



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**AR TECHNOLOGY:
EFFICIENCY IMPROVEMENT TOOL FOR
SHIPBOARD MAINTENANCE**

by

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March 2021

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REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 2021	3. REPORT TYPE AND DATES COVERED Master's thesis		
4. TITLE AND SUBTITLE AR TECHNOLOGY: EFFICIENCY IMPROVEMENT TOOL FOR SHIPBOARD MAINTENANCE			5. FUNDING NUMBERS	
6. AUTHOR(S) James C. Wiltshire				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			12b. DISTRIBUTION CODE A	
13. ABSTRACT (maximum 200 words) Maintenance is a constant throughout the lifetime of a ship and needs to be as efficient as possible for the U.S. Navy to maintain the readiness, capability, and capacity of its surface fleet. The inability to find a maintenance item on a ship by repair personnel during a maintenance period is unacceptable. The current process relies on the written description of a work order, which besides the ship compartment, offers little guidance regarding the precise physical location of the maintenance item. This ambiguity causes inefficiencies in the execution of the repair. Augmented Reality (AR) has strong evidence of positive influence on maintenance in the private sector and, now that it is more commonplace, the U.S. Navy should consider its first practical use. This research developed an experiment to compare the performance between the current process and AR-guided assistance, assessing the efficiency of subjects in terms of time, accuracy, and the subject's confidence in their ability to identify the proper item. The experimental environment involved two rooms differing in levels of complexity, representing shipboard compartments. Through statistical and exploratory analysis, the benefits of AR-guided assisted technology were demonstrated by its outperformance over the current process in all recorded measurements of the experiment. This research provides evidence that AR can potentially close the capability gap existing within the current process.				
14. SUBJECT TERMS augmented reality, shipboard maintenance, subject testing, maintenance availability, surface warfare			15. NUMBER OF PAGES 153	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

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TOOL FOR SHIPBOARD MAINTENANCE**

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Maintenance is a constant throughout the lifetime of a ship and needs to be as efficient as possible for the U.S. Navy to maintain the readiness, capability, and capacity of its surface fleet. The inability to find a maintenance item on a ship by repair personnel during a maintenance period is unacceptable. The current process relies on the written description of a work order, which besides the ship compartment, offers little guidance regarding the precise physical location of the maintenance item. This ambiguity causes inefficiencies in the execution of the repair. Augmented Reality (AR) has strong evidence of positive influence on maintenance in the private sector and, now that it is more commonplace, the U.S. Navy should consider its first practical use. This research developed an experiment to compare the performance between the current process and AR-guided assistance, assessing the efficiency of subjects in terms of time, accuracy, and the subject's confidence in their ability to identify the proper item. The experimental environment involved two rooms differing in levels of complexity, representing shipboard compartments. Through statistical and exploratory analysis, the benefits of AR-guided assisted technology were demonstrated by its outperformance over the current process in all recorded measurements of the experiment. This research provides evidence that AR can potentially close the capability gap existing within the current process.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	2-dimensional
3D	3-dimensional
AR	augmented reality
CNO	Chief of Naval Operations
CSMP	Current Ships Maintenance Project
CSV	comma-separated values
HMD	head-mounted device
HUD	heads-up display
IRB	Institutional Review Board
LCD	liquid crystal display
OMMS-NG	Organization Maintenance Management System—Next Generation
SME	subject matter expert
SWO	Surface Warfare Officer
TYCOM	Type Commander

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EXECUTIVE SUMMARY

The U.S. Naval ship maintenance industry is a multibillion-dollar industry that plays an integral role in maintaining the capability, capacity, and readiness of the U.S. Navy's surface fleet. A 2020 Congressional Research Service report estimated that when the USN reaches their desired force structure goal of 355 ships by the estimated year of FY2034 it would cost \$40B to sustain the fleet. The monetary value associated with this industry emphasizes its importance and the necessity of its efficiency. However, this industry is plagued with frequent schedule delays and cost growth. These delays and cost growths experienced can be caused by multiple different factors, but one factor in particular is new work. This thesis focused on a contributing factor of new work: the inability to identify maintenance items properly and/or in a timely fashion.

New work is considered work that did not make the original intermediate or depot-level maintenance contract deadline, whether the cause was either slow identification or delayed work authorization (GAO 2020). An example of the negative impact of new work was shown in the USS *Stout* (DDG 55) in her Chief of Naval Operations (CNO) Availability in 2018. According to a GAO case study the USS *Stout* experienced new work items caused by "requests for contract changes due to work that the Navy could not identify prior to the availability" (2020, p. 19). At the end of her availability, she experienced a schedule growth of 56 days (35% increase) and cost growth of \$4.3 million (23% increase). Inefficiencies in maintenance identification as experienced in the USS *Stout* CNO availability are a main contributor to new work. This research examines a possible solution to streamline inefficiencies in identification by using Augmented Reality (AR) guidance.

AR technology is becoming more commonplace and is a proven method within big industries showing potential to increase maintenance efficiency and to decrease execution time and human error. With AR, a user has an enhanced version of reality that is augmented with virtual information. AR could be used for supplemental information regarding a maintenance item, giving a repair party AR-guided assistance throughout the ship to identify its exact location. With this technology, the ambiguity created from the current

process of maintenance item identification during maintenance periods could be eliminated, streamlining the maintenance process.

The current process involves an input by ship's force into a computerized list of maintenance discrepancies called the Current Ship's Maintenance Project (CSMP). Using the shipboard computer program Organization Maintenance Management System—Next Generation (OMMS-NG), the sailor describes the location of the discrepancy. The maintenance item is then analyzed by the repair party, either civilian or sailor, who reads the description and must first find the physical location of the maintenance that needs to be performed. In the current process, the location of the maintenance item can at times be unclear. It is up to the author of the work order to be descriptive enough for the repair party to identify the maintenance item, as well as the repair party to correctly interpret the description as needed. This potential lack of clarity can become time consuming and very vulnerable to human error.

To determine the potential benefits of AR guidance for shipboard maintenance item identification, an experiment was conducted. This experiment involved two groups: a control group representing the current process, and an AR group with the Microsoft HoloLens 2. Each group consisted of 12 volunteers that were all active-duty military officers from the Naval Postgraduate School. This experiment involved identifying maintenance items in two separate spaces: a less complex space and a more complex space. These spaces differed in complexity to represent the different levels of complexity between shipboard compartments onboard a surface ship. The complexity of each space was determined by the number of different components and material within the space as well as the amount of maneuvering a subject must make to locate the components to be identified for the experiment. Within each space, subjects were required to identify items using their available guidance methods: location descriptions written IAW NAVSEAINST 4790 Ship's Maintenance and Material Management Manual for the control group and AR guidance and virtual cues for the AR group. Subjects identified a total of 22 items at the conclusion of testing: 10 items within the less complex space and 12 items within the more complex space. Subjects were assessed in three areas: their identification times for each item, identification accuracy and their confidence in their ability to identify the proper item.

Through statistical and exploratory analysis, the benefits of AR-guided assisted technology were demonstrated by its outperformance of the current process in all recorded measurements of the experiment. In terms of overall completion time, the AR notably outperformed the current process in both the less and more complex space with a percent difference of 81.64% and 103.24%, respectively. In terms of accuracy throughout testing, AR proved 100% accurate regardless of an increase in space complexity whereas the current process was 93.56% accurate. Of the items inaccurately identified by the current process, more than half of them were from active-duty Surface Warfare Officers involved in the experiment. These officers were the most familiar with the current process, and inadvertently demonstrated its ambiguity. AR's better performance also continued to show in the confidence of each subject, showing a high level of confidence 93.94% throughout the entire experiment compared to that of the current process having a high level of confidence of 85.6%. In conclusion, AR's ability to identify maintenance items within a space is more efficient, faster, and more accurate. With AR's proven successes in this research in terms of time and accuracy, its long-term cost benefits would be invaluable.

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ACKNOWLEDGMENTS

A huge thanks goes towards my thesis team: my thesis advisor, Dr. Quinn Kennedy, and my second reader, Clay Greunke. Thank you for the constant support and on-call expertise throughout the entire process.

I would like to thank the FutureTech team for their assistance in the development of the Microsoft HoloLens application they created for the research. Without their assistance, this thesis would not have been possible.

A final thanks to the entire NPS faculty who have contributed to the development of my education throughout my time as a student. They all have shown tremendous dedication to the educational and professional development of myself and all students at NPS.

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I. INTRODUCTION

A. RESEARCH PROBLEM AND MOTIVATION

Maintenance of surface ships within the Navy is a multi-billion-dollar industry. In 2016 the Navy delivered a five-year contract of \$1.3 billion to San Diego shipyards for repairs of warships; San Diego is only one of many U.S. Navy support facilities (Robbins 2016). The ship maintenance industry has a direct tie to the readiness, capability and capacity of the U.S. Navy Fleet and its efficiency is integral. However, this billion-dollar industry experiences a variety of schedule delays that result in increased costs and decreased fleet readiness. One of many examples is that of the USS *Stout* (DDG 55), which during its 2018 Chief of Naval Operations (CNO) Maintenance Availability experienced a 23% cost growth of \$4.3 million and a 35% schedule growth of 56 days (Government Accountability Office [GAO] 2020).

This research focuses on a contributing factor of these delays: the inability to identify maintenance items properly and/or in a timely fashion. This problem is commonplace throughout the different levels of maintenance, from actions performed on the ship by sailors to when the ship is in an intensive maintenance period where the maintenance/repair is being completed by outside contracted civilians or navy personnel. The current process involves an input by ships' force into a computerized list of maintenance discrepancies called the Current Ship's Maintenance Project (CSMP). Using the shipboard computer program Organization Maintenance Management System—Next Generation (OMMS-NG), the sailor describes the location of the discrepancy. The maintenance item is then analyzed by the repair party, either civilian or sailor, who reads the description and must first find the physical location of the maintenance that needs to be performed. In the current process, the location of the maintenance item can at times be unclear. It is up to the author of the work order to be descriptive enough for the repair party to identify the maintenance item, as well as the repair party to correctly interpret the description as needed. This potential lack of clarity can become time consuming and very vulnerable to human error.

The CSMP “is the primary repository of information concerning the current material condition of the ship” (Department of the Navy [DON] 2019, p. 2-3). If the maintenance items within the CSMP are poorly described, not easily seen, or only recognizable by a trained eye, then the maintenance or corrective repair cannot be completed nor be completed in a timely fashion. The OPNAVINST 4700.7M states that “maintenance should only be scheduled or executed when there is objective evidence to justify execution” (p. 2-2). If the repair is not easily recognizable or cannot be found, no repair will be executed, and the ship’s material readiness goes unchanged and over time, its readiness deteriorates.

Augmented reality (AR) technology has the potential to bridge this capability gap, removing the current processes’ ambiguity and in turn, potentially reducing scheduling delays experienced during USN ship’s maintenance intensive periods. AR is becoming more commonplace and is a proven method within big industries showing potential to increase maintenance efficiency and to decrease execution time and human error. Evidence of AR’s positive influence on maintenance comes from the private sector. One of the top aircraft engine suppliers, GE Aviation, utilizes AR in jet engine assembly. GE Aviation’s performance reports stated that, “on average, across all mechanics studied, the efficiency improvements were between 8 and 11 percent” and that the “tech could save the company millions over a decade” because of these improvements (Kloberdanz 2017).

With AR, a user has an enhanced version of reality that is augmented with digital information, as shown in Figure 1. This digital information becomes a part of the real world of the user’s perception (Schmalstieg et al. 2016, p. 3). AR could be used for supplemental information regarding a maintenance item, giving a repair party AR-guided assistance throughout the ship to identify the exact location of the maintenance item. With this technology, the ambiguity between the originating work order party and repair party could be eliminated and could streamline the maintenance process. This streamlined maintenance process could then reduce cost and schedule delays.



Figure 1. Maintenance Person Using the Microsoft HoloLens 2.
Source: Microsoft (2020).

B. SCOPE OF THESIS

This thesis has two areas of focus:

1. The first area of study is to understand a general consensus of how the surface warfare community would react to the implementation of shipboard AR technology. This area developed an online survey completed by Surface Warfare Officers (SWOs) currently attending the Naval Postgraduate School. These SWOs have a variety of maintenance experience and their inputs are highly valued on how this technology may assist or possibly be of concern during the maintenance process.
2. The second area of study is to determine the difference in performance through an experiment in which subjects are randomly assigned to find and identify maintenance item either with the assistance of AR (AR group) or with a written description of the location of each item (control group). Experiment results may identify the pros and cons of using this technology to identify specific maintenance items throughout a compartment. The data collected from this experiment will provide analysis and information to help the Navy determine if this technology can be considered for practical use.

C. RESEARCH QUESTIONS

This thesis will address the following research questions:

1. Do Surface Warfare Officers see Augmented Reality as a potential solution to bridging the capability gap between ship's force and outside maintenance personnel?
2. Is the use of Augmented Reality to identify maintenance items more efficient, in terms of time and accuracy, than that of the current process?
3. Does the use of Augmented Reality to identify maintenance items give the user more confidence in their ability to identify the correct maintenance item?

D. HYPOTHESIS

Research Question 1 was addressed through the informational online survey and therefore has no specific hypotheses associated with it. Research Questions 2 and 3 were addressed by the experiment. Below are three hypotheses and their associated alternatives that were crafted to address Research Questions 2 and 3:

1. Hypothesis 1

Null Hypothesis $H1_0$: There is no difference in mean time to identify maintenance items between the AR group and the control group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$.

Alternative Hypothesis $H1_A$: On average, the control group takes longer to identify maintenance items compared to the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} > 0$.

2. Hypothesis 2

Null Hypothesis $H2_0$: There is no difference in mean accuracy in identifying maintenance items between the AR group and the control group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$.

Alternative Hypothesis $H2_A$: The control group has a lower mean accuracy in identifying maintenance items than the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} < 0$

3. Hypothesis 3

Null Hypothesis H3₀: There is no difference in mean confidence rating in identifying the correct maintenance item between the control group and AR group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$.

Alternative Hypothesis H3_A: The control group has lower mean confidence ratings in identifying the correct maintenance items than the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} < 0$.

E. BENEFITS OF STUDY

The purpose of this study was to examine the potential practical use of Augmented Reality technology to the U.S. Navy. This study focuses on the use of AR for maintenance item identification as a potential avenue in saving the USN millions of dollars in scheduling delays and cost increases due to inefficient maintenance availabilities. With maintenance being an integral part of a ship's life cycle and readiness, this technology should be considered as a solution. With the USN Force Structure goal of 355 ships by fiscal year 2030, naval ship corrective maintenance and maintenance availabilities must be efficient in order to sustain the increased amount of future naval forces.

F. THESIS STRUCTURE

- Chapter I is an introduction regarding the problem, its motivation and its associated research questions to be answered and hypotheses to be tested.
- Chapter II discusses background information regarding the current maintenance processes and their experienced delays. This chapter also contains a literature review regarding AR and its proven capabilities within the private sector.
- Chapter III addresses the first area of this research, the online survey. It includes the development of the survey, demographics of the subjects who participated, and the survey results and overall findings.
- Chapter IV details the experimental methodology for the second area of focus.

- Chapter V provides analysis of the results from the experiment described in Chapter IV.
- Chapter VI encompasses a discussion of the results.
- Chapter VII is this research's conclusions, discussing strengths and limitations of the studies, and implications of the findings.

II. BACKGROUND

A. SHIPBOARD MAINTENANCE

There are three levels of U.S. Navy surface ship maintenance: organizational, intermediate level maintenance, and depot level maintenance. According to NAVSEAINST 4790.8 the three levels of maintenance are defined as follows:

- Organizational Level Maintenance—“maintenance that is the responsibility of ship’s force for accomplishment” (Department of the Navy [DON] 2015, p. I-6).
- Intermediate Level Maintenance—“maintenance that is normally performed by Navy personnel on board tenders, repair ships, Shore Intermediate Maintenance Activities (SIMAs), aircraft carriers, and fleet support bases” (DON 2015, p. I-6).
- Depot Level Maintenance—“maintenance that is performed by industrial activities. Depot-level maintenance requires major overhaul or a complete rebuilding of parts, assemblies, subassemblies, and end items, including the manufacturing of parts, modifications, testing and reclamation” (DON 2015, p. I-6).

Of concern to this research are the last two levels of maintenance mentioned, both of which require an outside party. This thesis focuses on the outside repair party whether conducting intermediate or depot level maintenance and their ability to identify maintenance items throughout a ship.

1. Current Method

Maintenance items to be corrected during the two aforementioned levels of maintenance are all pulled from the Current Ship’s Maintenance Project (CSMP), a computerized list of all requested corrective maintenance repairs for the ship. These requested corrective maintenance repairs or material discrepancies are known as work

candidates within the CSMP. Maintaining an accurate and up-to-date CSMP is the responsibility of ship's force.

Before maintenance can be completed at the intermediate or depot level, each work candidate must be validated by the Ashore Ship's Maintenance Manager. As described in the COMUFLTFORCOMINST 4790.3 the Ashore Ship's Maintenance Manager will only validate work candidates that are defined properly in terms of scope of work and technical accuracy. A list of elements of a valid work candidate provided by the COMUSFLTFORCOMINST 4790.3 REV D (Department of the Navy [DON] 2018) is as follows:

a. Configuration information automatically entered from the master configuration database (Configuration Data Manager's Database or Ship's Configuration and Logistics Support Information System) by the shipboard system:

- (1) Ship Unit Identification Code
- (2) Work Center Job Control Number
- (3) Allowance Parts List or Allowance Equipage List
- (4) Ship Name
- (5) Ship Hull Number
- (6) Equipment Noun Name
- (7) Equipment Identification Code
- (8) Location
- (9) Ship Work List Item Number
- (10) References

b. Job Sequence Number

c. Equipment Status Code

d. When Discovered Date

e. Deferred Date

f. Symptoms and Supporting Information

g. First Contact Name

h. Priority

i. Type Availability - (Recommended Accomplishment Level)

j. Required Delivery Date

k. Recommended resolution

- (1) Master Job Catalog, if applicable
- (2) Port Engineer's Notes
- (3) Additional references

l. Maintenance Action Requested

- (1) Assessment
- (2) Repair
- (3) Modernization

m. Maintenance Figure of Merit In CSMP Shore File

n. Initial Estimate (man days & material) In CSMP Shore file

- o. TYCOM Screening Code
- p. TYCOM Screening Remarks In CSMP Shore File

If the work candidate is valid for all the above-mentioned elements, the final product is screened by the Ashore Ship's Maintenance Manager and submitted for planning into an intermediate or depot level maintenance period. Before work can start during these maintenance periods, ship-checks are conducted by the repair party. Ship-checks consist of the repair party identifying the maintenance required to be done using the location and other applicable fields of the validated work candidate. This point in the current process is where problems arise. The repair party may be unable to identify the maintenance component and then defer the work, or the wrong maintenance item can be identified. This is because there is very little directional or location-based guidance provided. The impact of these problematic actions—or inactions—are described in in Section 2 of this chapter.

From the required elements listed above for each work candidate, the location requirement (highlighted) involves little description and detail. The location requirement is solely the nomenclature of the space and associated compartment number, for example: Berthing 1 (01-29-6-L). It is up to the originator of the work candidate to explicitly explain the exact location of the item within the “maintenance action requested” element.

Only limited location information is required for a work candidate to be validated; therefore, the only other form of a location description that can be provided is by the originator of the work candidate. If included, locational descriptions by the originating party can be unclear and difficult to interpret, leaving ambiguity in finding the maintenance item. It is up to the originator of the work candidate to be descriptive enough for the repair party to identify the maintenance item, as well as the repair party to interpret the description as intended. This ambiguity creates a capability gap between the originating party and the repair party and affects the repair party's ability in identifying the maintenance item during ship-checks.

2. Impact

The current method is time consuming and vulnerable to human error, resulting in inefficiencies in the identification and execution of maintenance. The aggregate of

individual inefficiencies then leads to schedule delays and cost growth. These inefficiencies in the identification and execution of the maintenance item are typically encompassed under the term: new work. New work is considered work that did not make the original intermediate or depot level maintenance contract deadline, whether the cause was either slow identification or delayed work authorization (GAO 2020). Ship-checks that were unable to be identified prior to the contract award, or identified incorrectly, contribute to new work experienced during these contracted maintenance periods. It is important to note that new work is comprised of multiple contributors and not just the inability of a repair party to identify maintenance items. Although there is no data on the percent of new work due to inefficiencies in locating and identifying maintenance items, from my professional experience the addition of new work due to identification issues has occurred multiple times in every maintenance availability I have been participated in. As shown in Figure 2, in multiple different maintenance areas for all surface ships through the years of 2003 and 2015, new work has accounted for billions of dollars in cost growth.

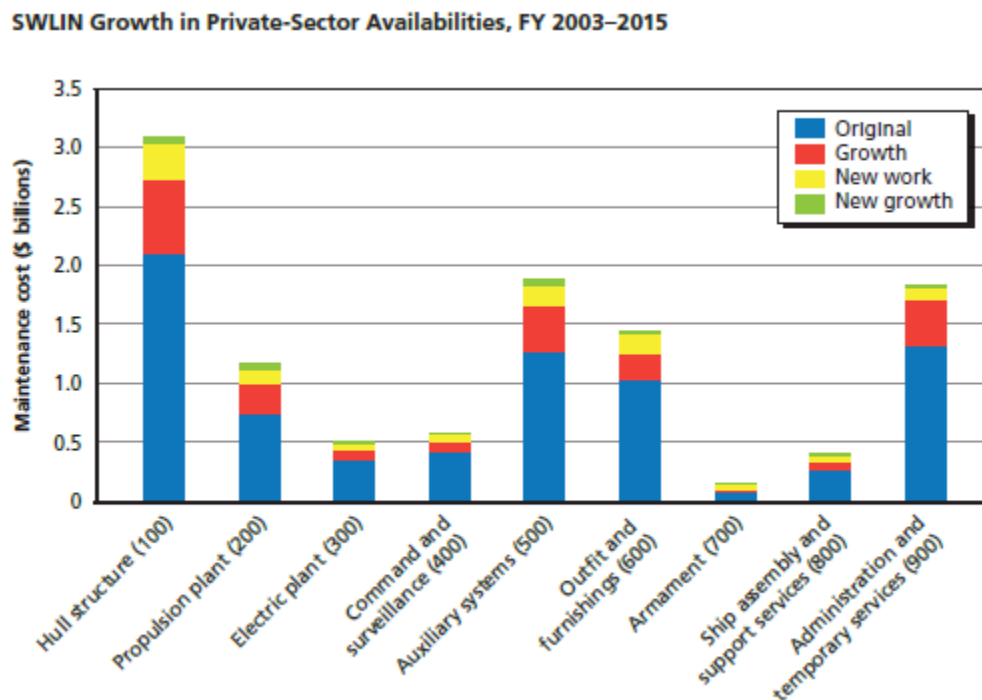


Figure 2. Ship Work Growth in Maintenance Availabilities from 2003–2015. Source: Martin et al. (2018).

A smaller-scale example of the effects of new work is that of the USS *Stout* in her Chief of Naval Operations (CNO) Availability in 2018, a depot level maintenance period. According to a GAO case study, the USS *Stout* experienced new work items that contributed to cost and schedule growth. The case study also stated that there were “many requests for contract changes due to work that the Navy could not identify prior to the availability” (2020, p. 19). At the end of her availability, she experienced a schedule growth of 56 days (35% increase) and cost growth of \$4.3 million (23% increase).

