user's eyes, in fact, these objects are at a constant distance from the retina. In short, there is a significant disparity between actual and apparent distance of objects from the retina. This forces the user into a constant state of high binocular convergence, generating significant eye-strain and even headaches in some users, with an increasing probability of both occurring the longer the user is integrated with the system. Importantly, AR systems do not cause this kind of discomfort to nearly this extent, allowing for longer and more comfortable durations of use. Of greater concern, however, is the tendency for VR systems to cause unpredictable and sometimes intensely negative symptoms in users (as mentioned previously), such as nausea and vertigo [10][18], which do not appear to occur with current AR systems. In one study [19], 80% of participants demonstrated mild but notable negative effects after immersion in a VE, while 5% had symptoms so severe they could not complete the immersion. It is important to note that these kinds of effects can reduce the quality of data collected during a session with SMEs or even stop data collection entirely, as some users can be so overwhelmed by nausea and disorientation, they cannot continue with assigned tasks.

In the end, after much iteration, prototyping AR in a VE will enter a state of diminishing returns. At some point, the technology of interest will need to be tested in both controlled laboratory and applied settings. While the approach to rapid prototyping that we have described has many benefits, some deficiencies of the technology will not be made obvious until more rigorous testing is completed. For example, there were several problems identified by command teams with respect to the HMD-based AR technology that were not readily made apparent until we demonstrated some early and rough approximations of our use-cases via a true AR system (Microsoft HoloLens) rather than simulating them in a VE. Firstly, an immediately obvious problem once they could handle the technology was that the system was not rugged (i.e. stoutly built), meaning rough treatment of the kind commonly seen in military settings would quickly lead to damage of sensitive components. The HoloLens was designed for commercial use and as such would not long survive the rigors of day-to-day handling aboard a warship. Secondly, while AR systems can be tethered (i.e. plugged in via a cable), they are purpose-built to be maximally effective when in a wireless setting. If tethered, they become a tangling hazard aboard ship and the current tethers, as above, are not rugged. Unfortunately, most modern navies have some (often strict) restrictions on the use of wireless technology aboard ship. Lastly, the current instantiation of the HoloLens is too bulky for long-term use (e.g. when standing long bridge watches). These are issues that can be addressed with time and further development but would not have become obvious without going beyond demonstrations of our various use-cases of AR in a VE.

Any attempt to prototype or develop use-cases for AR, whether for military, commercial, or industrial audiences, that plans to make use of a VE as the platform should keep the above differences and limitations in mind. In order to obtain the most meaningful data, it is recommended that in any instances where the properties of VR systems outstrip those of AR systems (e.g. field of view), researchers should endeavor to program these limitations directly into the simulation.

3.3 RCN Interest in AR Use-Cases

One of the primary goals of this work was to make an initial assessment as to whether or not AR HMD technologies provided RCN personnel with compelling alternatives to how they traditionally go about displaying, manipulating, and exploiting information in pursuit of operational activities. Even in the first iterative cycle, SMEs were excited by the capabilities of these nascent systems. The handful of use-cases we describe above are but a few of the potential applications of these technologies but they represent those that went through several iteration and, as such, in their current form represent novel methods of approaching day-to-day activities that have been closely titrated to the needs of RCN personnel (especially command teams).

The virtual Polaris received a great deal of attention from RCN personnel. Indeed, SMEs often forgot that we were engaged in early prototyping work, asking that the system be immediately installed aboard active naval vessels of the RCN. Their enthusiasm stemmed from several problems they are confronted with on a daily basis that they felt AR HMDs could resolve. For example, unless a crewmember is in a critical control space (e.g. Bridge, Operations Room), they have limited or no situational awareness as to what is occurring outside the vessel. The VP provides a quick and intuitive means of determining what contacts are nearby, their relative bearing in relation to own-ship, how close they are, and their threat level, regardless of where the user is situated. Further to this issue of situational awareness, the Fingers of God allow bridge teams to quickly localize objects external to the bridge. Spotting an aircraft or a person in the water can be a challenging task for bridge watch keepers but a virtual cue that calls their attention to the object of interest eases this process considerably.

However, it should be noted that all of the above statements assume that the AR system can act remotely (i.e. use wireless) or that there are tethered access points distributed throughout the ship. While the former is preferred, the latter would be a reasonable stop-gap measure. Indeed, due to space concerns and security issues (see below), traditional displays cannot be liberally distributed around the ship, whereas it would be a comparatively straightforward engineering process to install many small access points for tethers.

Another advantage of AR HMDs noted by SMEs was the ability of the system to allow key command personnel ready access to critical ship system displays, on command, regardless of their location aboard ship. Indeed, the commanding officer (CO) is often called upon to assess emergent situations and provide orders, though he or she may not be in a critical control space to access key systems to gather additional information to aid in decision-making. According to SMEs, the ability for the CO or other command personnel to bring up essential data on virtual displays accessed through a readily available AR HMD would ease this process considerably. AR HMDs are highly portable, something that traditional displays do not offer. While laptops do provide some portability with respect to traditional displays, in extreme situations (e.g. combat, high-sea states, damage stations), they become unwieldly as they often require two hands to operate, unlike an HMD (interfacing occurs via voice and one-handed gestures). As mentioned above, a crewmember must always have one hand for their task and one for the ship to remain balanced and secure.