There are multiple factors and contributors to scheduling delays and cost growth during ship maintenance periods. This thesis focuses on one such factor—inability to locate the correct maintenance item—and examines a possible solution to streamline inefficiencies in the identification and execution of the maintenance item by using AR guidance. I predict that AR guidance would quickly and accurately guide repair party personnel to the maintenance component as well as give them an idea of the scope of work. If this prediction is supported, AR guidance could streamline the ship-check portion of the current process and reduce the amount of new work identified throughout a maintenance period.

B. AR EXPLAINED

Augmented reality (AR) gives a user an enhanced version of reality that can be augmented by digital information that provides visuals, audio and haptic feedback. Craig (2013, p. 13) states that “an important aspect of augmented reality is that you “remain” in the physical world, that is, there is not an attempt to make you believe you are not in the real world at the position you are standing or sitting.” This experience is unlike virtual reality, and other media to include the cinema, where you are placed in a scenario where the physical world is not visible or audible. AR combines virtual elements into a user’s real environment and enhances people’s awareness of the actual world and the capacity to process information (Wang et al. 2020). This thesis utilizes AR’s ability to provide virtual cues to identify specific items within a real environment.

When AR is experienced in a head-mounted device (HMD), such as the HoloLens 2 used in this thesis, the user is able to use the technology hands-free and while mobile. A

HMD is also oriented to the user's point of view and requires a low cognitive load for them to visualize augmented displayed information (Gruenefeld et al. 2019).

The following section of this chapter provides examples of AR's impact on maintenance through various studies conducted in the private sector as well as for the military. The last section of this chapter (Section II.D) goes into detail of a similar study that focuses on the ideal visualization techniques and strategy when using AR for identifying objects. This last section is important because the first step in conducting maintenance is to properly identify the component for the which the maintenance is being completed.

C. AR'S INFLUENCE ON MAINTENANCE

AR has shown itself as a valuable tool in multiple different fields to include education, medical, entertainment, and industry. Of concern to this research is AR's discovered positive impacts on maintenance. Below, I describe two industry studies and one military study that directly relate to this topic. The aviation industry has taken the lead in investigating the potential impact of AR on aircraft maintenance procedures.

Boeing, a well-known name within the industry, has conducted research on AR maintenance training systems that have been implemented in the maintenance of their complex equipment and received excellent results (Wang et al. 2020). A recent Boeing study investigated the effect of implementing AR to assist in the installment of electrical wiring throughout the fuselage of their KC-46 aircraft (Boeing 2017). This pilot study gave their technicians HMD AR technology, giving them the mobile ability to virtually see the planned schematics for wiring installation. The current process is complex and involves the technicians interpreting a two-dimensional diagram to understand where the proper installment locations of the electrical wirings are located. According to a Boeing Research and Technology Associate, their pilot study results were extremely significant, and he stated that their studies "have shown a 90 percent improvement in first-time quality when compared to using two-dimensional information on the airplane, along with a 30 percent reduction in time spent doing a job" (Boeing 2017). These results show how influential AR can be in increasing maintenance efficiency and decreasing maintenance time. With AR,

the technicians were able to virtually see and identify the correct locations of the electrical components, guiding them through their maintenance process to ensure first-time quality. The results from the Boeing study support AR technology's ability in helping the user identify maintenance components quickly and accurately.

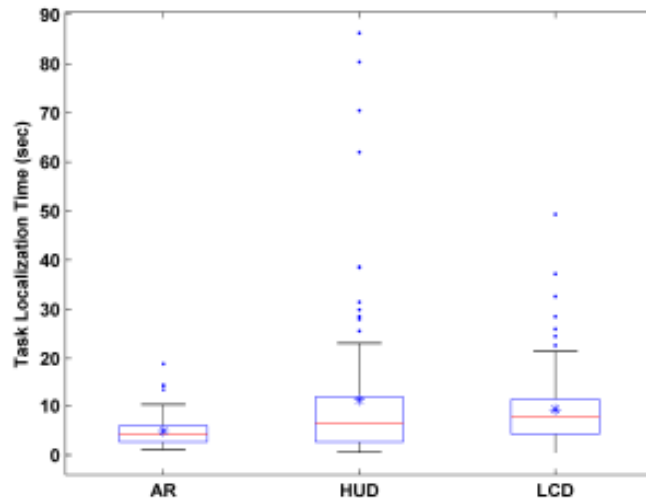
GE Aviation, a top aircraft engine supplier, conducted a pilot program that involved a comparison of maintenance assembly tasks of the CF34-8C engine between the traditional method and a method involving wearable AR technology (Robertson et al. 2017). Fifteen experienced mechanics completed two different maintenance tasks on the engine, one on the Variable Geometry Actuator and, the other on the Main Fuel Pump. Each mechanic conducted these two tasks twice: once with a standard torque wrench and hard-copy maintenance steps and then again using a wireless torque wrench with wearable AR technology. The Glass, previously known as Google Glass, was used as the AR Head Mounted Display to guide each mechanic through virtually displayed images, maintenance procedures and a live display of the amount of torque being applied by the mechanics via the wireless torque wrench. As depicted in Table 1, use of AR led to significant decreases in maintenance completion times for both tasks (7.77% for the Variable Geometry Actuator and 11.6% for the Main Fuel Pump) (Robertson et al. 2017). The large decrease in time from using AR could not be explained by mechanics' previous use with the technology, as only one mechanic reported ever having used AR technology before.

Table 1. GE Aviation Study Task Times. Source: Robertson et al. (2017).

Component	Without Wearable Technology	
	Mean (Min)	Standard Deviation (Min)
<i>Variable Geometry Actuator</i>	43.02	9.92
<i>Main Fuel Pump</i>	51.46	12.75
Component	With Wearable Technology	
	Mean (Min)	Standard Deviation (Min)
<i>Variable Geometry Actuator</i>	39.7	11.31
<i>Main Fuel Pump</i>	45.49	8.36

Results are from 15 GE Aviation Mechanics completing the same tasks with and without AR technology.

The U.S. military has also been involved with research regarding implementation of AR for equipment maintenance. One study conducted by a Columbia University research team (Henderson and Feiner 2009) assessed the benefits of AR for task localization in maintenance of the LAV-25A1, an armored personnel carrier turret. Their study examined 18 common tasks of the LAV-25A1, conducted by professional military mechanics utilizing either an AR HMD or one of the two baseline conditions: using a heads-up display (HUD) or a LCD monitor with texts and 3-D graphics. The HUD was displayed on the same equipment as the AR HMD, but only provided screen-fixed graphics that depicted text instructions and images. Results demonstrated that AR was the most significant in reducing the task localization time, the time required to identify the maintenance component. The mean task localization time for AR was 4.9 seconds (56% faster than the HUD, and 47% faster than the LCD), 11.1 seconds for the HUD, and 9.2 seconds using the LCD (Henderson and Feiner 2009). Figure 3 is a box plot representation of the difference in task localization time and illustrates that use of AR led to the most consistent times.



Task Localization times (seconds) for AR, HUD, and LCD. The blue asterisk marks represent the mean task localization time for each condition.

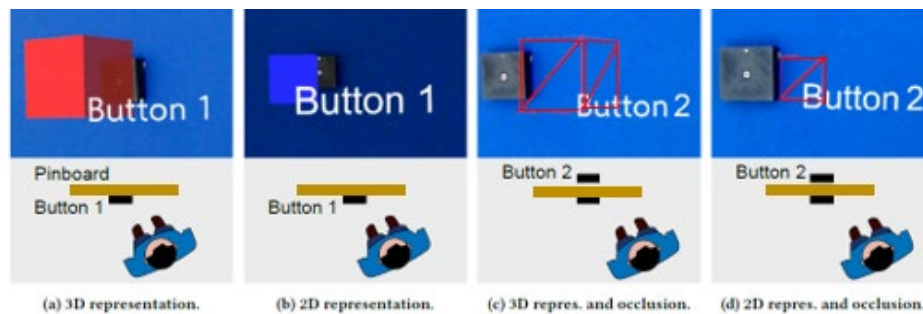
Figure 3. Task Localization Times. Source: Henderson and Feiner (2009).

This Columbia University study (Henderson and Feiner 2009) displays the positive impact that AR has on a user's ability to identify components. This thesis will extend upon this finding by examining the impact of AR when subjects are required to find multiple items throughout a compartment.

D. DETERMINING THE OPTIMAL AR VISUALIZATION STRATEGY

With AR, different virtual images can be projected; it is important to understand which visualization techniques are the most successful in guiding users to physical objects. In research by Gruenefeld, Pradel, and Heuten (2019), two stages of testing were conducted to determine: (1) which visualization *technique* worked best in locating physical objects in-view and (2) which visualization *strategy* worked best for locating physical objects regardless of their location, whether in-view or out-of-view. Visualization technique is how the user sees the object in AR, and visualization strategy is how the user is guided to the object in AR. Each stage of testing had its own scenario. As this study is highly relevant to this thesis, it is described in detail below.

For the first stage of this research multiple visualization techniques were tested: 3D and 2D representation, and 3D and 2D representation with occlusion. Occlusion refers to the AR image being blocked by a physical object that may be located in front of it from a given viewpoint. In Gruenefeld et al.'s (2019) experiment, their occluded objects were shown by a wireframe model in order to improve spatial perception, as shown in the Figure 4, along with the other visualization techniques.



Shown above are the four in-view visualization techniques shown in the user's point of view when locating a button on a pinboard.

Figure 4. In-view Visualization Techniques. Source: Gruenefeld et al. (2019).

In Figure 4, the two far-left images represent what the subject would see if searching for Button 1, and the subtitles below them identify them as either 3D or 2D. The two far-right images are the visualization techniques that include occlusion. These two images represent the point-of-view of the subject looking at Button 1 on a pinboard but actually searching for Button 2. From this subject's point-of-view, Button 2 is occluded, or blocked, because it is on the other side of the pinboard. Because Button 2 is occluded, the user is given a wireframe model of Button 2 in red visually representing that the object is on the other side of the Pinboard. Figure 5 is a visual representation of the setup for the first stage of the experiment, testing these visualization techniques.

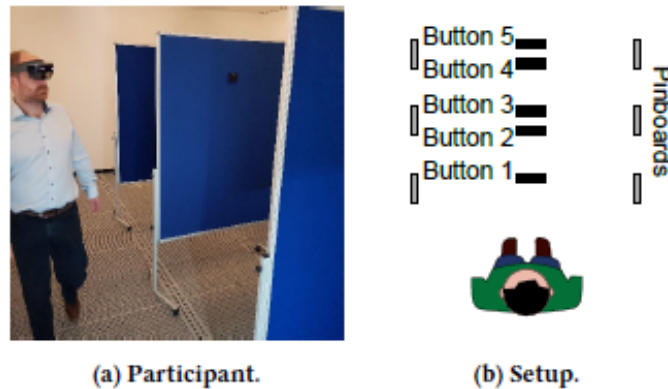


Figure 5. Experimental Environment of First Study.
Source: Greunefeld et al. (2019).

Their first experiment consisted of 12 subjects using a Microsoft HoloLens in which they had to select 5 buttons dispersed among 3 pinboards. As illustrated in Figure 5, all three pinboards were in a single column so that the subject had all buttons in-view. Two of three pinboards had two buttons on the front and back at approximately the same location. This was done to motivate real world situations such as a button being on the front and back of a monitor. Subjects were directed by the headset to depress buttons in a randomized order. A repeated measures design was used in which every subject conducted the button task with each AR visualization technique. For each visualization technique

experienced, the buttons were re-labeled to avoid any learning effects throughout the experiment. Figure 6 depicts the results with boxplots centered at the median search time.

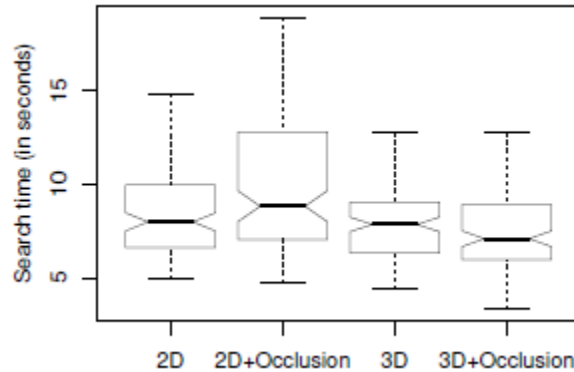
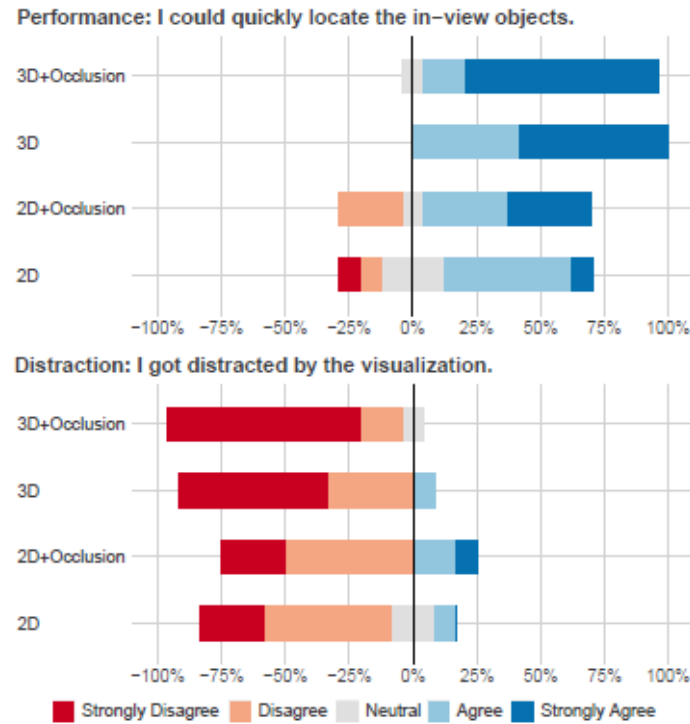


Figure 6. Search Time Results of Different Visualization Techniques.
Source: Greunefeld et al. (2019)

3D+Occlusion visualization technique also was the most accurate with 99.2% followed by 3D (96.7%), 2D (95.8%) and 2D+Occlusion (83.3%). Subjects also reported that it was the least distracting and one of the easiest to use to locate items (see Figure 7). 3D+Occlusion allows the user to quickly decipher that the object being searched for is being physically blocked by something in front of it and its 3D shape gives the user depth and shape orientation to help them understand how near or far it may be. Based on the results of this study I conjecture that 3D+Occlusion performed better than the strictly 3D visualization technique because the 3D technique only showed the AR 3D image if the button was within the point of view of the user. This visualization technique does not give the user any visual representation of the button being on the other side of pinboard.



Subject's responses are based on their experience of each visualization technique.

Figure 7. Post Task Questionnaire Results. Source: Gruenefeld et al. (2019).

Continuing with their determined best visualization technique, 3D+Occlusion, Gruenefeld et al. then determined the optimal visualization strategy. These strategies included printed map (baseline), in-view (visualization is only displayed when within the subject's point of view), out-of-view (visualization is only displayed when the item is out of the subject's point of view) and combined (in-view and out-of-view). This iteration of their study included 16 subjects experiencing each visualization strategy, 4 pinboards and 8 buttons to be located and depressed. The layout of this iteration of their experiment is shown in Figure 8. The subject started in the center of the space with a pinboard to their front, behind, left and right, each with two buttons on either side located in the same approximate location. Pinboards and buttons were placed accordingly so that buttons were either in-view or out-of-view to determine which visualization strategy was the fastest and most accurate. Like the first iteration of the study, all buttons were to be depressed in a

random order and buttons were re-labeled after each visualization strategy was experienced by the subject.

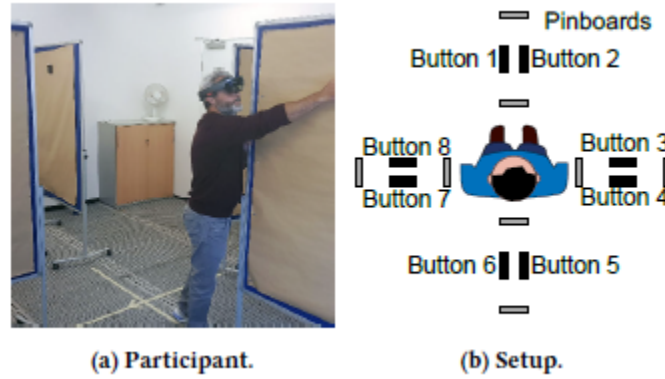


Figure 8. Experimental Environment for Second Part of Study.
Source: Gruenefeld et al. (2019).

It was determined that based on median search times the Combined visualization strategy was the most efficient with a time of 5.58s (Gruenefeld et al. 2019). The comparison between the other strategies is seen in the box plot depicted in Figure 9.

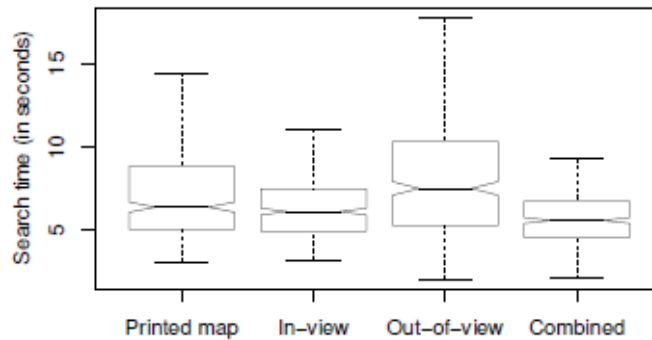


Figure 9. Visualization Strategy Search Time Results.
Source: Gruenefeld et al. (2019).

Object selection accuracy also was assessed across the 4 strategies. The most accurate being the combined strategy with 99.7% accuracy, followed by in-view (99.2%),

out-of-view (93.0%) and printed map (89.6%). The researchers concluded that the combination of in-view and out-of-view visualization strategy improves object selection accuracy and search times. Of note, for all participants, using the printed map (baseline) led to the most errors. With a combined visualization strategy, the subjects had the assistance of AR to direct them to the desired button whether in-view or out-of-view, leaving the subject with little ambiguity in which direction the desired button would be if out-of-view. In conclusion, Gruenefeld, Pradel and Heuten recommend a 3D+Occlusion visualization technique with a combined visualization strategy to identify objects via Augmented Reality.

There exist multiple shared aspects from the Gruenefeld, Pradel and Heuten (2019) research and this thesis. First, this thesis requires subjects to identify components throughout a room while assessing their time and accuracy. Second, thesis subjects in the AR experimental group will wear an AR HMD (Microsoft HoloLens 2) utilizing the optimal combined visualization strategy and 3D+Occlusion visualization technique as described in the Gruenefeld et al. research. Finally, this thesis extends upon their work by focusing on the AR application for a real-world task, the identification of shipboard maintenance items.

Shipboard maintenance items are all different in size and have multiple different locations that are not always clearly visible. For any sailor or outside contracted civilian conducting the maintenance, the first step always is identifying the proper maintenance item. This thesis will compare the current process of locating maintenance items (without AR) to locating maintenance items with AR in terms of search time, accuracy, and the subject's associated confidence in correctly identifying each item.

III. SME ONLINE SURVEY

Given that AR technology is new technology, an online survey was created to develop and understand the general consensus and first impressions of Surface Warfare Officers (SWOs) on implementing AR Technology for shipboard use. To my knowledge, this survey is the first to query SWOs on this topic. This chapter covers the targeted audience of this survey, a description of the survey, how the questions were developed, and the survey results.

A. SUBJECTS

The sample comprised 31 SWOs currently attending the Naval Postgraduate School. The NPS SWO community includes naval officers with different career backgrounds. Collectively their sea tours may be similar but not a single experience is the same. Their experiences may range from high tempo deployments on an Arleigh-Buke Class Destroyer to large overhaul and maintenance availabilities on an Aircraft Carrier. The NPS SWO community was targeted because of the diversity of their experience, particularly their maintenance experience. The tables shown in the sections that follow provide demographic data collected from the survey relative to the subjects' tour and military maintenance experience. Subjects have a collective estimate of over 200 years of surface warfare experience (mean years per subject = 8.5, $s = 4.33$, 95% CI: 6.98,10.02) and 150 years of military maintenance (mean years per subject = 5.48, $s = 1.72$, 95% CI: 4.875,6.085). Importantly, their maintenance experience comes from a leadership perspective, enabling them to be Subject Matter Experts (SMEs) in determining potential benefits that AR technology would have for shipboard use.

B. SURVEY DESCRIPTION

The SME Online Survey taken by the NPS Surface Warfare Officers was a NPS IRB approved survey administered via Qualtrics XM. Qualtrics XM is a free online survey generator software that was used to develop an easy access survey to be taken by laptop, phone, tablet or any internet able device. This software also allowed the responses to be exported into a CSV file for further data analysis. The survey consisted of 12 questions that

would take the subject between 5 and 10 minutes to complete (see Appendix A). Survey responses were anonymous and no identifying information was collected. This survey was designed to understand the potential benefits of Augmented Reality technology from the perspective of the officer leadership onboard U.S. Navy ships. The questions developed would give the research team insights into how the U.S. Navy might welcome this new technology as well as give them the opportunity to express concerns regarding this technology's implementation.

C. CONSTRUCTION OF SURVEY QUESTIONS

This survey was created to facilitate responses from the NPS SWOs. The 12 multiple questions within this survey were developed so that SWOs of all levels of experience could provide an adequate response with the available answer options. Applicable questions also provided comment sections if the survey taker wished to provide an experience or feedback related to that question. The first couple questions of the survey develop a basic demographic of the survey taker regarding his/her years in service and maintenance experience. This information would help our research team understand if the insights of more senior SWOs on this new technology differ from that of junior SWOs or if there exist any trends in answer selection based on the subjects' demographic.

The remaining survey questions were created to understand the possible benefits of AR in three areas: maintenance time completion, impact/effect on sailors, and overall effect on the ship. The first area of these questions, maintenance time completion, had two associated questions (Question 3 and 7). This area of questioning first asked the subject if shipboard maintenance completion is an issue and provided an opportunity for the subject to share an anonymous experience. These experiences could include any maintenance related issues during their tours such as delays, maintenance identification issues etc. This question helped the research team understand possible applications of the AR technology based on their shipboard hardships. It then asked if AR were available for shipboard-use approximately how much time it would save. This response gave our research team an estimated numerical value on how valuable SWOs believe AR technology could be if available.

The second area of this survey, AR's impact/effect on sailors, had three associated questions (Questions 4, 5, 6, and 9). Question 6 in particular asked the survey taker which personnel of the ship's force would benefit from this technology the most. The subject could select multiple answers for this question and the answers ranged from the enlisted sailors (workcenter supervisors, leading petty officers, etc.) to the senior leadership of the command (Executive Officer and Commanding Officer). The remaining three questions asked questions regarding the potential impact on the performance of sailors and/or maintenance personnel in three different areas: identification, effectiveness and accountability. These questions were developed to understand how this technology would impact the personnel utilizing it from the leadership perspective of the NPS SWOs.

The third area of this survey had three associated questions (Questions 8,10,11) and focused on AR's overall effect on the maintenance of ship. The first question (Question 8) asked how it would impact the Current Ship's Maintenance Project (CSMP), the answers to this question give our research team an idea how this AR would impact the amount of maintenance issues identified and how it could help update the CSMP. The second question (Question 10) focused on how AR could influence the completion of maintenance during an intense maintenance availability, these answers would help us understand if this technology does in fact have the ability of bridging the capability gap between ship's force and the outside maintenance personnel during these frequent periods throughout a ship's life cycle. The last question (Question 11) allowed the subject to voice any concerns that AR would possibly present if it were implemented on the ship. This question also allowed the subject to write any comments to anonymously fully voice their concern. These comments would provide insight of potential hurdles that this technology might have to overcome if implemented for shipboard use.

All questions had multiple choices for potential answers. When applicable these multiple-choice answers were subject to the Likert Scale, a total of five questions had answers of this scale. The use of the Likert scale for these questions represented a range of responses which provided our research team with deeper insight and more granular data than that of binary choices such as "yes" or "no." There were also images associated with questions throughout the survey. These images were not necessary for the subject to answer

the question but instead would provide a visual context of what the question was referring to. An example of one of these images is shown in Figure 10.

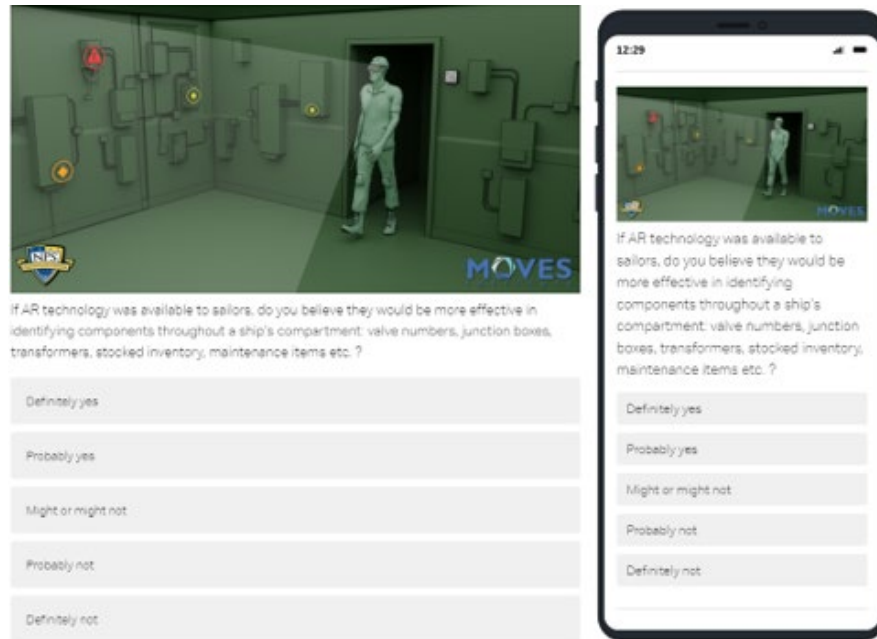


Figure 10. Online Survey Question with an Accompanied Image

D. SURVEY PROCEDURES

The survey was distributed via the SWO NPS SAKAI site; all NPS SWOs are members of this SAKAI site and received notifications when the announcement is made on the page. The announcement was created in accordance with the Recruitment Script that was approved by the IRB. This recruitment script explained the value of the survey to our research team as well as hyperlinks to short videos that would give the subject some basic background information on what Augmented Reality technology is if they were unfamiliar.

E. RESULTS

With a total of 31 responses from NPS SWOs, this sample size met our research team's goal of collecting responses from 10–50 subjects. Results cover the three parts of the survey previously discussed in Section C of this chapter: maintenance time completion, impact/effect on sailors, and overall effect on the ship.

1. Impact of AR on Maintenance Completion Time

Question 3: How often during your time on-board was the identification of the maintenance or corrective maintenance repair not completed in a timely fashion?

Table 2. Survey Question 3 Responses

Responses	Count	Percentage
0 times a month	2	6.45
1-3 times a month	10	32.26
4-7 times a month	11	35.48
Greater than 7 times a month	5	16.13
Not Sure	3	9.68

Each subject's career is different and therefore are exposed to different ships and different operational tempos but based on the responses to this question, maintenance delays are a normal occurrence on shipboard life and substantiates the motivation behind this research. Of the 31 subjects who took this survey, an overwhelming 83.87% have experienced maintenance delays throughout their careers.

This question also allowed the subjects to share an experience applicable to maintenance delay in the form of a comment. A total of 14 comments were recorded. A few selected excerpts are shown below:

“At least once a month, a spotcheck would indicate that the Sailor identified the incorrect piece of equipment or that the CSMP job was not well defined and they were unable to identify the work to be completed. Even walking through zone inspections, by the end of the inspection the recorder had written vague descriptions of corrective actions and locations of items for work”

“Lack of experience on the DDG led to a lot of issues with corrective maintenance not being identified”

“Majority of sailors conducting maintenance are relatively junior in rank and may have the least amount of maintenance experience on board. There is hesitation in the identification of a maintenance item with nothing but a valve number or compartment space to describe its location. This hesitation takes up valuable time that could be used towards other maintenance tasks which in most cases causes these other maintenance tasks to be delayed.”

All these comments and the remaining 11 not shown all voiced the same problem: identification of maintenance items on ships is an issue.

Question 7: How many man-hours a week would you estimate AR technology would save?

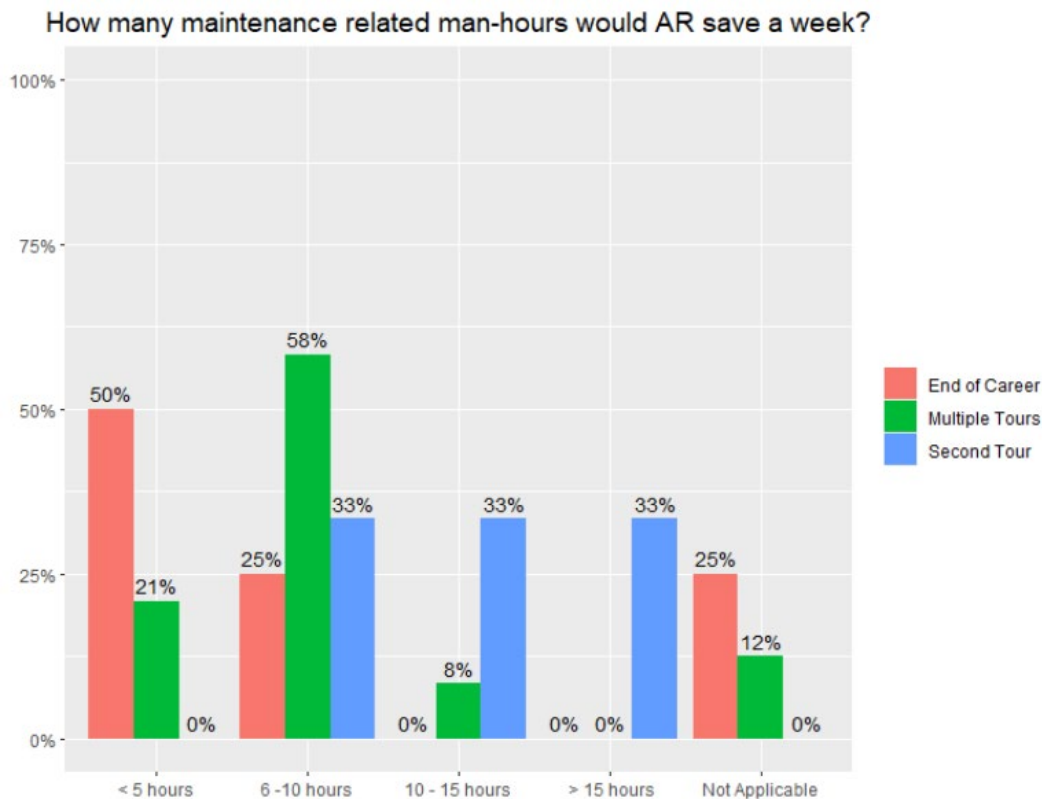
Table 3. Survey Question 7 Responses

Responses	Count	Percentage
<5 hours	7	25.93
6 - 10 hours	16	59.26
10 - 15 hours	3	11.11
> 15 hours	1	3.7
Not Applicable	4	14.81

Table 3 shows that majority of responses were in favor of AR potentially saving man-hours each week, with the answer of “6-10 hours” being selected by almost 60% of the subjects which translates to approximately one workday. This figure also shows that some subjects were unsure of the impact on weekly man-hours based on the “Not Applicable” selection. This is expected since there is no shipboard maintenance data involving AR outside of the private sector. Overall, from the responses of this area of the survey it can be concluded that maintenance delays are an issue and AR could potentially be an avenue for its correction.

Exploratory analysis was conducted to investigate the distribution of answers to the questions of this area of the survey. In Figure 11 the distribution of answers for Question 7 is broken down by the different demographics of the subjects that took this survey:

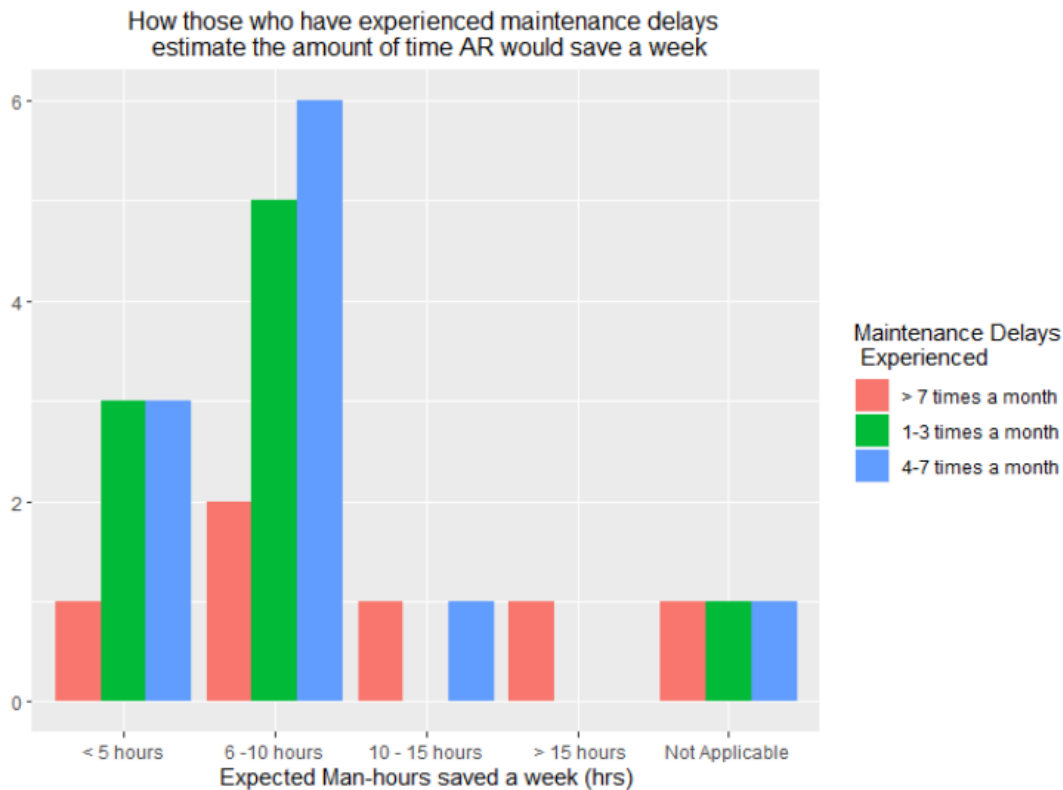
Second Tour, Multiple Tours and End of Career SWOs. All subjects, regardless of demographic, show that they believe AR will have a positive impact in saving maintenance related man-hours each week. 87% of Multiple Tour SWOs and 75% of End of Career SWOs believe that AR will reduce a significant number of man-hours a week. The Second Tour SWOs are the most optimistic of the demographic, with 100% of them estimating that AR technology will save at least 6 man-hours a week. The most pessimistic group of the subject pool was the End of Career SWOs, with a quarter of the group selecting “Not Applicable,” meaning weekly maintenance man-hours would more than likely remain the same. Although there exist some doubts among few subjects in AR’s ability to reduce weekly man-hours the data still shows that SWOs would expect AR to save time if implemented for shipboard use.



The above graph breaks down each SWO demographic that participated in the survey and how many potential man-hours could be saved with AR

Figure 11. SWO’s Prediction on Saved Man-Hours

Continued exploratory analysis combined the responses of Question 3 and Question 7 as shown in Figure 12. Figure 12 shows subjects who have experienced a certain number of maintenance delays and how effective they believe AR would be in reducing man-hours a week. The number of man-hours a week and maintenance delays are intertwined. Maintenance delays result in more man-hours to make up for the delay and the inverse case being that the more man-hours it takes to complete a maintenance task the greater the chance of there being maintenance delays as a result.



This graph takes the responses from two questions and gives a visualization of how SWOs who have experienced maintenance delays believe how impactful AR will be in saving man-hours per week.

Figure 12. Maintenance Delays vs. Man-Hours Saved

Based on the data presented in Figure 12, the more maintenance delays experienced by the subject the more they believe AR can save in man-hours per week. Those who have experienced 4–7 or > 7 maintenance delays a month are the most optimistic in AR's impact in saving man-hours each week. Regardless of the amount of maintenance delays

experienced by each subject, the majority of their demographics responses show that AR can save at least 5 man-hours each week.

2. AR's Potential Impact on the Efficiency of Sailors

Question 4 : If AR technology was available to sailors, do you believe they would be more effective in identifying components throughout a ship's compartment?

Table 4. Survey Question 4 Responses

Responses	Count	Percentage
Definitely yes	11	35.48
Probably yes	14	45.16
Might or might not	4	12.9
Probably not	1	3.23
Definitely not	1	3.23

Based on the responses collected from this question, 80.64% of subjects voted that AR technology would make sailors more effective in identifying components throughout a ship. Approximately 6% of the subjects believed that AR would not increase a sailor's identification ability while almost 13% remained unsure of its potential impact.

Question 5: If anyone, who would benefit from this technology?

Table 5. Survey Question 5 Responses

Responses	Count	Percentage
Senior Leadership(XO, CO)	7	12.73
Khaki Leadership (CPOs, Junior Officers, Department Heads)	21	38.18
Enlisted Sailors (LPO's, Workcenter Supervisors, Maintenance Persons)	26	47.27
Other	0	0
None	1	1.82

For this question, subjects could select multiple responses in order to represent the range of use throughout the ship. The most favorable two parties expected to benefit from this technology was “Khaki Leadership” and “Enlisted Sailors,” which made up 85.45% of the total responses. “Senior Leadership” was the least selected party which is of no surprise because they would have the least amount of involvement in maintenance and direct management over maintenance completion.

Question 6: Do you believe Augmented Reality technology would increase a sailor’s effectiveness?

Table 6. Survey Question 6 Responses

Responses	Count	Percentage
Definitely yes	9	29.03
Probably yes	15	48.39
Might or might not	5	16.13
Probably not	1	3.23
Definitely not	1	3.23

With 77.42% of the responses voting some degree of “yes” and 62.5% of those responses being “probably yes,” the majority of subjects believe AR technology would increase a sailor’s effectiveness. Compared to the positive responses received by AR in Question 4 on sailors’ identification ability, 3.23% more subjects were either unsure or did not believe that AR would increase a sailor’s effectiveness.

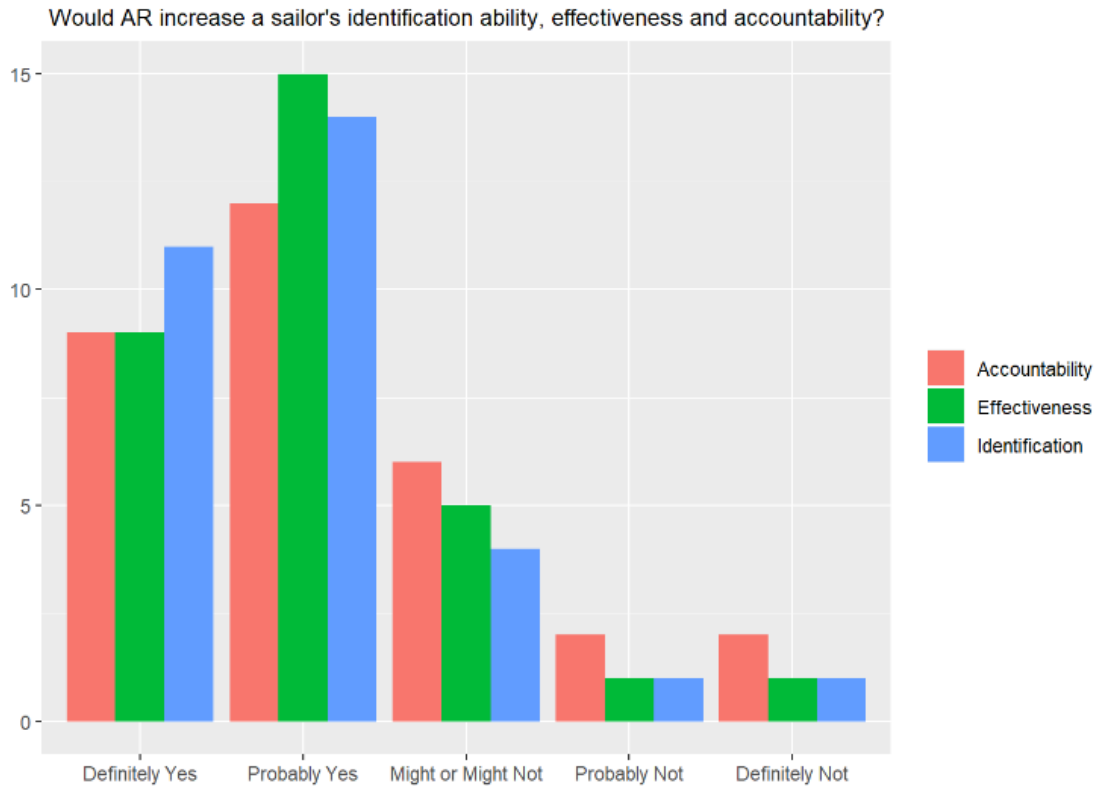
Question 9: Do you think with the addition of AR, accountability in making sure these maintenance items are completed would be increased?

Table 7. Survey Question 9 Responses

Responses	Count	Percentage
Definitely yes	9	29.03
Probably yes	12	38.71
Might or might not	6	19.35
Probably not	2	6.45
Definitely not	2	6.45

Of the 31 subjects 67.74% of them selected a response with a degree of yes as shown in Table 7. With 32.25% of subjects not believing that AR would increase sailor accountability in maintenance completion, this is the most negative response when comparing to potential increase in sailor identification ability and effectiveness (Questions 4 and 6). This questions' results show that the most hesitant factor of sailor improvement from AR involvement would be the improvement of increased accountability.

For ease of interpretation Figure 13 combines the results of Questions 4,6 and 9 which collectively asked if AR technology would increase a sailors' accountability in completing maintenance, their maintenance identification ability, and their effectiveness. The graph shows that subjects believe AR will have the most positive impact on sailors' effectiveness and the least impact on their accountability. The graph does show that a few subjects are uncertain and that an even fewer number of subjects believe AR will not increase a sailor's accountability, effectiveness and identification.



This graph combines the results from Survey question 4,6 and 9 and shows the distribution of answers of all three questions about how likely AR would increase sailor traits.

Figure 13. Increase Sailor's Accountability, Effectiveness and Identification

Further examining these three questions, it is important to analyze the relationship between the SWO's shipboard experience and how they believe AR would impact/effect a sailor. More senior SWOs such as the "End of Career" demographic may be more hesitant and indifferent on the implementation of this technology because throughout their many tours they perhaps have seen sailors work efficient without the involvement of a new technology. Figure 14 breaks down each question along with the demographics of SWOs to understand if a relationship or trend exists.

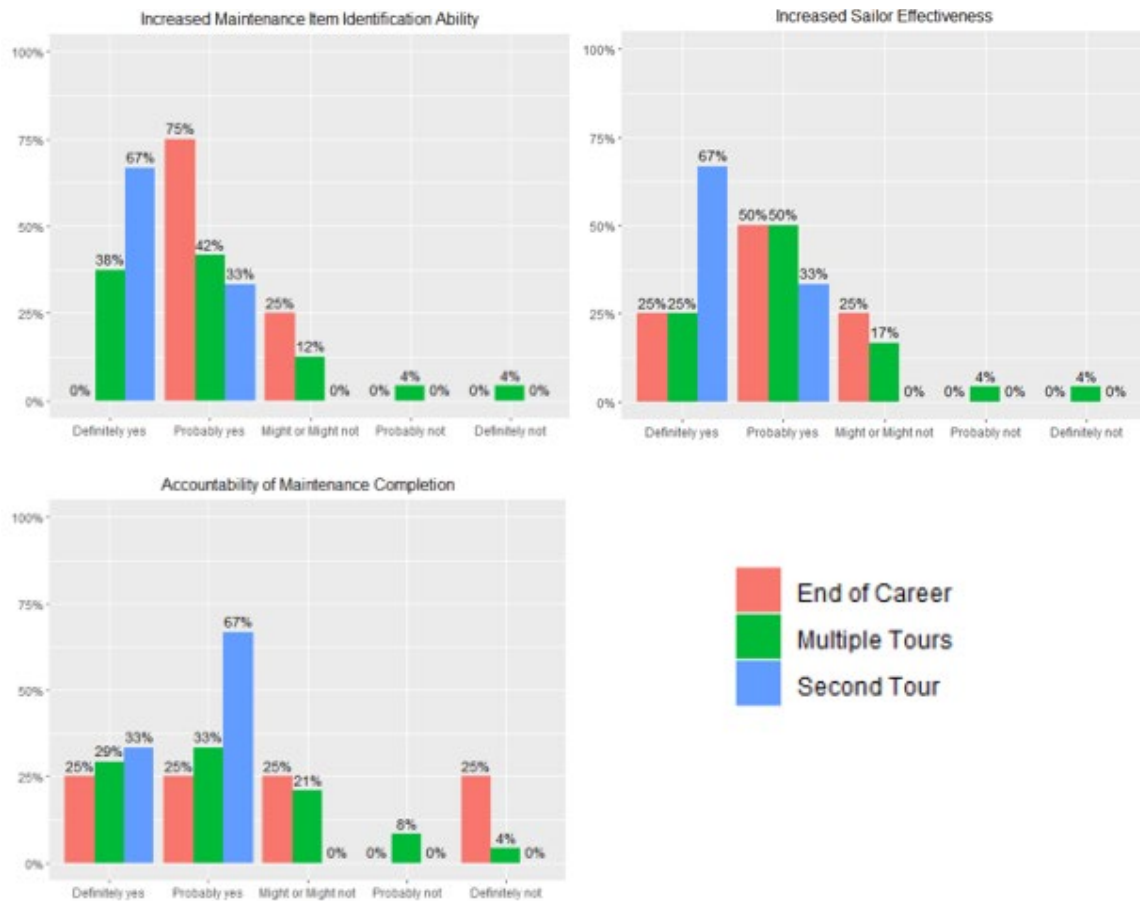


Figure 14. SWO Demographic Answer Distribution for Questions 3,4,9

As shown in the graphs within Figure 14 the “Second Tour” demographic shows the most support in AR technology being a positive influence on sailors, with all of them selecting some degree of “yes” for each attribute. “Multiple Tour” SWOs believe that AR will have the greatest effect on a sailor’s maintenance identification ability (Total of 78% voted a degree of “yes”) and a sailor’s effectiveness as a close second (Total of 75% voted a degree of “yes”). “End of Career” SWOs show the most support for AR in terms of it increasing a sailor’s identification ability but they also show the most amount of disapproval towards AR increasing a sailor’s accountability.

3. AR's Overall Effect on the Ship

Question 8: What type of effect would the added AR capability of virtually tagging equipment, maintenance items, and repairs have on your Current Ship's Maintenance Project (CSMP)?