Virtual displays allow the user to organize information in a manner that suits their needs (i.e. personalization), something that is difficult to do with traditional displays as this information must be shared by multiple users. More importantly to the RCN, limiting information presented by an AR HMD on a “need to know” basis is a relatively easy proposition. Since virtual displays are only viewable by the headset wearer, it is likely there would be no risk of unauthorized personnel viewing restricted data, without physically appropriating the headset for themselves (and these could be pass-coded, like any terminal). Currently, due to the nature of traditional displays, areas of the ship either must be cordoned off or sanitized when personnel without the appropriate security clearance are aboard. This can impede the flow of information and the ability of crewmembers to complete tasks efficiently. Virtual displays also help to solve the issue of limited real estate aboard the bridge for the placement of monitors. Bridge windows cannot be obstructed for obvious safety reasons. However, using AR HMDs, bridge watch keepers can mount (anchor) virtual displays for any system in any location. In our work, we found that SMEs were most comfortable with either anchoring displays at waist level, such that they followed them around, or anchoring them above the bridge windows. An added benefit of the virtual displays that we demonstrated to our SMEs was that they expand when fixated upon, making it simple to gather much needed data from the display in question (e.g. navigation display), and then revert to a small and unobtrusive size when no longer being examined. This serves to prevent virtual displays cluttering the user’s field of view, a real concern that was identified during early iterations of this use-case.

While drones are little used by the RCN at present, they comprise an area of expanding interest for use in a variety of RCN activities. As our SMEs stated, drones have been used in the past and they will play a role in the future. How to manage the information these devices will provide commands teams is currently an area of interest. Considering the capabilities demonstrated in this paper, AR HMDs may provide an effective means by which to control the flow of information provided by drones in the maritime domain. This predicted near future problem will require further assessment but the potential for AR HMDs to allow pilots, payload operators, and command team personnel to efficiently integrate with drones (e.g. via telepresence) was raised repeatedly by our SMEs and bears mentioning here.

As mentioned, RCN SMEs were excited by the potential of AR HMDs, as evidenced by their significant engagement during feedback sessions and their desire to return to our lab to assess the newest iteration of each use-case. Having observed the most recent iterations of our prototyped use-cases, SMEs have expressed a keen interest in seeing these virtual simulations of AR use-cases implemented physically on one or more AR platforms (as opposed to the VEs we have made use of) and then tested in more rigorous settings. As such, we have started the process of standing up demonstrations of our uses-cases using the Microsoft HoloLens. Our findings will be described in a future paper but early trials show promise.

3.4 Future Work

We intend to complete a series of follow-on projects to expand on our findings detailed in this paper, remembering this work was only an initial attempt to understand AR technologies and how they might impact RCN activities in a variety of settings. We plan to develop more uses-cases and engage our iterative prototype development process with a greater number of users, across more trades within the RCN. We predict this will allow us to better understand how broadly AR technology can be applied to solve current and predict future problems faced by RCN and allied navies. We are also currently developing a formal set of survey questions to more thoroughly and consistently explore the use-case prototypes with SMEs. The qualitative data gathered from these surveys may make clear other strengths and weaknesses of the technology not made readily apparent by the free and semi-guided interview processes we have used to date.

As mentioned above, we are also currently working on moving the most promising of our use-cases from the AR (VE) platform to the HoloLens AR HMD. Building on our current positive findings, our plan is to evaluate these use-cases in both laboratory and applied settings, in order to empirically validate when and where AR HMDs provide the RCN (command teams in particular) with practical and compelling alternatives to traditional methods of displaying, manipulating, and exploiting information.

Finally, just as we were interested in how practical a VE would be as a platform for rapid prototyping, we are also intrigued by the possibility of using these technologies as platforms to perform experiments, similar to efforts by other labs [5][13]. Often experiments designed to assess the effectiveness of a new technology require extensive efforts in acquiring the technology, let alone arranging to assess the technology in an ecologically valid but controlled environment. This risk is compounded by the fact that military environments are unforgiving and rejections of new technologies are high. Just as VEs provide a low-cost, easy to use, and moderate to high-fidelity platform for prototyping, they may also serve similar ends when it comes to providing an early (i.e. first-pass) method of empirically assessing new technologies for their fitness for use in military contexts.

4 Conclusions

Though the work this paper is based on represents only a first assessment of the subject, we feel our current findings provide some evidence that AR HMD technologies offer the RCN (command teams in particular) practical and compelling alternatives to traditional methods of displaying, manipulating, and exploiting information. As these technologies mature, their capabilities may result in a paradigm shift in terms of how the RCN interacts with information. Undeniably, AR-systems are maturing, as advancements in AR-oriented technologies are appearing with extraordinary rapidity.

These technologies provide a variety of novel solutions to current and predict near future problems faced by the RCN and other modern navies. It is recommended that AR HMD technologies be subjected to more rigorous empirical assessment in order to better understand how they improve upon current approaches to the management and exploitation of information in contexts relevant to modern navies.

This work also provides initial evidence that VEs can act as reasonable platforms for demonstrating the capability of a new technology to disrupt RCN operational activities and that they can act as effective methods for rapid prototyping. Simulating AR in a VE has many benefits, providing a moderate to high-fidelity, low-cost, and easily implemented system, but there are also some costs to this approach. The impact of the identified issues will depend on the purpose of the simulation but for high-level concept development, we feel that VEs can act as a suitable and even preferred platform. Once concepts are explored to an appropriate level of detail with SMEs, through multiple iterations in the VE, we anticipate that a similar exploration and refinement process will be required in a true AR environment, using the real world as a backdrop. Simulated AR can act as a valuable part of a larger concept development effort. It can help identify the ideas with the greatest promise to evolve further in a more sophisticated setting, thereby reducing overall R&D costs, through the avoidance of commitment to projects that are identified as impracticable after an initial assessment in a VE.

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