Table 8. Survey Question 8 Responses

Responses	Count	Percentage
Increase the size of the CSMP	13	41.94
CSMP size would stay the same	12	38.71
Decrease the size of the CSMP	6	19.35

The CSMP is a computerized list of the active maintenance items within the ship. With AR, there is a potential of having an improved identification ability. This question was developed to understand if SWOs would think that with this improved ability would it increase, decrease, or have no effect on the current list of maintenance items throughout the ship. With the largest group of subjects (41.94%) selecting “Increase the size of the CSMP” it shows the possibility that with an increased identification ability due to AR there will exist more active and current maintenance items.

Question 10: During your ship's Continuous Maintenance Availabilities (CMAVs) would you expect more or less work to be completed with the assistance of AR? Outside entities such as contracted workers or Navy Regional Maintenance Center personnel would be able to identify repairs using AR technology

Table 9. Survey Question 10 Responses

Responses	Count	Percentage
Much more	7	22.58
Moderately more	12	38.71
Slightly more	6	19.35
About the same	5	16.13
Slightly less	0	0
Moderately less	0	0
Much less	1	3.23

This question asked how AR would affect the ship during an intensive maintenance period. 80.64% of the subjects believed that during an intensive maintenance availability more work would be completed with the assistance of AR. Only one subject believed that AR would be counterproductive and that “Much less” work would be completed.

Question 11: Does implementing AR technology give you any reason for concern?

Table 10. Survey Question 11 Responses

Responses	Count	Percentage
Definitely yes	3	9.68
Probably yes	7	22.58
Might or might not	10	32.26
Probably not	10	32.26
Definitely not	1	3.23

According to Table 10, the subjects are almost evenly split between being concerned (answered with a degree of “yes”), undecided (“might or might not”), or not concerned (answered with a degree of “no”) in implementing this technology. This spread between the subject pool proves that AR technology is still relatively new, and that the Navy requires education on its capabilities for the fleet.

There also was a comment section provided with this question so that the subjects could explain and voice their concerns. A total of 16 comments were made. Five extracted comments are provided below:

“One more system to train on; one more database that needs to be kept up-to-date and must be hull specific in order to maximize its effectiveness.”

“My main concern would be a loss of the learning process. There is a level of learning that happens with the current system (trial and error in finding a piece of equipment, learning how to write a job effectively, etc.). I agree that there are man-hours lost with the current system, but making something too efficient for sailors can also hurt their learning process—that during an emergency—could save lives.”

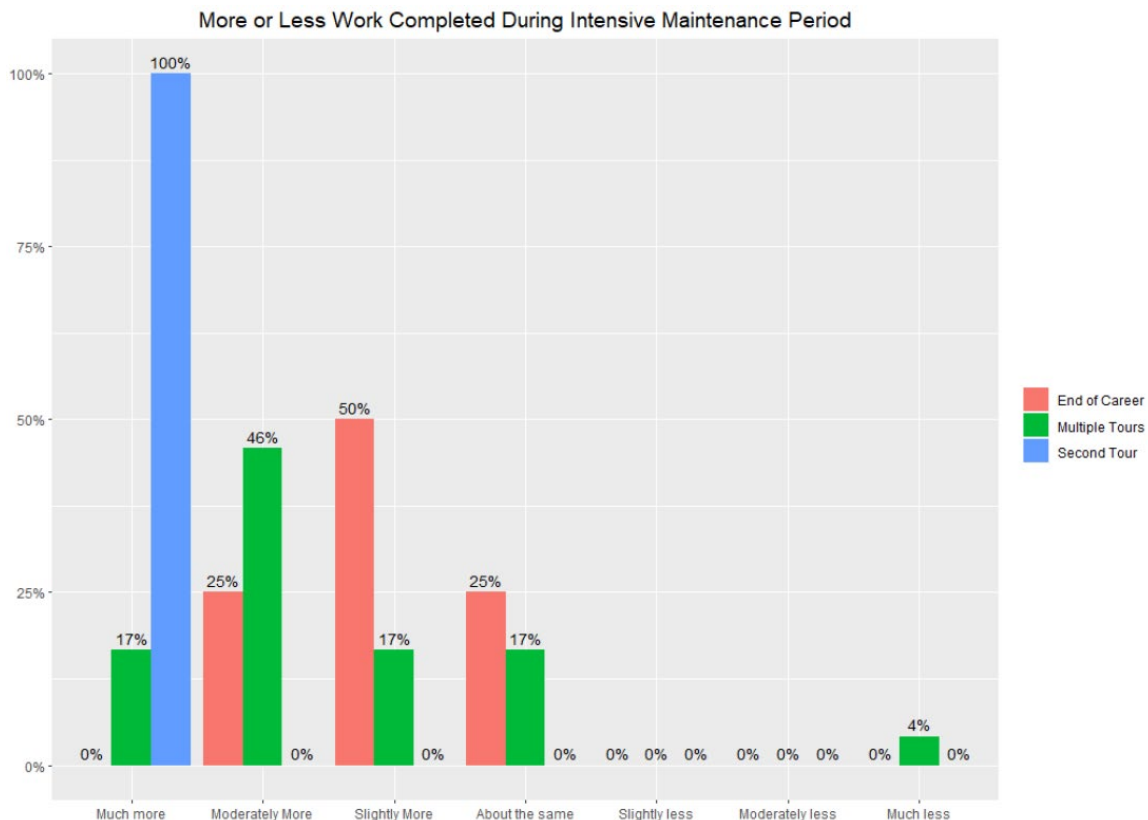
“Building the database or map of items into the ship or AR Headset would be extensive, but if done would be a major help in quickly identifying and tagging out items.”

“I fear reliance on the technology would decrease the knowledge of a sailor to take effective action during an emergency i.e. They only know how to isolate a leaking pipe by using this technology.”

“The lack of “buy-in” from senior leadership and seasoned CPOs that are averse to change could cause lag times in training and sustainment of the AR technology.”

These comments selected represent the reoccurring themes mentioned throughout the 16 recorded comments. The major concern of SWOs with AR is that there may be a loss in the learning process for sailors, creating a culture where sailors will use the AR technology as a necessity instead of an assistance tool. If this concern became reality, the consequences during a shipboard emergency would be grave. Other concerns voiced were the maintenance, upkeep, training, and installment required of this AR technology on ships.

Further analysis was conducted on Question 10, to understand the stance of the different SWO demographics on AR's impact during intensive maintenance availabilities. Figure 15 shows that "Second Tour" SWOs are the most optimistic of AR's influence during these maintenance periods with a 100% selecting "Much more" work would be completed. "End of Career" SWOs are the most indifferent on how effective AR would be during these periods, with 25% of the demographic selecting the amount of work completed would be "About the same." The only demographic that believed less work would be completed was the "Multiple Tour" SWOs with 4% of the demographic saying that "Much less" work would be done, voicing the opinion that AR would have a negative impact on the work completed during these periods. Overall, across all demographics the subjects' selections state that AR would have a positive impact on these maintenance periods resulting in more work completed.



This graph shows the distribution of each SWO demographic and how they believe AR would impact the level of work completed during Intensive Maintenance Periods.

Figure 15. Level of Work Completed During Intensive Maintenance Periods

4. Summary and Discussion of Survey Results

Of the three separate areas within this survey, the responses from the subjects show AR has potential to have a positive impact on all three areas: maintenance time completion, impact/effect on sailors, and overall effect on the ship. The first area of the survey, maintenance time completion, proved that delayed maintenance completion due to inability to identify items was an issue with the mean of subjects stating that delays occur “4–7 times” a month. This area of the survey also showed evidence that AR could help reduce the amount of these maintenance delays by an average of “6–10” man-hours a week. More than 75% of each SWO demographic that participated in this survey believed AR would save time in maintenance completion.

The second area of the survey assessed how SWOs would expect AR to impact sailors. Three attributes of sailors were assessed: their identification ability of maintenance items, effectiveness, and accountability in maintenance completed. According to the subjects of all demographics the most positively influenced attribute would be a sailor’s identification ability of maintenance items and the least positively influenced attribute would be a sailor’s accountability in completing maintenance. Based on personal experience, sailors’ accountability in completing maintenance was possibly the least improved attribute because the technology would not be as effective as managerial leadership provided from senior sailors and officers.

The third area of the study assessed how SWOs react to AR’s influence on the overall ship. As shown in the results for Question 10, AR would improve the amount of maintenance and work completed especially during an intensive maintenance period. This area also allowed subjects to voice some concerns regarding the implementation of the technology. Themes from these comments were: sailor reliance on the technology, hindering sailor on-the-job training, and the man-power required to train and upkeep the technology. As a new technology it is of no surprise that these comments show reservation on believing AR is the answer to increase shipboard maintenance efficiency.

Throughout all areas of the survey the most optimistic regarding the potential impact of AR technology for shipboard use was the “Second Tour” SWOs. The most

critical of AR's potential positive impact were the "End of Career" SWOs. Overall, with the results of this survey our research team can conclude that SWOs believe this technology would have a positive impact on shipboard maintenance.

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IV. DESIGN OF EXPERIMENT

The sections of this chapter discuss study design and methodology.

A. STUDY DESIGN

1. Physical Environment

The physical environment consisted of an NPS classroom and lab within Watkins Hall. These two rooms within Watkins Hall represented shipboard compartments. Compartments within a ship all vary in size and complexity, for example, the ship's mess decks and engine room differ in size and the amount of material within the space. The two rooms within Watkins Hall were selected to represent this difference in complexity between shipboard compartments. The classroom served as the less complex space and the lab as the more complex space. The complexity of each space was determined by the number of different components and material within the space as well as the amount of maneuvering a subject must make to locate the components to be identified for the experiment.



Figure 16. Less Complex Space, Classroom within Watkins Hall

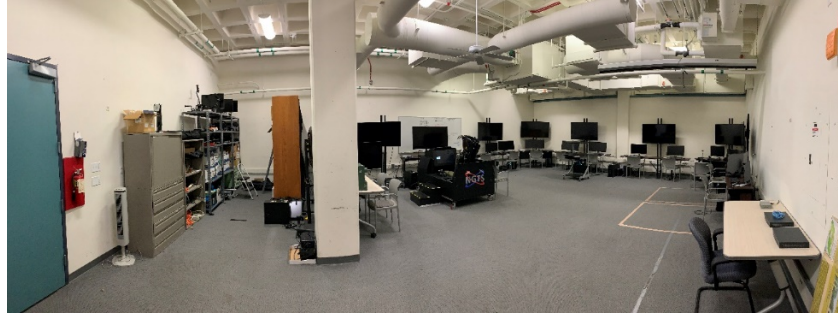


Figure 17. More Complex Space, MOVES Lab within Watkins Hall

2. Experimental Conditions

This study created two different subject groups for the main experiment, a control and AR group. The control group represented the current shipboard process of identifying maintenance items throughout the ship. The current process involves an input by ships force into a computerized list of maintenance items. Using Organization Maintenance Management System—Next Generation (OMMS-NG) the sailor describes the location of the discrepancy. The maintenance item is then analyzed and screened by a second party, civilian or sailor, who reads the description and finds the physical location of the maintenance that needs to be performed. The maintenance item description and its location must be properly described for the second party to be able to accurately interpret and identify the work to be done. The control group in this experiment represented the second party of the current shipboard process. The research team served as the maintenance item originating party who wrote the description of the item. Shown below are two images, a screenshot from an example maintenance item or Job Sequence Number (JSN) found in OMMS-NG (Figure 18) and the research team created maintenance item location description of an item within the experiment (Figure 19). These experimental item location descriptions were written IAW NAVSEAINST 4790 Ship's Maintenance and Material Management Manual to replicate of a JSN or Work Order on a U.S. Navy ship. The research team created maintenance item has significantly less information than the JSN shown below; this was because this experiment only focused on subjects' ability to find a maintenance item and not to correct it.

The highlighted red boxes on this example work candidate represent where maintenance item location information can be placed.

Figure 18. Example Work Candidate

Find the Following Items: Item Name: Classroom Thermostat Location Description: This classroom thermostat is approximately 3" by 2" in size. Located on the left bulkhead of the classroom upon entry and near the secondary exit of the space. It is labeled "VAV-203".

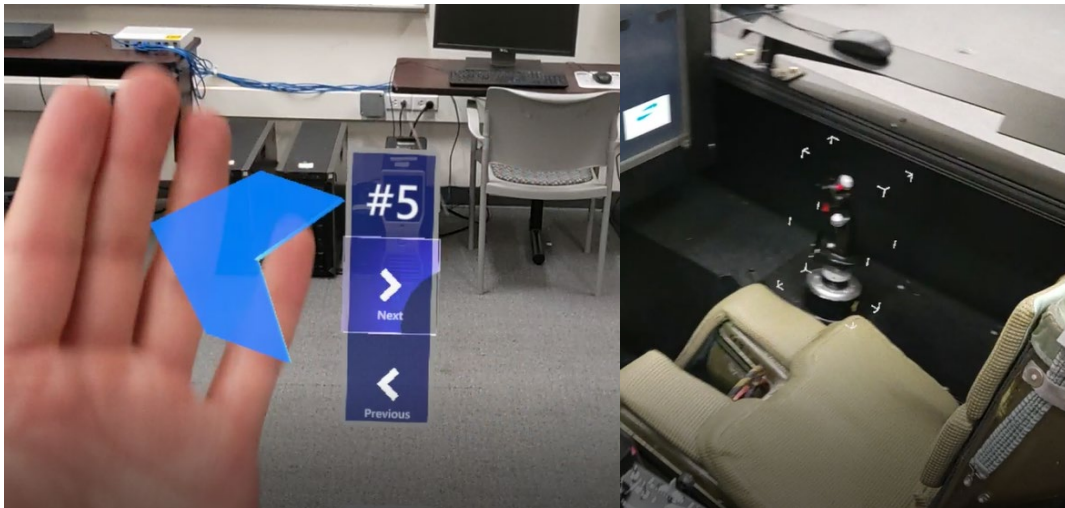
Figure 19. Control Group Item Information Given

The AR group did not require any maintenance item descriptions. The only maintenance item information given to them by the research team was the item nomenclature with no amplifying information (Figure 20).

Find the Following Items: <u>Item 1:</u> Classroom Thermostat
--

Figure 20. Experimental Group Item Information Given

Without any written item location descriptions, the AR group used the AR headset to assist them in identifying the same items as the control group. The headset provided them with blue directional arrows and highlight the desired item in a white 3-dimensional reticle (see Figure 21). Both groups had the same objective of identifying the same components within each of the two spaces. Each subject will identify 22 items in all, 10 items within the least complex space (classroom) and 12 items within the most complex space (lab). One subject completed the experiment at a time. The provided maintenance item descriptions for the control and experimental group can be found in Appendix C and D, respectively.



Above are two screenshots of the point of view that the subject of the experimental group will see. Directional arrows to guide the subject to the object and white 3D reticle to highlight the item to be found.

Figure 21. Experimental Group AR Point-of-View

Each item to be found within the space had a component ID number. These ID numbers range from 0–999 and were hand-written on yellow stickers on or directly next to the item to be found. All component ID numbers were 3-digits (ex. 27 would be 027). The numbers on each sticker were created using =RANDBETWEEN(), a random number generator function within MS Excel. Stickers were also placed on incorrect items that appear similar or in the same relative area of the item to be found, an example of this is shown in Figure

22. All component ID numbers for the correct items to be found within each room were annotated by the research team.



Although only one item is correct above, the component ID (yellow sticker) will signify the subject's accuracy in identifying the correct item by their capability in locating the correct component ID Number. The correct item is highlighted in blue.

Figure 22. Component ID Numbers

Component ID numbers contributed to the recording of two of three outcome variables: time to taken to identify each item (recorded in seconds), and subjects' accuracy in identifying the correct item (correct/incorrect). The third outcome measure is subject's self-reported level of confidence that they correctly identified the item. Subjects could report one of three levels of confidence for a given item: low confidence, medium confidence, or high confidence. All three outcome variables were collected by a recorder who was a member of the research team. This recorder accompanied the subject throughout testing. During testing, the subject provides all the information the recorder needs vocally. Once the experiment was completed the recorder input all measurements for each item into a spreadsheet for later analysis.

3. Surveys

a. *Demographic Survey*

Prior to experiment start, each subject completed a demographic survey (see Appendix E Demographic Survey). The demographic survey consisted of 10 questions.

The survey was used to document each subject's age, gender, military experience, military maintenance experience, AR experience and other related information. The data collected from the Demographic survey would help our research team to describe the demographic characteristics of the sample and determine if there was any correlation between any of the questions asked and the subject's performance.

b. Post task Survey

The post-task survey was specific to the subject's testing group. Both versions of the survey collected information from the subjects such as how difficult it was to complete the tasks and why. The AR group post task survey inputs would help our research team understand their reaction in using the AR headset to complete the tasks, (see Appendix F Post-Task Survey).

4. Hardware

The Microsoft HoloLens 2 was chosen as the hardware to be utilized for the AR headset throughout this experiment. This headset was used because of its intuitive use and easy integration with Unity coding language. Another benefactor of the selection of the HoloLens 2 was their availability. The NPS MOVES department owns several of these headsets for research and educational purposes, with this study only requiring one for experimental testing, the availability of this headset was of no concern.



Figure 23. Microsoft HoloLens 2. Source: Microsoft (2020).

5. Software

The NPS Future Tech Team received funding to produce an application using UNITY coding language that would allow the research to create and view persistent tags of locations in 3D space using the HoloLens 2. These tags were in the shape of a transparent cube as shown in Figure 20. This Future Tech application also allowed the researcher to tailor each cube to the size of the physical object being tagged, as well as adjust the position and rotation of the cube in 3D space to better “fit” the item being tagged.

B. PROCEDURES

The main focus of this study was to understand the potential benefits of AR technology for shipboard maintenance with particular focus on locating shipboard items, work candidates, Job Sequence Numbers (JSNs) etc. The total time to complete the experiment for one subject was approximately 60 to 85 minutes. The structure and order of subsequent tasks within the experiment and the data collected are outlined below.

1. Pre-experiment

Before beginning, each subject would answer COVID symptom and risk related questions to ensure their safety and the safety of the research team. Then they would be provided the time to review and sign the NPS institutional review board (IRB) approved consent form (see Appendix G Standard Experiment Consent Form). Upon providing informed consent, the subject would complete the demographic survey. The amount of time taken to complete the COVID questions, consent form and demographic survey was approximately 15 minutes.

At the conclusion of the demographic survey, the subject was given a brief introduction of what will be required of them and on what they will be assessed throughout the experiment. Once the subject understood what was required of them throughout the experiment, the subject participated in an undocumented trial run in which they practiced identifying three items throughout a room separate from the experimental rooms. All subjects, regardless of testing group, identified the same items within this room and had

the opportunity to ask questions or request clarification regarding their task. The introduction and trial run took approximately 20 minutes per subject.

After the completing the pre-experiment requirements each subject was assigned a Subject ID number. This Subject ID number was a three-digit number, with the first digit either being a one or two (example: 112 or 205). The first digit represented the subject's group: "1" for control group and "2" for experimental group. This Subject ID Number would accompany the subject throughout all their required tasks (consent form, surveys, and experimental testing).

2. AR Environment Training

If the subject was a part of the AR group, they participated in AR environment training. This training is an introduction to the use of the AR headset within this experiment and took approximately 20 minutes. The introduction was provided by the research team and gave the subject an opportunity to get comfortable with the headset. This AR training taught the experimental group subjects how to follow the visual cues the headset provided and how to use the headset to find each item. Once the AR introduction was completed, the subject would then complete the trial run explained in the previous section. In the unlikely event that any of the subjects experienced any type of nausea or discomfort from the AR headset during this training, training paused and the subject would have the opportunity to quit the experiment or participate as a subject in the control group.

3. Main Experiment

As discussed in the Study Design (Section A.2) of this chapter, each subject was required to identify 22 components, 10 in the least complex space (classroom) and 12 in the more complex space (lab). All subjects completed the tasks within the classroom first, followed by the lab. Dependent on the subject's testing group they used their given information (JSN type information for the control group, brief description for the AR group) to identify each item correctly and efficiently. The sequence of how each subject identifies each item throughout the experiment is as follows:

1. Subject, depending on which testing group, either reads item location description or follows AR visual cues to determine item location

2. Once subject believes they have found the item, they will vocally announce the associated component ID Number. When this number is vocalized by the subject, the recorder will record the time split and component ID number for that item.
3. After the subject identified the Component ID Number, the subject will then vocally announce their level of confidence in their ability to find the item with one of the following options: “Low,” “Medium,” or “High.” The recorder will annotate the subject confidence level associated with the item.
4. After the subject has identified the component ID number and expressed their confidence level they will continue onto the next item.
5. Once the subject has identified all items within the compartment, the overall run time will be stopped. The subject and recorder will then move onto the next testing room if applicable.

If the subject had any questions regarding the item description or AR related questions, time was not be stopped and their question counted towards their time searching for the item.

4. Post-experiment

Once the subject has completed the experiment and found all items in each room, they completed the post-task survey. The completion of this survey took approximately 5 minutes. After the completion of the post-task survey and a debrief, the experiment would end. Subjects who participated in the control group were given the opportunity to try the AR headset during their debrief.

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V. RESULTS AND ANALYSIS

A. HYPOTHESES RESTATED

The following hypotheses originally stated in Chapter I Section D, will be tested throughout this chapter. Each hypothesis tests the performance of the control and experimental groups in three areas: time, accuracy, and subject confidence levels.

1. Hypothesis 1

Null Hypothesis H_{10} : There is no difference in mean time to identify maintenance items between the AR group and the control group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$

Alternative Hypothesis H_{1A} : On average, the control group takes longer to identify maintenance items compared to the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} > 0$.

2. Hypothesis 2

Null Hypothesis H_{20} : There is no difference in mean accuracy in identifying maintenance items between the AR group and the control group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$.

Alternative Hypothesis H_{2A} : The control group has a lower mean accuracy in identifying maintenance items than the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} < 0$

3. Hypothesis 3

Null Hypothesis H_{30} : There is no difference in mean confidence rating in identifying the correct maintenance item between the control group and AR group, $\mu_{\text{control}} - \mu_{\text{AR}} = 0$.

Alternative Hypothesis H_{3A} : The control group has lower mean confidence ratings in identifying the correct maintenance items than the AR group, $\mu_{\text{control}} - \mu_{\text{AR}} < 0$.

B. VERIFYING ASSUMPTIONS

Before conducting statistical analysis, we checked the assumptions of a two-sample t-test for analyses comparing control and AR group differences for time and accuracy.:

- The data values are independent. The performance for any one subject does not depend on the performance for another subject.
- We assume the subjects participating represent a random sample from the population of the Naval Postgraduate School.
- We assume the data are normally distributed.
- The measurements are continuous.

After plotting a histogram for time and accuracy, the data was determined to not be normally distributed and therefore a two-sample t-test was not the appropriate method to evaluate the hypotheses. These plots can be found in Appendix H. With non-normal data, a Wilcoxon Ranked Sums Test was chosen to compare the two groups for time and accuracy. The third measurement of the analysis, the subject's confidence levels in their ability to find the object, was completed using the chi-squared test of homogeneity due to the categorical nature of the data set.

Finally, to determine if complexity of the room impacted any of the outcome variables, multiple regression was conducted for these outcome variables. The predictors are the level of room complexity (less complex or more complex), guidance method represented by the subject's group (Control or AR), and the interaction between these two predictors. For all analyses, an alpha level of .05 was utilized.

C. SUBJECT DEMOGRAPHICS

Table 11 shows the demographic results across both groups (AR and Control). A total of 24 subjects completed the experiment, with all subjects being active-duty U.S. military members from the Naval Postgraduate School. Only two females volunteered to participate in the experiment resulting in such a low percentage for both. Table 11 also shows the distribution of subject experience in virtual environments, military maintenance, and experience in identifying maintenance components. The distribution between the two groups is relatively equal. Although there were more subjects in the AR group with virtual

reality experience, this difference was not statistically significant ($\chi^2(1) = 1.527$, $p = 0.2165$).

Table 11. Experimental Subject Demographics

		Control	AR
Age	Min	27	25
	Mean	30.25	31.9
	Max	39	44
Sex (%)	Male	92%	92%
	Female	8%	8%
Dominant Hand (%)	Left	8%	17%
	Right	92%	83%
Branch of Service (%)	USA	0%	17%
	USAF	0%	0%
	USMC	8%	8%
	USN	92%	75%
Years of Active Duty Service	Min	4.5	3.5
	Mean	7.8	9.5
	Max	16.25	17
Highest Rank (%)	O3	75%	67%
	O4	25%	17%
	O5	0%	8%
Job required to ID maintenance items (%)	Yes	83%	58%
	No	17%	42%
Years involved with military maintenance	Min	0	0
	Mean	5.1	5.4
	Max	12	17
Experienced Virtual Environment (%)	Yes	42%	67%
	No	58%	33%

With all subjects active-duty military, it also is important to understand their military backgrounds to see if different service members perform better or worse than others. Out of all 24 subjects, there were eight military occupations represented. Figure 24 shows the distribution of active-duty military occupations throughout the control and AR

groups. The AR group had the most diversity, with at least one subject representing each military occupation. Half of the control group consisted of SWOs, and lacked the diversity compared to the AR group. This SWO majority is the reason behind the notable difference of “Job required to ID maintenance items” between the control and AR group. The control group of this experiment represented the current shipboard process, to which the SWOs were accustomed, a possible advantage. This potential advantage was of no concern, because if it could be shown that the AR group could outperform an experienced SWO majority control group, it would only emphasize the efficiency of AR technology in locating shipboard items.

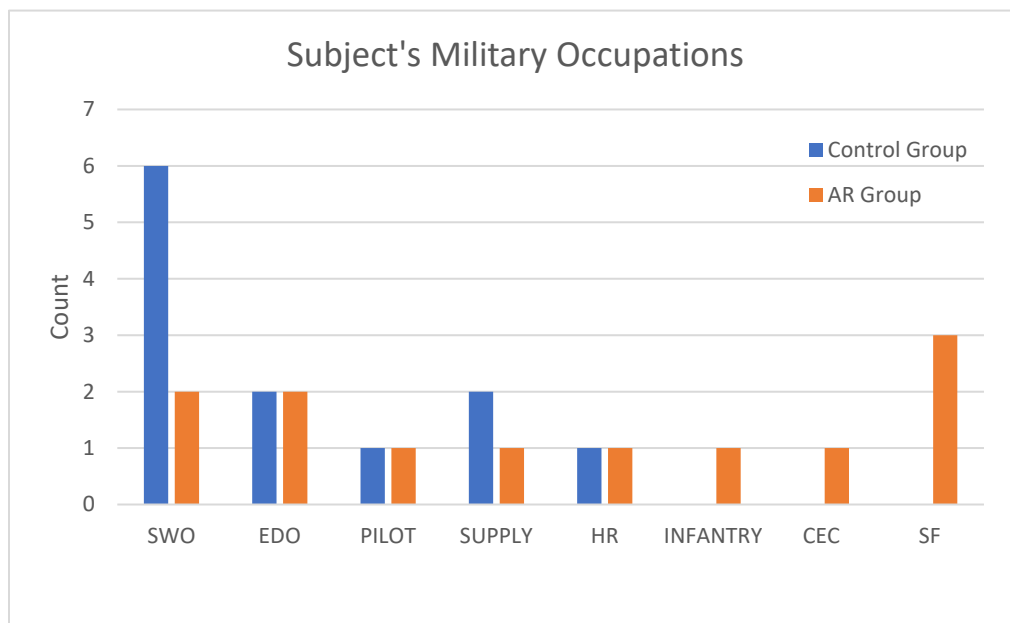


Figure 24. Subject’s Military Occupations for the Control and AR Groups

D. ANALYSIS

1. Time

Analysis was conducted to determine the difference between the control and AR groups performance in terms of time. Overall completion times were first examined. For the less complex space, the overall completion time differences were significant with a

percent difference in mean completion time of 81.64%. When comparing Max and Mins between the two groups within the less complex space, the Min of the Control group was still greater than the Max of the AR group as shown in Table 12. For the more complex space, the overall completion time difference was significant with a percent difference in mean completion time of 103.24%. When comparing the AR group's mean overall completion time between the two spaces there was only a difference of 21.72 seconds, a percent difference of 18.23%.

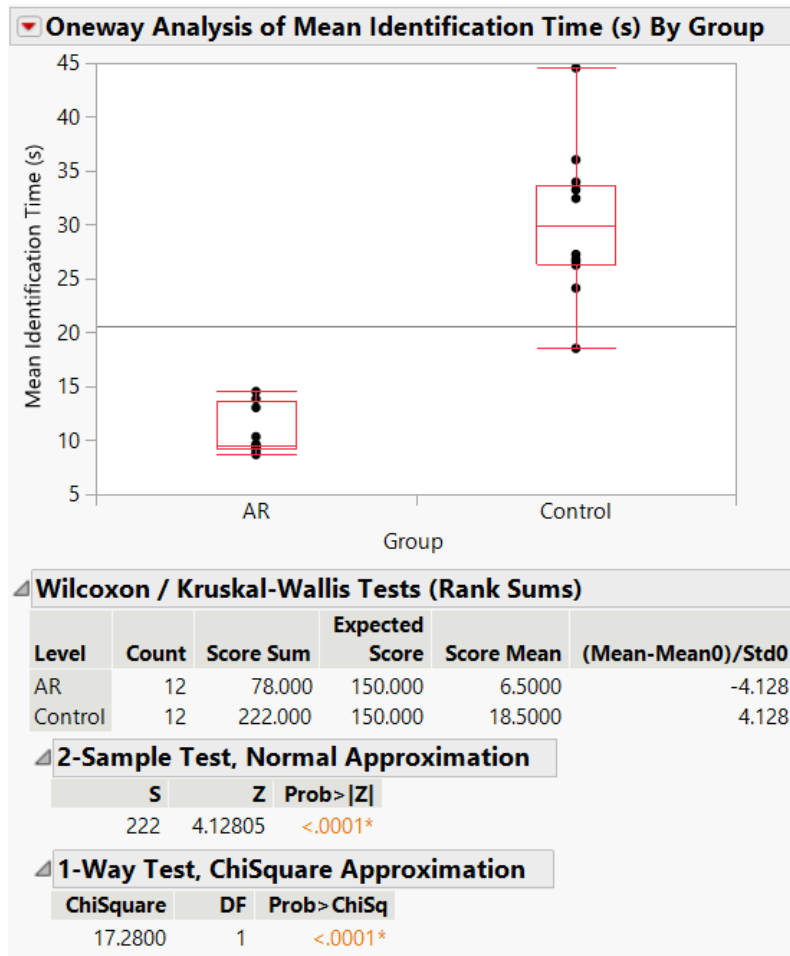
Table 12. Less Complex Space Overall Completion Times

Overall Completion Time			
Less Complex Space (mm:ss)			
	Mean	Max	Min
Control	04:17.2	06:03.0	03:15.1
AR	01:48.3	02:31.6	01:16.3

Table 13. More Complex Space Overall Completion Times

Overall Completion Time			
More Complex Space (mm:ss)			
	Mean	Max	Min
Control	06:47.4	10:16.1	03:31.3
AR	02:10.0	02:52.9	01:39.4

Statistically, the Wilcoxon non-parametric test was used to determine if there was a difference in the time to identify maintenance items between the AR and control group. The time data consisted of the mean item identification time of each subject across both spaces. This mean identification time is the average amount of time the subject took to identify an item, whether it was in the less or more complex space. The output from JMP PRO is shown in Figure 25.



Testing Null Hypothesis H_{10}

Figure 25. JMP PRO Output for Wilcoxon Test

From the above JMP PRO output, The control group took significantly longer, on average, to find items ($Z = 4.12805$, $p < 0.0001$).

Next, a regression was run to determine the impact that room complexity and the subject's guidance method (control or AR) had on item identification time. A significant interaction effect was found, such that room complexity made no difference in item identification time for the AR group, but the control group was significantly slower in average item identification time in the more complex room than the less complex room (see Figure 26).

Summary of Fit

RSquare	0.363808
RSquare Adj	0.360166
Root Mean Square Error	13.42592
Mean of Response	20.52227
Observations (or Sum Wgts)	528

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	54013.65	18004.5	99.8836
Error	524	94453.79	180.3	Prob > F
C. Total	527	148467.44		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	20.335149	0.586718	34.66	<.0001*
Room[Least Complex]*Group[AR]	2.0557326	0.586718	3.50	0.0005*
Room[Least Complex]	-2.058358	0.586718	-3.51	0.0005*
Group[AR]	-9.503608	0.586718	-16.20	<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Room*Group	1	1	2212.906	12.2765	0.0005*
Room	1	1	2218.561	12.3079	0.0005*
Group	1	1	47294.081	262.3727	<.0001*

Tukey HSD All Pairwise Comparisons

Quantile = 2.57734, Adjusted DF = 524.0, Adjustment = Tukey-Kramer

All Pairwise Differences

Room	Group	-Room	-Group	Difference	Std Error	t Ratio	Prob> t	Lower 95%	Upper 95%
Least Complex	AR	Least Complex	Control	-14.8957	1.733279	-8.59	<.0001*	-19.3630	-10.4285
Least Complex	AR	Most Complex	AR	-0.0052	1.659488	-0.00	1.0000	-4.2823	4.2718
Least Complex	AR	Most Complex	Control	-23.1239	1.659488	-13.93	<.0001*	-27.4010	-18.8469
Least Complex	Control	Most Complex	AR	14.8905	1.659488	8.97	<.0001*	10.6134	19.1676
Least Complex	Control	Most Complex	Control	-8.2282	1.659488	-4.96	<.0001*	-12.5052	-3.9511
Most Complex	AR	Most Complex	Control	-23.1187	1.582260	-14.61	<.0001*	-27.1967	-19.0407

Multiple Predictor Regression was used to analyze the impact of room complexity and guidance method on time.

Figure 26. Multiple Predictor Regression (Time)

From the output shown above in Figure 4, the control groups identification times were negatively impacted by the increase in space complexity (Difference = -8.2282 sec, $p < 0.0001$).

Further analysis was conducted to demonstrate the differences of mean identification times for each item of the control and AR group. When comparing the mean item identification time of the control group ($\bar{x}_C = 00:26$) to the AR group ($\bar{x}_{AR} = 00:11$) there existed a 57.69% decrease in time from control group to the AR group. Referencing Figure 27, one item was identified faster by the control group than the AR group.

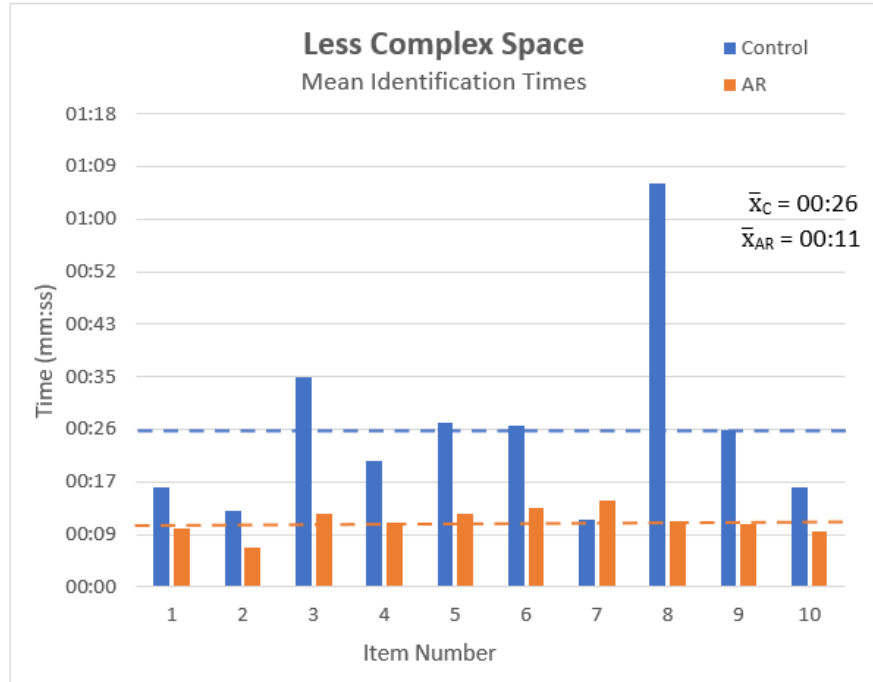


Figure 27. Less Complex Space Mean Identification Times

Table 14. Less Complex Space Item Numbers

Less Complex Space Items	
1	Thermostat
2	Light Switch
3	Overhead Sprinkler
4	Projector Up/Down Switch
5	Fire Alarm
6	Wall Panel
7	Computer Monitor
8	Ceiling Tile
9	Presentation Speaker
10	Floor Outlet

This item was a computer monitor within the classroom. As shown in Figure 28 there was more variability in identification time within the AR group than control group.

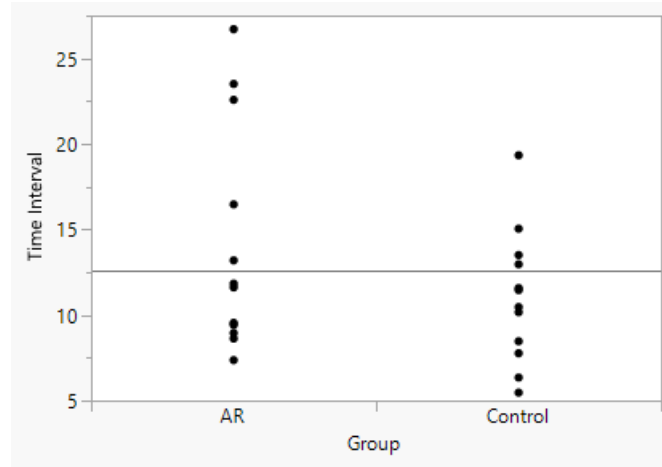


Figure 28. Time Intervals of Item 7 (Computer Monitor)

The differences in mean identification times for the 12 items in the more complex space were more pronounced between the two groups when compared to the mean identification times for the 10 items in the less complex space as shown in Figure 29. When comparing the mean identification time of the control group ($\bar{x}_c = 00:34$) to the AR group ($\bar{x}_{AR} = 00:11$) there existed a 67.64% decrease in time from control group to the AR group. Space complexity did not affect the performance of the AR group, which maintained the same mean identification time of each item regardless the complexity of the space.

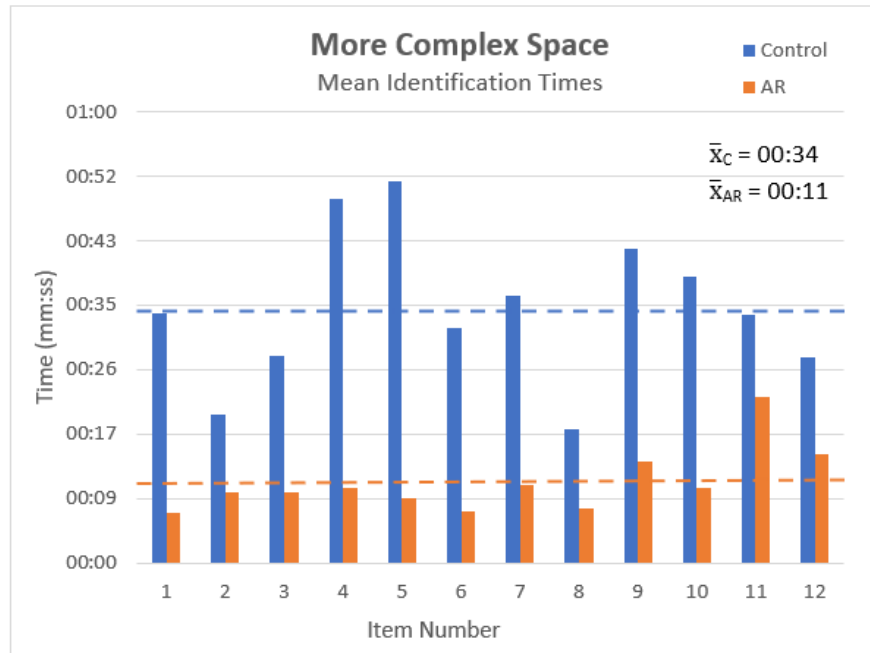


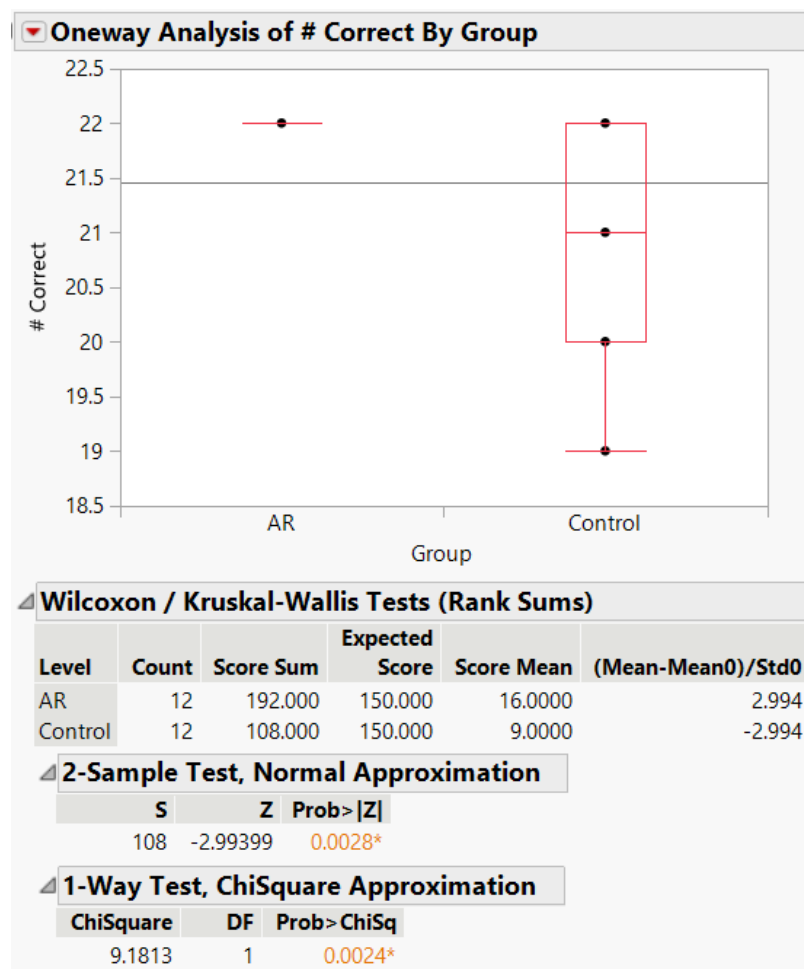
Figure 29. More Complex Space Mean Identification Times

Table 15. More Complex Space Item Numbers

More Complex Space Items	
1	Overhead Junction Box
2	Flight Simulator Joystick
3	Overhead Sprinkler
4	Fan Coil Assembly
5	Damper Solenoid
6	Large Computer Monitor
7	Wall Outlet
8	Power Panel
9	HTG Hot Water Return Piping
10	Floor Stain
11	Toolbox Drawer
12	Flight Simulator TV Monitor

2. Accuracy

The Wilcoxon non-parametric test also was used to statistically determine if there was a difference in the accuracy in identifying maintenance items between the AR and control group. A subject's accuracy was assessed on their ability to identify the correct component ID number that correlated to the item to be found. Therefore, accuracy was measured by the total number of items identified correctly (“# Correct”) by all subjects. The output from JMP PRO is shown in Figure 30.



Testing null hypothesis H_{20}

Figure 30. JMP PRO Output for Wilcoxon Test

Results shown in Figure 30 indicate that the control group has a significantly lower mean accuracy in identifying maintenance items than the AR group ($Z = -2.99, p = 0.0028$).

To determine the impact that room complexity and the subject's guidance method (control or AR) had on accuracy a multiple regression model was created in JMP PRO. The output of this regression model is shown in Figure 31.

Summary of Fit

RSquare	0.067314
RSquare Adj	0.061974
Root Mean Square Error	0.150231
Mean of Response	0.975379
Observations (or Sum Wgts)	528

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.853535	0.284512	12.6061
Error	524	11.826389	0.022569	Prob > F
C. Total	527	12.679924		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.9774306	0.006565	148.88	<.0001*
Room[Least Complex]*Group[AR]	-0.022569	0.006565	-3.44	0.0006*
Room[Least Complex]	0.0225694	0.006565	3.44	0.0006*
Group[AR]	0.0225694	0.006565	3.44	0.0006*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Room*Group	1	1	0.26672980	11.8182	0.0006*
Room	1	1	0.26672980	11.8182	0.0006*
Group	1	1	0.26672980	11.8182	0.0006*

Tukey HSD All Pairwise Comparisons

Quantile = 2.57734, Adjusted DF = 524.0, Adjustment = Tukey-Kramer

All Pairwise Differences

Room	Group	-Room	-Group	Difference	Std Error	t Ratio	Prob> t	Lower 95%	Upper 95%
Least Complex	AR	Least Complex	Control	0.000000	0.0193948	0.00	1.0000	-0.049987	0.0499869
Least Complex	AR	Most Complex	AR	-4.44e-16	0.0185691	-0.00	1.0000	-0.047859	0.0478588
Least Complex	AR	Most Complex	Control	0.090278	0.0185691	4.86	<.0001*	0.042419	0.1381366
Least Complex	Control	Most Complex	AR	-4.44e-16	0.0185691	-0.00	1.0000	-0.047859	0.0478588
Least Complex	Control	Most Complex	Control	0.090278	0.0185691	4.86	<.0001*	0.042419	0.1381366
Most Complex	AR	Most Complex	Control	0.090278	0.0177049	5.10	<.0001*	0.044646	0.1359093

Multiple predictor regression to analyze the impact of room complexity and guidance method on accuracy.

Figure 31. Multiple Predictor Regression (Accuracy)

Results from the “Tukey HSD All Pairwise Comparisons” section of the output above along with Tables 16 and 17 illustrate the space complexity by group interaction effect on accuracy. The AR group’s accuracy was unaffected by space complexity, with 100% accuracy in both spaces. In contrast, the control group’s accuracy decreased from 100% in the less complex space to an average of 90% in the more complex space.

Table 16. Accuracy of Control and AR Groups in Less Complex Space

	LESS COMPLEX SPACE		
	Identified Correctly (max = 120)	Identified Incorrectly	% Correct
Control	120	0	100%
AR	120	0	100%

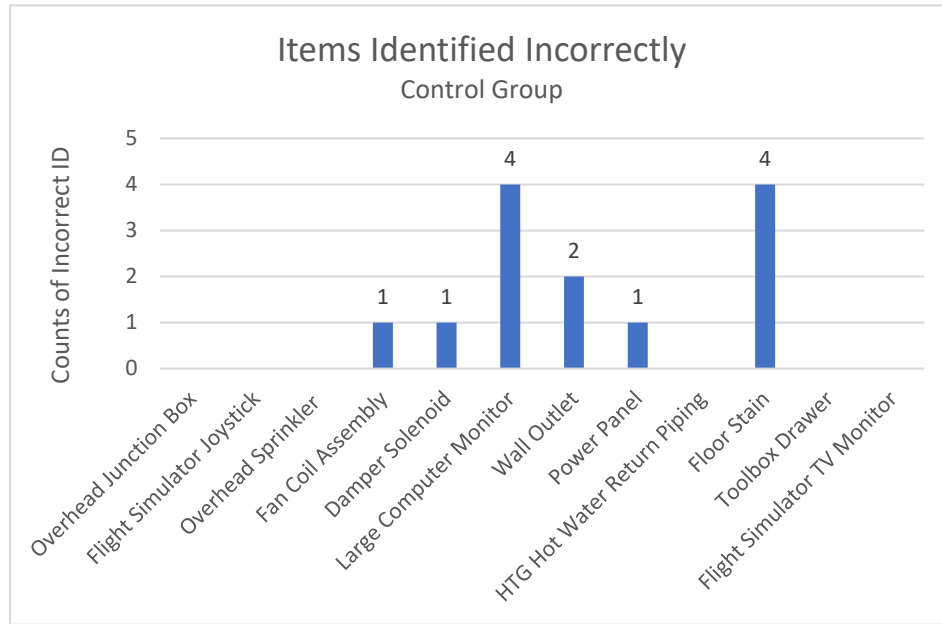
The less complex space had a total of 10 items, and therefore 120 items were identified by each group.

Table 17. Accuracy of Control and AR Groups in More Complex Space

	MORE COMPLEX SPACE			
	Identified Correctly (max = 144)	Identified Incorrectly	# of Subjects that were inaccurate	% Correct
Control	131	13	7	90%
AR	144	0	0	100%

The more complex space had a total of 12 items, and therefore 144 items were identified by each group.

In further examination of errors made in the more complex space, six of the 12 items were identified incorrectly. As shown in Figure 32, two items accounted for more than half of the incorrectly identified items: Large Computer Monitor and Floor Stain.



The only items identified incorrectly were within the more complex space. The control group was the sole contribute to incorrectly identified items.

Figure 32. Items Identified Incorrectly

Exploratory analysis also was conducted to determine if a certain demographic of the control group was the source of incorrectly identified items. Figure 33 shows the amount of incorrectly identified items by each of the military occupations within the control group. The SWO's contributed to the majority of the incorrectly identified items throughout the complex room.

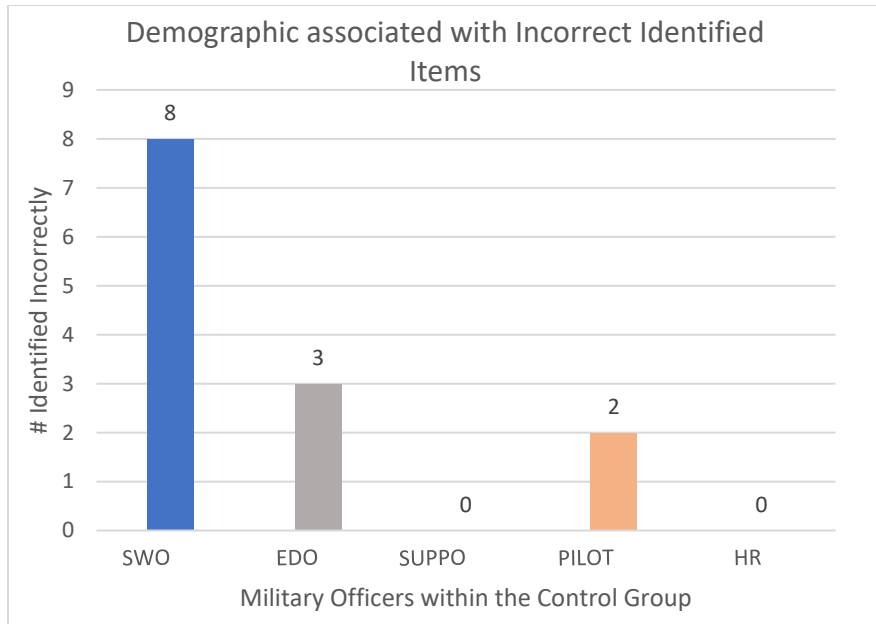


Figure 33. Control Group Demographics and Associated Accuracy

3. Confidence

Subject's confidence levels represented their confidence in their ability to identify the correct item. These levels were either High (H), Medium (M) or Low (L). Table 18 shows the frequency of these confidence levels across the control and AR group.

Table 18. Confidence Level Frequencies

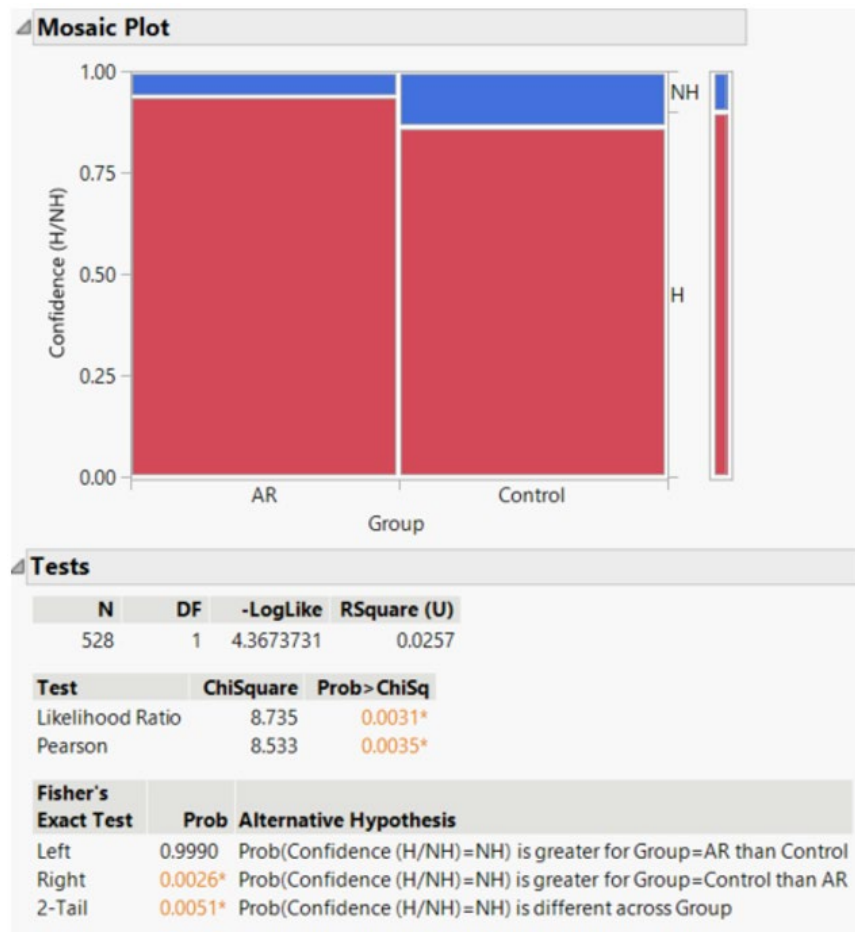
Confidence Level	Frequency		Sum
	Control	AR	
H	228	248	476
M	27	14	41
L	9	2	11

Frequency of High (H), Medium (M) and Low (L) confidence levels of subjects throughout the entire experiment. The total number of items identified by both the Control and AR group was 528.

In comparing the two groups, the Control group provided 69% of the confidence levels that were other than High, and 91% of the total “Low” confidence levels. To test the third hypothesis statistically, a Chi-squared test of homogeneity was conducted. With less

than “5” occurrences of low confidence for the AR group, the frequency table was modified to two levels of confidence: High (H) and Not High (NH).

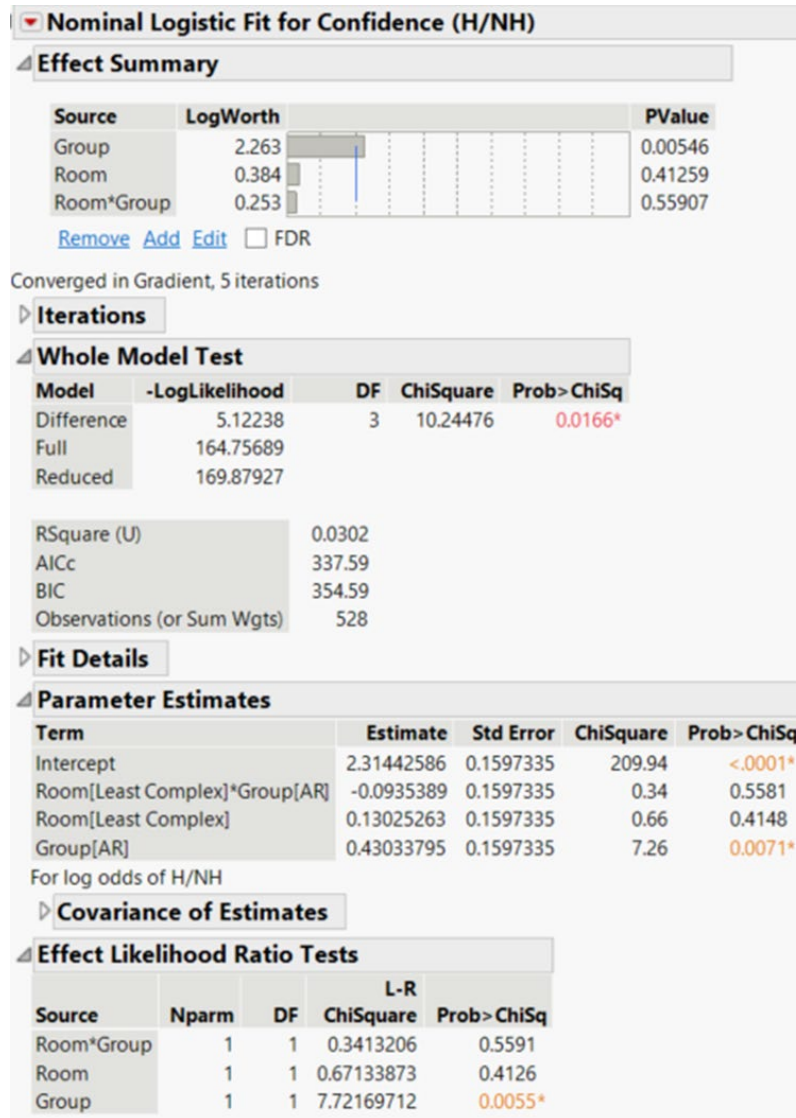
The Mosaic Plot (Figure 34) is a visual representation of these two variables and shows the contingent distributions of one variable at a particular level of the other. Results demonstrate that the Control group reported having high confidence on significantly fewer items than the AR group (that $\chi^2(1) = 8.375$, $p = 0.0031$).



This Chi-squared output shows the significance of subject confidence levels between the control and AR group.

Figure 34. JMP PRO Chi-squared Output

A logistic regression was conducted to determine the impact that room complexity, the subject's guidance method (control or AR), and their interaction had on confidence. The output of this nominal logistic regression model is shown in the Figure 35.



Multiple predictor regression to analyze the impact of room complexity and guidance method on a subject's confidence.

Figure 35. Multiple Predictor Regression (Confidence)

Examining the regression output shown in Figure 35 above, neither the room complexity nor the room*group interaction had a significant impact on confidence ratings.

To ascertain that subjects' subjective ratings of confidence were consistent with their performance, I examined whether higher confidence ratings were associated with faster identification times and greater accuracy. To determine if there was a significant relationship between confidence and time a Wilcoxon test was conducted for each group because the two groups significantly differed on all three outcome measures. The output for these Wilcoxon tests is shown in Figure 36 and 37.

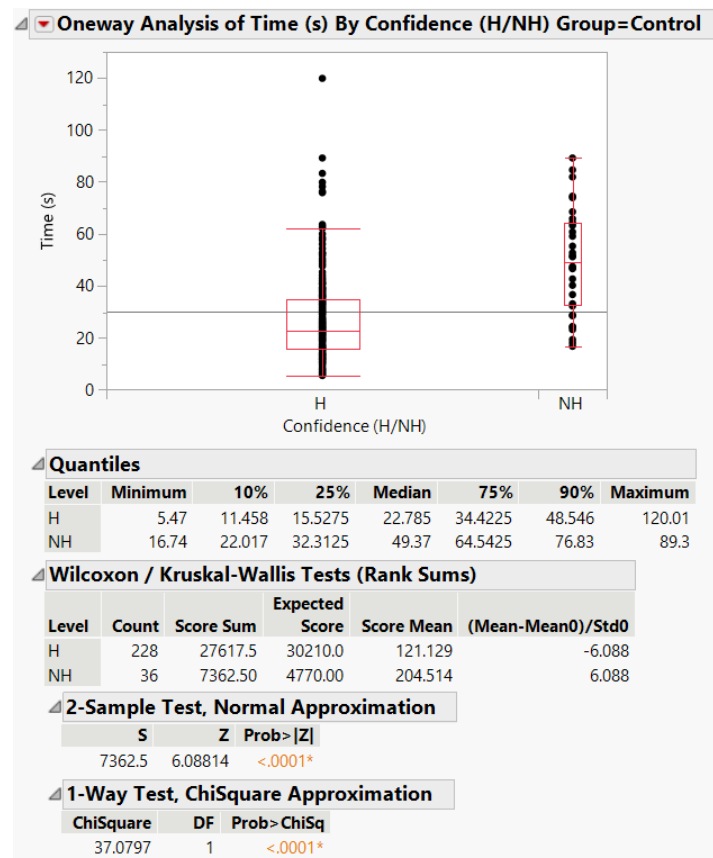


Figure 36. Statistical Significance between Time and Confidence (Control)

The above Wilcoxon test, states that there is a significant association between a control group subject's confidence and their performance in time ($Z = 6.088$, $p < 0.0001$). This output shows that higher confidence is associated with faster item identification times than not high confidence.

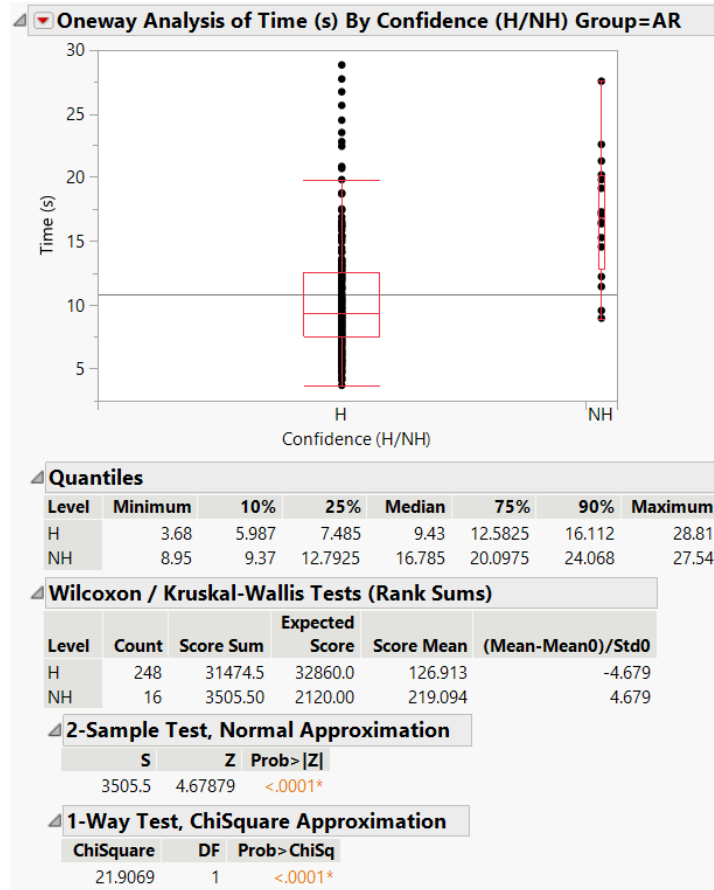


Figure 37. Statistical Significance between Time and Confidence (AR)

The above Wilcoxon test, states that there is a significant association between an AR group subject's confidence and their performance in time ($Z = 4.678$, $p < 0.0001$). The AR group also demonstrated that higher confidence is associated with faster identification times.

The next statistical test conducted for this exploratory analysis was a Chi-squared test which tested the significance of a subject's confidence level on their accuracy. The accuracy data for this test was binary: 1 = identified correctly, 0 = identified incorrectly. Since there was no variability in accuracy within the AR group, this Chi-squared test was only conducted on the control group. The output for the Chi-squared test, testing the significance between accuracy and confidence is shown in Figure 38.

Tests			
N	DF	-LogLike	RSquare (U)
528	1	3.9117920	0.0641
Test	ChiSquare	Prob>ChiSq	
Likelihood Ratio	7.824	0.0052*	
Pearson	12.290	0.0005*	

Figure 38. Statistical Significance between Accuracy and Confidence (Control)

For the control group, the relationship between a subject's confidence and accuracy is significant ($\chi^2(1) = 7.824$, $p = 0.0052$). This significance demonstrates that with higher confidence the more likely the subject identified the item accurately. However, in this exploratory analysis it was determined that items were still incorrectly identified even when the subject's confidence level was high (see Table 19). Out of the total 13 items identified incorrectly, 61.5% had associated confidence levels of high.

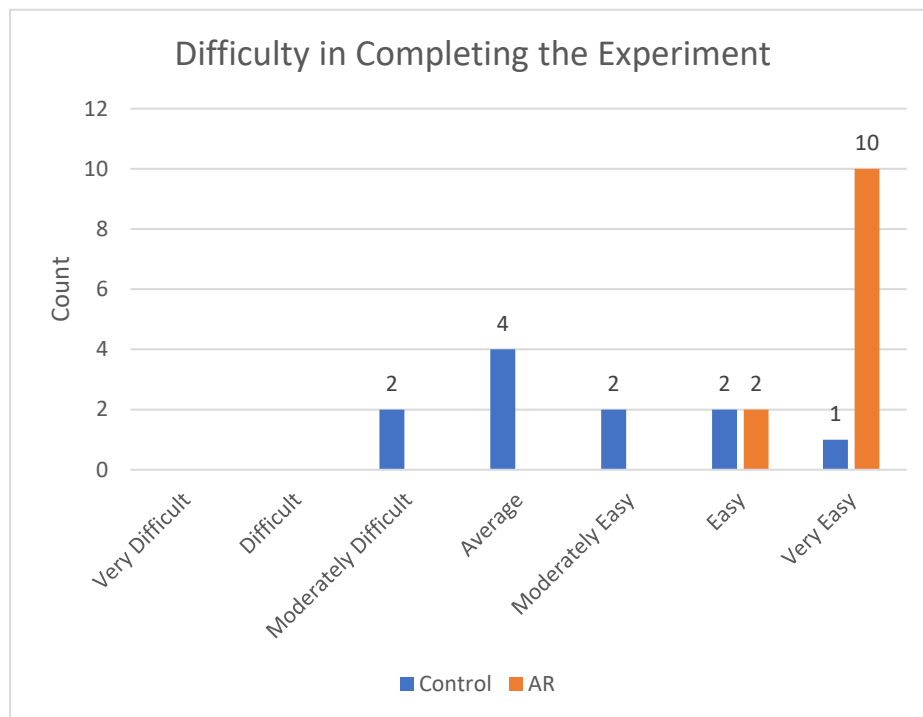
Table 19. Confidence Levels Associated with Inaccuracies

Associated Confidence Level with Incorrect Items	
Confidence Level	# of Incorrect Items
High	8
Medium	2
Low	3

In sum, the exploratory analysis found that there existed a statistically significant relationship between a subject's confidence level and their identification time performance for both groups. The control group also demonstrated a significant relationship between their confidence levels and accuracy.

E. POST-TASK SURVEY ANALYSIS

The post-task survey was distributed to identify how difficult the task was for all subjects. The survey also gave the subjects the opportunity to express what they may have found particularly difficult throughout the experiment. Figure 39 represents extracted data from the post-task surveys of how difficult the overall experiment was for the control and AR groups.



At the conclusion of the experiment all subjects rated their experienced difficulty by selecting Likert Scale responses.

Figure 39. Difficulty in Completing the Experiment

The AR group was the most efficient across the three measurements of time, accuracy and subject's confidence levels as proven in the previous analysis sections. Due to AR's efficient performance, it is of no surprise that the subjects within the AR group thought the experiment was "Easy" or "Very Easy." There existed 6 subjects within the control group that felt like the experiment difficulty was anything other than a degree of easy. To understand the source of the potential difficulty experienced by the control group

the survey next asked how difficult it was for these subjects to understand the location descriptions, these results are pictured in the Figure 40.

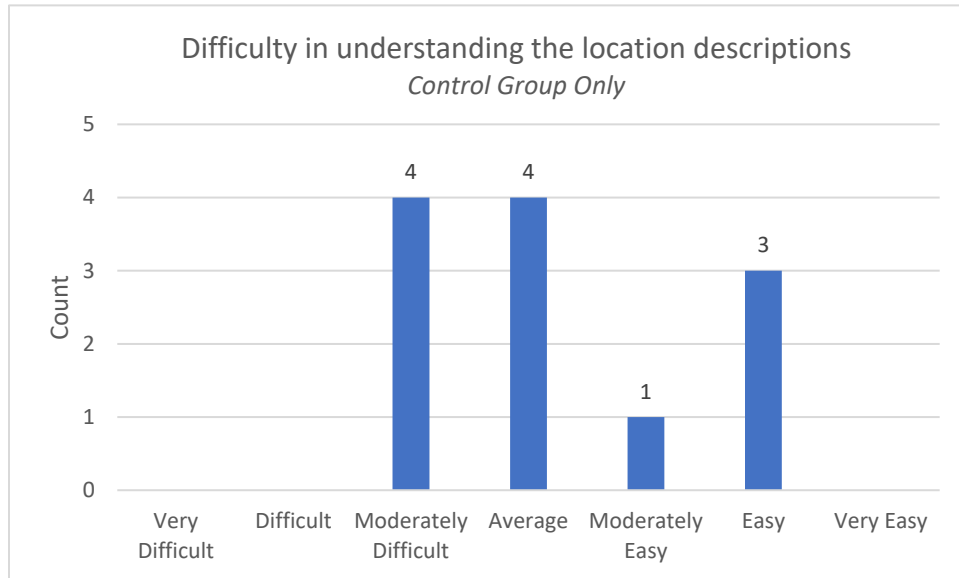


Figure 40. Control Subjects Expressed Difficulty with Location Descriptions

A total of two thirds of the control group found the location descriptions at least average in difficulty. Of the four subjects that found it moderately difficult they expanded on why they experienced difficulty through additional statements:

“The location descriptions became difficult, especially when there existed multiple items similar to the item being found.”

“The location descriptions are subjective to the writer’s perception of the space.”

“After I found each item, I was disoriented about what part of the room was the front or back when reading the item location descriptions.”

“Some descriptions can be subjective or easily miss-interpreted. I experienced difficulty whenever there were multiple items of the same type, or I was required to count from a certain point to find the item.”

These comments emphasize the ambiguity of the current process, and how easily a misinterpretation of a maintenance item can occur even if the description of a maintenance item is written in accordance with the appropriate references.

The subjects from both groups also annotated which items were the most difficult to find as shown in Figure 41. For the least complex space, the majority of the control group selected the Ceiling Tile within the least complex space. The difficulty experienced in identifying the ceiling tile is also recognizable through the measurements of time and accuracy. The control group had the greatest mean identification time for the ceiling tile as shown earlier in Figure 5. The difficulty of the ceiling tile also influenced the confidence levels of the control group: three subjects assessed their confidence level as low and six subjects assessed their confidence as medium. This item experienced the greatest decrease in confidence of the control group across both spaces. The most difficult item for the AR group, as expressed by almost half of the group, was the computer monitor.

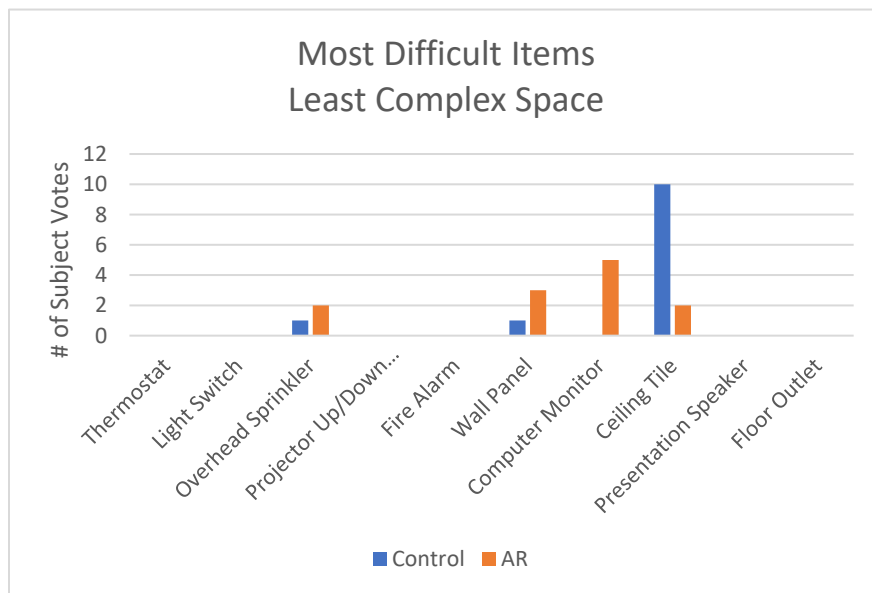


Figure 41. Most Difficult Items in Less Complex Space

For the most complex space, the majority of the control group expressed their difficulty in identifying the Floor Stain and the majority of the AR group expressed their difficulty in identifying the Toolbox Drawer (Figure 42).

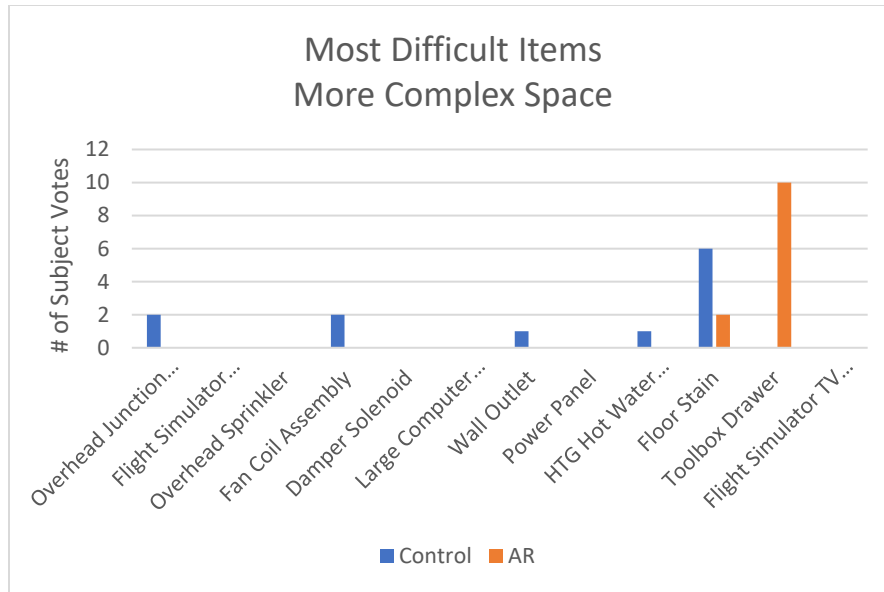


Figure 42. Most Difficult Items in More Complex Space

The expressed difficulty with the Toolbox Drawer for AR group was also reflected in the performance of the AR group's identification time and confidence. The mean identification time of the toolbox drawer for AR group was the greatest across all 12 items which can be shown in Figure 8. Of the 12 AR subjects, four of them assessed their confidence in identifying this item correctly as "medium." These four confidence assessments consisted of 25% of the amount of confidence levels other than "high" within the AR group throughout the whole experiment. The Figure 43 is a point-of-view perspective of the Toolbox Drawer from the AR headset. The item is low and close to ground and the virtual box identifying the item appears off-center. The virtual image is off-center because of the vantage point of the subject. From my observations while recording, there were several instances throughout the experiment when the AR subject had to get low to the ground to bring themselves eye-level to confidently identify the correct toolbox drawer. These observations suggested that with the HoloLens 2, items may slightly move around and appear at slightly different positions depending on the user's vantage point.



These images are an example of the point-of-view perspective that a AR group subject would have of the toolbox drawer. The image on the left is the point-of-view when not at eye-level of the item. The image on the right is the point-of-view when the user is centered and at approximate eye level of the item.

Figure 43. AR Point-of-View Image for Toolbox Drawer

There were also questions within the post-task survey specifically for the AR group, asking if the virtual images were clear and if they experienced any discomfort. All 12 AR subjects stated they could see all virtual images clearly and experienced no discomfort throughout the experiment.

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VI. DISCUSSION

This chapter expands on the results found in the analysis and exploratory analysis of the three experimental measurements of time, accuracy and the subject's confidence levels.

A. TIME

On average, the AR group outperformed the control group in overall completion time for each space as shown in Figure 44.

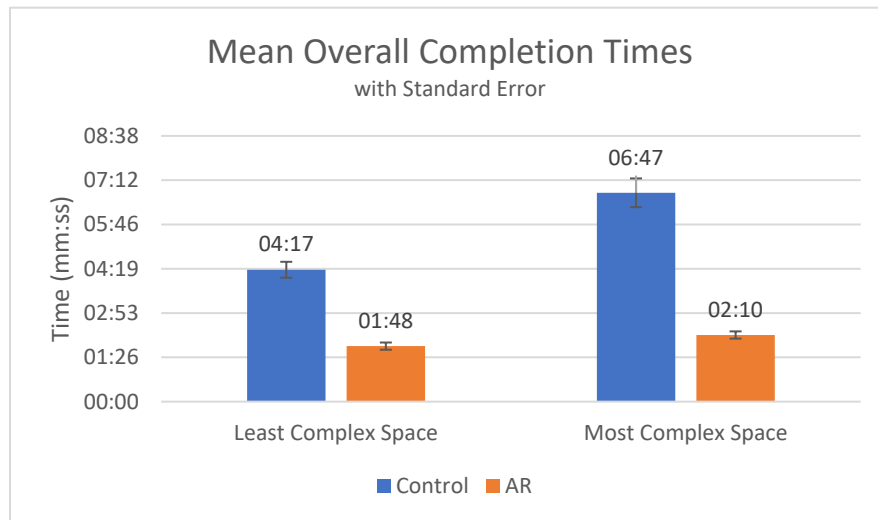
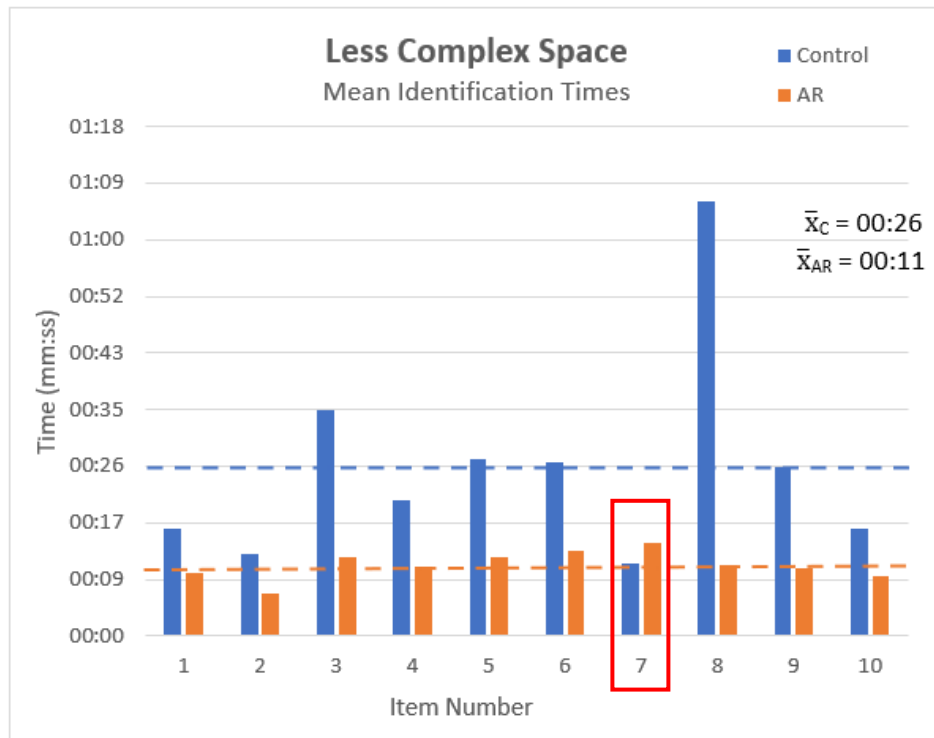


Figure 44. AR and Control Group Overall Mean Completion Times

The significant difference in completion time between the two groups can be related to differences in cognitive load and general work required to identify each item between the two groups. The control group had to read the written location description of each item, recognize their surroundings and then make an informed decision based on their interpretation of the description. Comparatively, the AR group simply had to follow the AR guided cues to identify the object. The identification time results indicate that if there is less work required to identify an item, it will take less time to locate and identify the item. On average, this statement proved to be true, with one exception. This exception was

the mean identification time of Item 7 (Computer Monitor). Item 7 was within the less complex space where the mean identification time for the AR group was slower than the control group (see Figure 45).



In the less complex space, the AR group outperformed the control group for all items with the exception of Item 7 (Computer Monitor).

Figure 45. Less Complex Mean Identification Times

Within the less complex space (classroom) there existed only one computer monitor (Item 7). For the control group it did not take them much time to decipher the written description and identify the sole monitor within the space. The AR group seemed to struggle with the identification of this sole monitor most likely due to the placement of the virtual box containing it shown in Figure 46. With several other component ID numbers within close proximity of the computer monitor, and the monitor not fully encompassed within the virtual box, the slow identification time shown by the AR group was most likely due to subject's hesitation and lack of confidence.



The top two images show two different points-of-view of the virtual box identifying the computer monitor while using the Microsoft HoloLens 2. The bottom image shows the space from the starting location of all subjects, highlighting the location of the computer monitor within the space.

Figure 46. AR Point-of-View of Computer Monitor in Less Complex Space

In terms of time, an increase in space complexity adversely affected the control group. However, regardless of an increased level of complexity, the AR group's time results showed minimal impact (see Table 19). When assessing the mean identification times, the average time required for a subject to identify the item, the control group experienced an increase of 30.77% from the less to more complex space. The AR group experienced no increase in mean identification time as the space complexity increased,

indicating that space complexity has no impact on performance in terms of time. As complexity increases within the space, an AR group subject is not distracted by the increase of items or size of the space because they can simply follow the AR guidance cues to identify each object.

Table 20. Mean Identification Time for Items

Mean Identification Time (mm:ss)		
	Less Complex Space	More Complex Space
Control	00:26	00:34
AR	00:11	00:11

This table shows the average amount of time it took each group to identify one item within each space.

B. ACCURACY

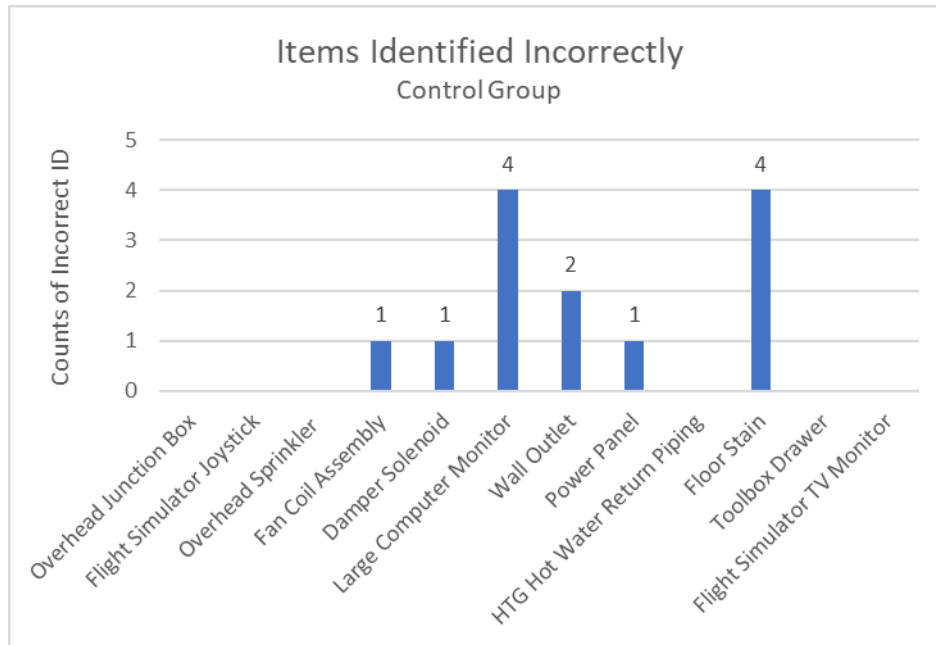
The AR group outperformed the control group in terms of accuracy in both the less and more complex spaces. Both groups were 100% accurate in the less complex space. The difference in accuracy performance between groups was evident in the more complex space where the control group accounted for all 13 inaccuracies as shown in Table 20. The AR group's perfect accuracy throughout the experiment indicates that space complexity has no effect on identification accuracy when using AR technology.

Table 21. Control and AR Group's Accuracy Performance

	MORE COMPLEX SPACE			
	Identified Correctly	Identified Incorrectly	# of Subjects that were inaccurate	% Correct
Control	131	13	7	90%
AR	144	0	0	100%

Of the 12 items within the more complex space, six items were the source of the 13 occasions of inaccuracy demonstrated by the control group. Two items within the more

complex space accounted for more than half of the inaccuracies: “Large Computer Monitor” and “Floor Stain,” as shown in Figure 47.



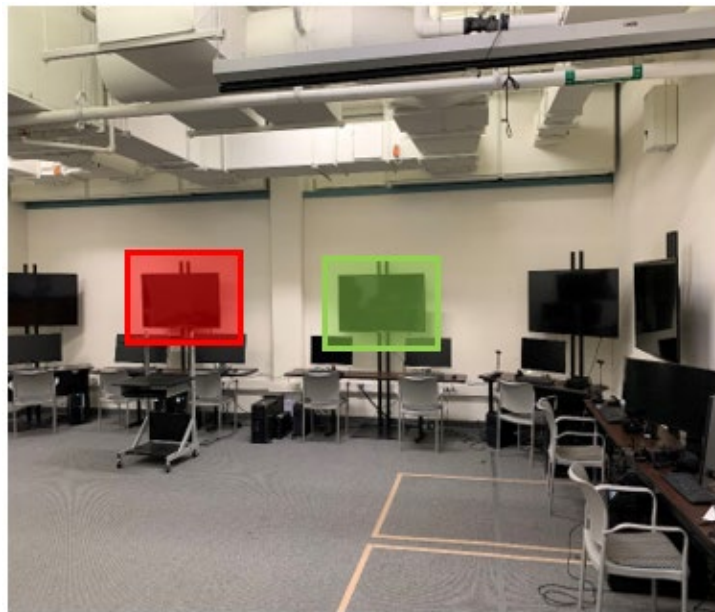
The control group only identified items incorrectly in the more complex space. This figure only shows items within the more complex space.

Figure 47. Items Identified Incorrectly by the Control Group

When collecting the accuracy data from the subject throughout the experiment, the component ID number that the subject believes is associated with the correct item is recorded. This component ID allowed us to not only determine if the subject *is* correct but also in the event that they were wrong, to determine what they *believed* was the correct item. The “Large Computer Monitor” and “Floor Stain” items were both one of many of the same type of item throughout the complex space. The Large Computer Monitor, even though a large 42” screen, was one of 12 within the space. Figure 48 shows the correct Large Computer Monitor outlined in green along with the incorrect monitor identified on all four occasions outlined in red. The provided written location description of this Large Computer Monitor was as follows:

Description: This large computer monitor is located at one of the workspaces towards the back wall of this space. This monitor is elevated above the workspace. Counting these elevated monitors from right to left within the space it is third.

Based on the provided description and the known wrong identified item, I conjecture that because the statement mentions the “back wall” of the space, the subjects assumed that when counting from right to left, the counting would start on the right side of the back wall.



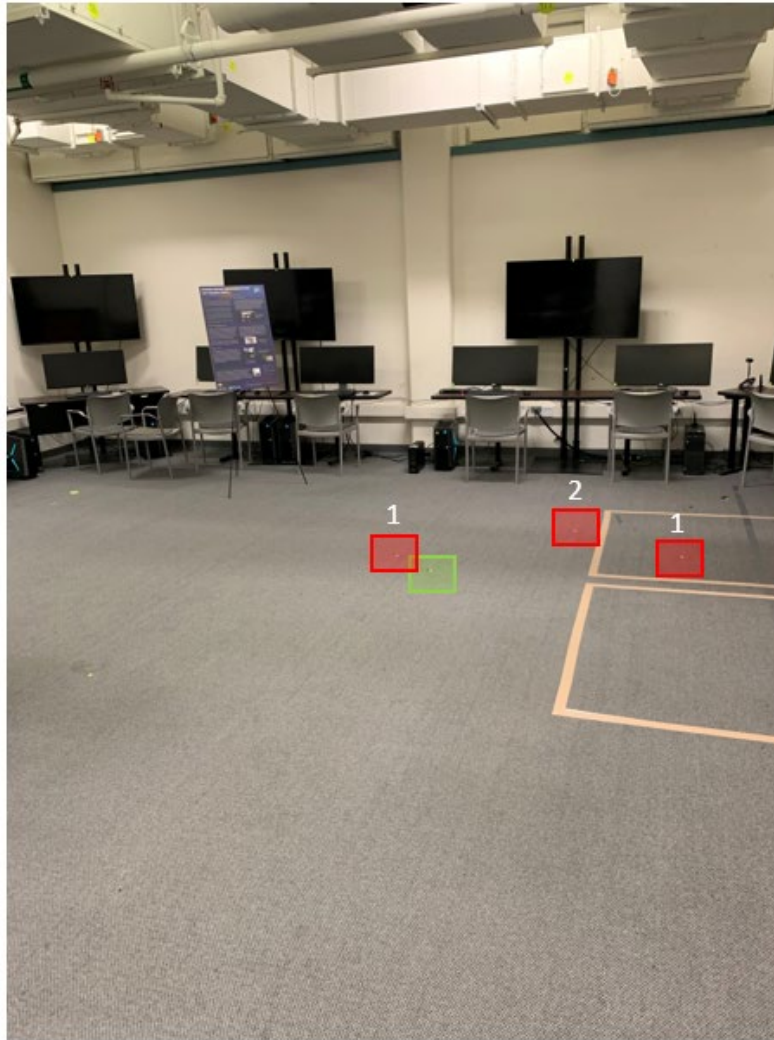
The “Large Computer Monitor” item is shown above in green. Of the 12 control subjects, four of them selected the incorrect monitor outlined in red.

Figure 48. Control Group Inaccuracy Occurrences for the Large Computer Monitor

The next trouble item was the “Floor Stain” within the space. As a carpeted space, floor stains were numerous. Identifying this floor stain was intended to be difficult, with multiple other stains within its proximity. The provided written location description of the correct floor stain was as follows:

Description: This floor stain is one of many within the space but located approximately in the center of the space. It is approximately the diameter of a quarter. To locate this stain, it is approximately 12 paces or 10 yds when walking directly into the space. It is black in color.

This item was incorrectly identified four times by the control group, identifying other floor stains within the vicinity of the correct one. One floor stain was incorrectly selected twice as shown in Figure 49; the red boxes signify the wrong items identified and their accompanying numbers were the number of times they were identified. The inaccuracy of the control group with this item shows that it is difficult to identify an item correctly if there are multiple items like it within the same area as well as having the same shape and or size.



Green box signifies the correct floor stain to be identified. The red boxes signify incorrect selections of other floor stains throughout the space.

Figure 49. Control Group Inaccuracy Occurrences for the Floor Stain

These inaccuracies demonstrated by the control group show that subject's accuracy is compromised when the item to be found is of the same shape, size, color, and in the same vicinity. These items can be representative of components within a complex shipboard space such as an engine room where multiple valves, pipes, power panels, etc., may all be within the same vicinity. These inaccuracies also show the lack of accuracy that the current process can elicit due to the ambiguity of the interpretation of the written location descriptions for the desired maintenance item.

Of these 13 inaccuracies throughout the more complex space, SWO's were responsible for 61.5% of them. Of the six SWO's within the control group, they accounted for 25.5 years of experience involved in military maintenance which made them the most military maintenance experienced demographic throughout the control group. Although this group had the most military maintenance experience, four of six SWO's identified items incorrectly. This result shows that regardless of the amount of maintenance experience a person has, they are still capable of inaccurately identifying maintenance items through the current process and contributing to the problem of which this thesis is focused.

C. SUBJECT'S CONFIDENCE

The theme of AR's best performance continued with the experimental measurement of the subject's confidence level in identifying the items correctly. Although both groups had subjects that experienced confidence levels other than high, the control group was the largest contributor. Table 22 shows the distribution of confidence levels throughout the experiment.

Table 22. Confidence Level Frequencies throughout the Experiment

Confidence Level	Frequency		Sum
	Control	AR	
H	228	248	476
M	27	14	41
L	9	2	11

As shown in the results, regardless of their group, confidence levels that were other than high were statistically significant regarding their identification times. These "low" and "medium" confidence levels were measurements that could have represented a subject's hesitation during identification, causing slower identification times. For the control group, the source of these not high confidence levels could have been from their difficulty experienced in reading the written location descriptions, interpreting them as intended. For the AR group, these confidence levels may have been from occasions where the virtual

reticle was off-center or did not fully encompass the item to be identified. These virtual images may have been the source for the lack of confidence from the AR group. However, it's important to note that they were also the contributors of why AR subject's showed higher confidence levels than the control group. With these images, there is little reason to doubt what the item to be identified is with each item highlighted by a virtual 3D box and if was out of sight virtual arrows directed the subject to its location.

Of the 264 total items identified by the 12 individuals in the AR group throughout the experiment, 94.7% of the items were identified with a high confidence level. Comparatively, the control group identified 86.4% of the items with a high confidence level. Within the control groups recorded high confidence levels there were eight occurrences where the item was identified incorrectly. Even though a small percentage, 3.5%, of the items identified with high confidence were incorrect it is important to understand the potential impact that this relatively small value could have on the current problem. If the maintenance item is identified incorrectly by the repair party who believes it to be correct, then the potential for re-work and its negative contributions of schedule delays and cost growth add to the current problem of new work.

VII. CONCLUSION

A. LIMITATIONS

1. Subject Group

All volunteers were part of the Naval Postgraduate School population and were all active duty graduate students. This research focused on the capability gap between ship's force and repair party personnel and the ability of the repair party personnel to identify maintenance items to be repaired. During these maintenance periods these repair party personnel can vary from civilian contractors to navy repair personnel. This experiment's subject population was not a direct representation of the personnel who would benefit from the use of AR during these maintenance periods.

2. Sample Size

The study was impacted by the COVID-19 pandemic. Volunteers were difficult to obtain to conduct the research, leading to the minimum possible sample size of 24 subjects.

3. Location/Complexity

This research focused on AR's potential capability of locating shipboard items. Due to travel restrictions and COVID-19 exposure concerns, the experiment chose two Naval Postgraduate School rooms to represent shipboard compartments. The experiment's testing locations were not shipboard compartments and did not have the same level of complexity.

B. FUTURE WORK

This research determined AR's potential benefits for shipboard maintenance. All future work related to this research should expand and ensure that testing is as close to a direct representation of the current shipboard process as possible. The following list has areas of expansion to make the experiment as close to the current process as possible:

- Expand the sample size and sample types. How do civilians, in particular civilian maintenance contractors, perform with AR? Does AR's positive

impact on maintenance item identification hold true for personnel that have no maintenance experience?

- Conduct in a more complex environment. Use an actual ship, such as the Self Defense Test Ship in Port Hueneme, Ca, so that the complexity of the experiment is a direct representation of a shipboard space.
- Focus more on the importance of identification of maintenance items. Further work can determine the compounding negative effects of incorrect identification. This could be done by adding a sequence of maintenance tasks associated with the identification of a maintenance item.
- Determine a threshold. This research did not determine a threshold for which AR proved ineffective or showed no improvement over the measurements collected in this experiment. A threshold for AR's efficiency benefits could be ascertained through iterations of increased complexity.
- Determine if there is a relationship between a subject's confidence and their identification mistakes. Further testing could be conducted to determine a relationship such as if low confidence is correlated with incorrect decisions. This research did not provide enough information to draw any conclusions on this focus due to the amount of highly confident identified items. Future testing with this focus could develop an understanding of what maintenance items give subjects lower confidence values. These possible conclusions would give the U.S. Navy insights on what should be prioritized when using AR for identification purposes.
- Cost Simulation. A simulation study could be conducted to determine the benefits of AR for the big picture of maintenance periods to include cost and scheduling benefits.

C. IMPLICATIONS

The lack of efficiency in the identification of shipboard maintenance items is a contributing factor of the U.S. Navy's problem of new work. This new work is experienced during intensive maintenance periods at the intermediate and depot level and is the result of the current process' lack of efficiency. The inability of repair party personnel to identify shipboard maintenance items is a cause of this new work. This research focused on leveraging the proven benefits of AR technology demonstrated in the private sector to address this problem.

This thesis addressed the current process' lack of efficiency in maintenance item identification by comparing it to a process in which the individual was guided by AR. This comparison was conducted in two spaces, a less and more complex space. It was hypothesized that with AR technology, there would be a decrease in time required to identify objects, an increase in identification accuracy, and an increase in the subject's confidence in identifying the correct items. An experiment consisting of a random sample of 24 active-duty military subjects (12 control, 12 AR) showed that the use of AR was statistically more efficient in terms of time, accuracy and confidence. In terms of overall completion time, the AR notably outperformed the current process in both the less and more complex space with a percent difference of 81.64% and 103.24%, respectively. In terms of accuracy throughout testing, AR proved 100% accurate regardless of an increase in space complexity whereas the current process was 93.56% accurate. Of the items inaccurately identified by the current process, more than half of them were from active-duty Surface Warfare Officers involved in the experiment. These officers were the most familiar with the current process, and inadvertently demonstrated its ambiguity. AR's better performance also continued to show in the confidence of each subject, showing a high level of confidence 93.94% throughout the entire experiment compared to that of the current process having a high level of confidence of 85.6%. In conclusion, AR's ability to identify maintenance items within a space is more efficient, faster and more accurate.

Based on the GAO report GAO-20-370 new work comprised of approximately \$1.5B in repair from the years FY03 to FY15 (see Figure 2). Although it is unclear how much the inefficiencies in maintenance item identification contribute to new work, if it

accounted for only 2% of its total dollar amount in FY03-15 approximately \$30M could have been saved. With AR's proven successes in this research in terms of time and accuracy its long-term cost benefits would be invaluable.

APPENDIX A. ONLINE SURVEY

AGREEMENT OF CONSENT TO PARTICIPATE

Introduction. You are invited to participate in a research study entitled *AR Technology effect on efficiency of locating items throughout a compartment*. The purpose of the research is determine the Surface Navy's first practical use of Augmented Reality Technology.

- 1) Participation is voluntary
- 2) This survey will take approximately 5–10 minutes
- 3) The purpose of this research is determine the initial reaction of Surface Warfare Officers about the use of Augmented Reality technology for shipboard use, in specifically locating maintenance items throughout the ship.
- 4) This survey will help determine possible benefits of Augmented Reality for the Surface Navy's first practical use of this technology

Procedures. Answer the following questions to the best of your ability. There is no time limit. Completed surveys will be collected until maximum sample size is reached. Desired sample range is 10 to 50 completed surveys.

Location. This is an online survey and can be taken by using your PC, laptop, mobile phone or any online enabled device.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential. The research team will collect as many surveys as possible until maximum sample size is reached, no personal information will be associated with the answered questions.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, *Dr. Quinn Kennedy* mqkenned@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831–656-2473, lgshattu@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to

participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

- ☐ I consent to participate in the research (1)
 - ☐ I do not consent to participate in the research (2)
-

1) Where would you be on this scale?

- ☐ Just entered the service (1)
 - ☐ First Tour (2)
 - ☐ Second Tour (3)
 - ☐ Multiple Tours (4)
 - ☐ End of Career (5)
-

2) How many years of maintenance experience do you have total?

- ☐ < 3 years (1)
 - ☐ 3 - 6 years (2)
 - ☐ > 6 years (3)
-

3) How often during your time on-board was the identification of the maintenance or corrective maintenance repair not completed in a timely fashion?

- ☐ 0 times a month (1)
 - ☐ 1-3 times a month (2)
 - ☐ 4-7 times a month (3)
 - ☐ Greater than 7 times a month (4)
 - ☐ Not sure (5)
-

If your answer to the previous Question was anything greater than 0, do you have an example you would like to share?

- ☐ Yes (1) _____
 - ☐ No (2)
-

4) If AR technology was available to sailors, do you believe they would be more effective in identifying components throughout a ship's compartment: valve numbers, junction boxes, transformers, stocked inventory, maintenance items etc. ?

- ☐ Definitely yes (1)
 - ☐ Probably yes (2)
 - ☐ Might or might not (3)
 - ☐ Probably not (4)
 - ☐ Definitely not (5)
-

5) If anyone, who would benefit from this technology?

☐

Senior Leadership (XO, CO) (1)

☐

Khaki Leadership (CPO's, Junior Officers, Department Heads) (2)

☐

(3)

Enlisted Sailors (LPO's, Workcenter Supervisors, Maintenance Persons)

☐

Other (4) _____

☐

None (5)

6) Augmented Reality has shown proven benefits in the private industry such as increasing efficiency for GE Aviation mechanics. Do you believe this technology would increase a sailor's effectiveness?

☐

Definitely yes (14)

☐

Probably yes (15)

☐

Might or might not (16)

☐

Probably not (17)

☐

Definitely not (18)

7) If you answered the previous question with a degree of “yes,” how many hours a week would you estimate it would save?

- ☐ < 5 hours (1)
 - ☐ 6 -10 hours (2)
 - ☐ 10 - 15 hours (3)
 - ☐ > 15 hours (4)
 - ☐ Not Applicable (5)
-

8) What type of effect would the added AR capability of virtually tagging equipment, maintenance items, and repairs have on your Current Ship’s Maintenance Project (CSMP)?

- ☐ Increase the size of the CSMP (1)
 - ☐ CSMP size would stay the same (2)
 - ☐ Decrease the size of the CSMP (3)
-

9) Do you think with the addition of AR and its relationship with the CSMP, accountability in making sure these maintenance items are completed would be increased?

- ☐ Definitely yes (1)
 - ☐ Probably yes (2)
 - ☐ Might or might not (3)
 - ☐ Probably not (4)
 - ☐ Definitely not (5)
-

10) During your ship's Continuous Maintenance Availabilities (CMAV's) would you expect more or less work to be completed with the assistance of AR? Contracted workers or Navy Regional Maintenance personnel would be able to identify the repair required not solely based on a work order description but with the work order description and supplemental information supplied by the AR technology.

- ☐ Much more (1)
 - ☐ Moderately more (2)
 - ☐ Slightly more (3)
 - ☐ About the same (4)
 - ☐ Slightly less (5)
 - ☐ Moderately less (6)
 - ☐ Much less (7)
-

11) Does implementing AR technology give you any reason for concern? If so, please explain

- ☐ Definitely yes (1)
 - ☐ Probably yes (2)
 - ☐ Might or might not (3)
 - ☐ Probably not (4)
 - ☐ Definitely not (5)
 - ☐ If yes, please explain (not required): (6)
-

APPENDIX B. LIST OF MAINTENANCE ITEMS

A. LEAST COMPLEX SPACE



Item: Classroom Thermostat

Description: This classroom thermostat is approximately 3" by 2" in size. Located on the left bulkhead of the classroom upon entry and near the secondary exit of the space. It is labeled "VAV-203".

Assigned Component ID: 897



Item: Light switch

Description: This classroom light switch is located on the left bulkhead of the space upon entry. It is located above waist height near the secondary entrance of the space. It is off-white and is labelled "L-12".

Assigned Component ID: 907



Item: Overhead Sprinkler

Description: This overhead sprinkler is 1 of 6 located within the space. It is the middle of three sprinkler heads on the right-hand side of the space upon entry. It is located in the overhead and one ceiling tile forward and three ceiling tiles to the right of the space's projector.

Assigned Component ID: 961



Item: Project Screen Up and Down Switch

Description: This switch controls the up and down movement of the projector screen. It is located on the furthest bulkhead from the entry point of the space. Height on the wall is approximately 4 feet above the deck. This switch is black and is behind the instructor's desk.

Assigned Component ID: 439



Item: Fire Alarm

Description: This fire alarm is 1 of 1 located within the space. It has an orange covering and is approximately 7 feet above the deck. It is located on the bulkhead to the immediate right upon entering the space. On each side of this alarm the label "ALERT" can be seen.

Assigned Component ID: 781



Item: Wall Panel

Description: This wall panel is 1 of 8 located within the classroom. All wall panels make up the right bulkhead of this space. Upon entry of the space this panel is the third from the front side of the room.

Assigned Component ID: 264



Item: Computer Monitor

Description: This computer monitor is 1 of 1 located within the space. Located near the forward most bulkhead of the space on top of the instructor's desk. It is an all black "Dell" monitor.

Assigned Component ID: 921



Item: Ceiling Tile

Description: This ceiling tile is closest to the right bulkhead of the space. If counting the columns of ceiling tiles from the intersection of the right and rear bulkhead of the space this ceiling tile is three full columns to the right and 11 ceiling tiles towards the front of the space.

Assigned Component ID: 896



Item: Presentation Speaker

Description: This is 1 of 2 speakers located within the space. There are two speakers that located on the forward most bulkhead of the space. These speakers are above the projector screen. This speaker is the left speaker of the projector screen. It is white and JBL brand. There is a water stain located to the left of this speaker on a ceiling tile above it.

Assigned Component ID: 197

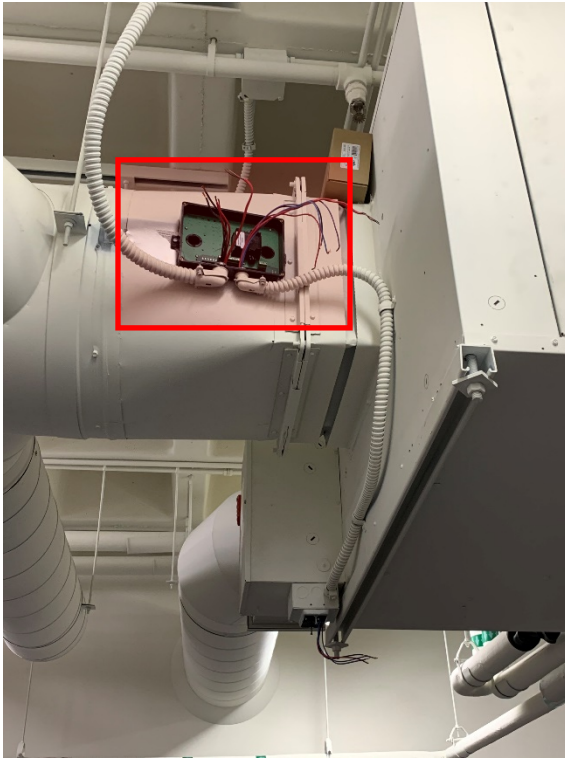


Item: Floor Outlet

Description: This is one of many floor outlets within this space. This floor outlet has a brass covering that covers 3 of 4 outlets. This outlet is located in front of the instructor's desk approximately 5 inches from the front end of its base.

Assigned Component ID: 862

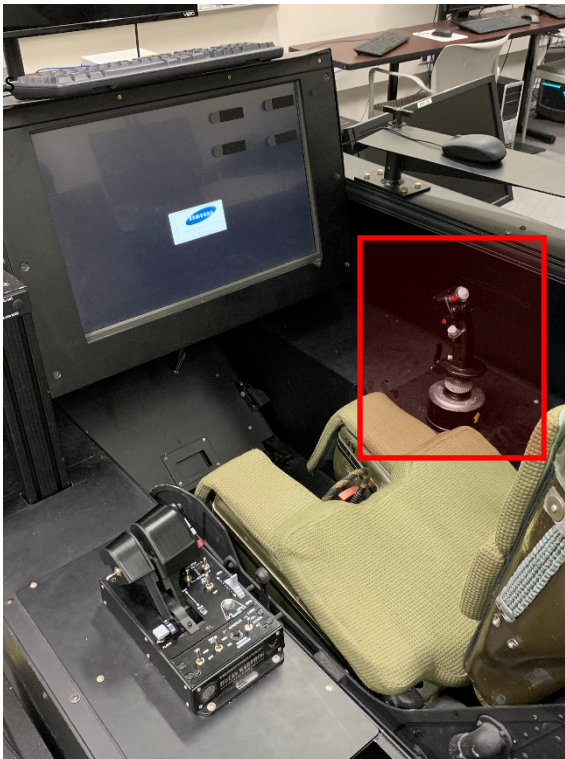
B. MOST COMPLEX SPACE



Item: Overhead Junction Box

Description: This exposed junction box is located in the overhead approximately in the center of the space. It is located on ventilation ducting and its cover faces the right bulkhead of the room. This junction box has exposed wires of red and blue colors, its sides are black and interior is dark green. It is approximately 6 inches by 3 inches and has two electric conduits that lead into the junction box.

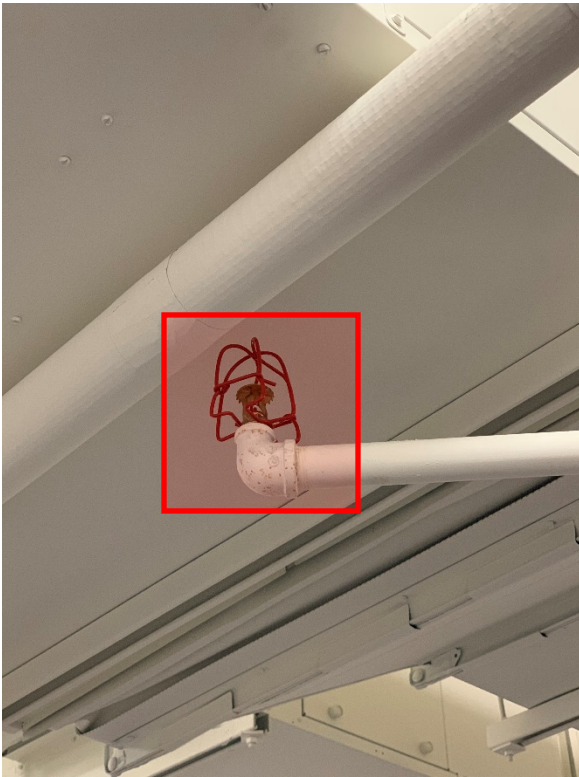
Assigned Component ID: 827



Item: Flight Simulator Joy Stick

Description: This joy-stick is a part of the flight simulator within the space. It's all black with buttons colored red. It's on the right hand side of the flight simulator, to the right of the pilot seat.

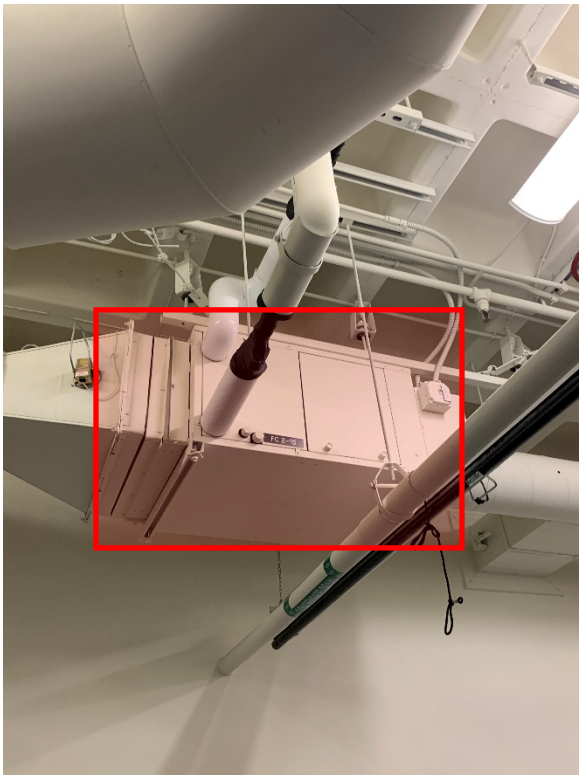
Assigned Component ID: 392



Item: Overhead sprinkler head

Description: This over-head sprinkler is located towards the middle of the space. It is located in the overhead and the lowest hanging of the others. It has a red colored wire guard encasing it. It is located under a large overhead air duct.

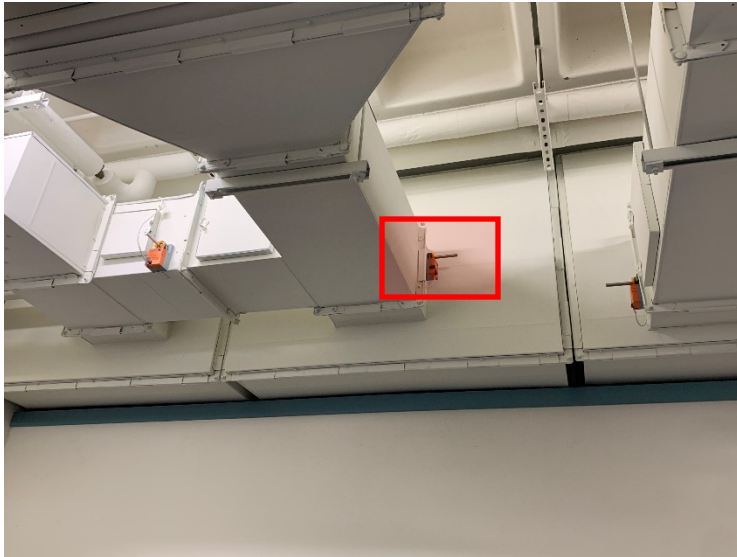
Assigned Component ID: 461



Item: Fan Coil Assembly

Description: This component is nearest the right-hand side of the space. It is located above the projector screen mount and approximately 1 foot above the "Condensate Drain" overhead piping. This Fan Coil Assembly is all white and rectangular in shape, it also has a black label "FC-2-15".

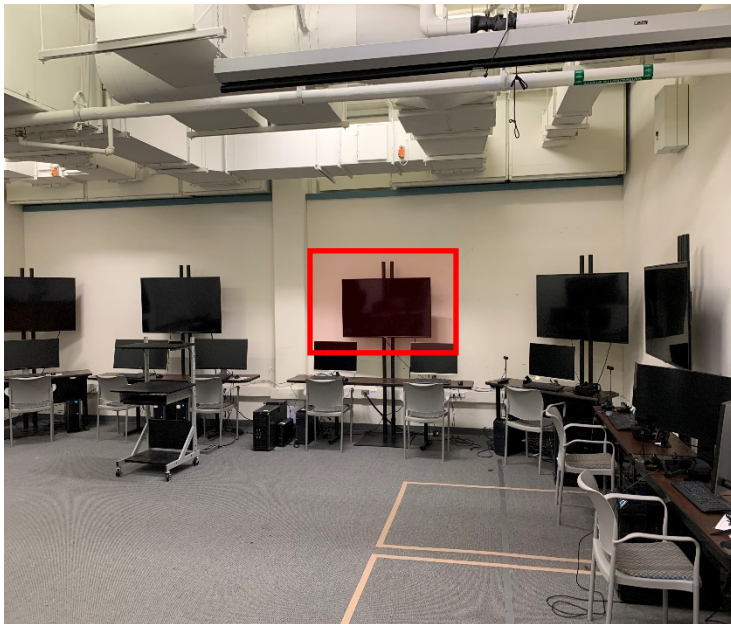
Assigned Component ID: 385



Item: Damper Solenoid

Description: This Damper Solenoid is located in the overhead and rectangular in shape. It is orange in color and has a metal rod (thermometer) protruding out from its body. This component is located towards the intersection of the back and left walls. There are three of these solenoids located in its general vicinity. This one faces the right wall of the space.

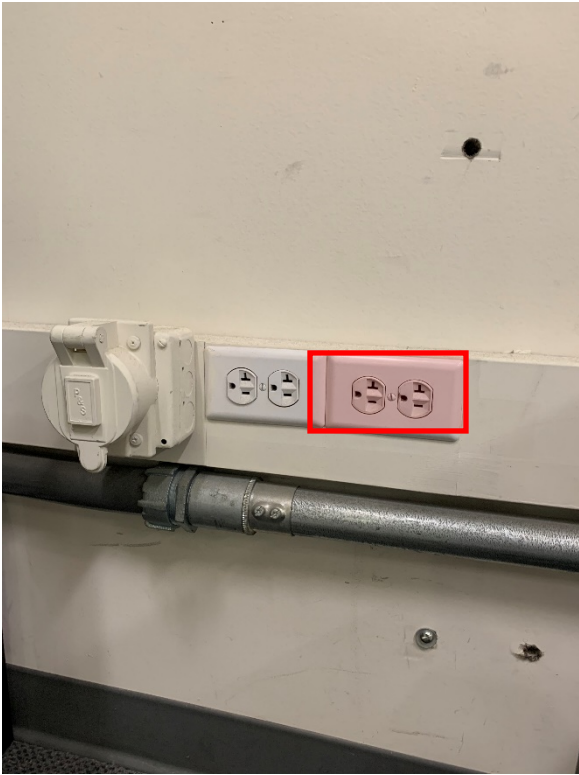
Assigned Component ID: 371



Item: Large Computer Monitor

Description: This large computer monitor is located at one of the workspaces towards the back wall of this space. This monitor is elevated above the workspace. Counting these elevated monitors from right to left within the space it is third.

Assigned Component ID: 669



Item: Wall Outlet

Description: There are multiple wall outlets throughout this space. This wall outlet is on the right bulkhead of the space right before the first workstation. This outlet consists of two adjacent outlets as well as a 440V Outlet. They are all white in color. There is no equipment plugged into them.

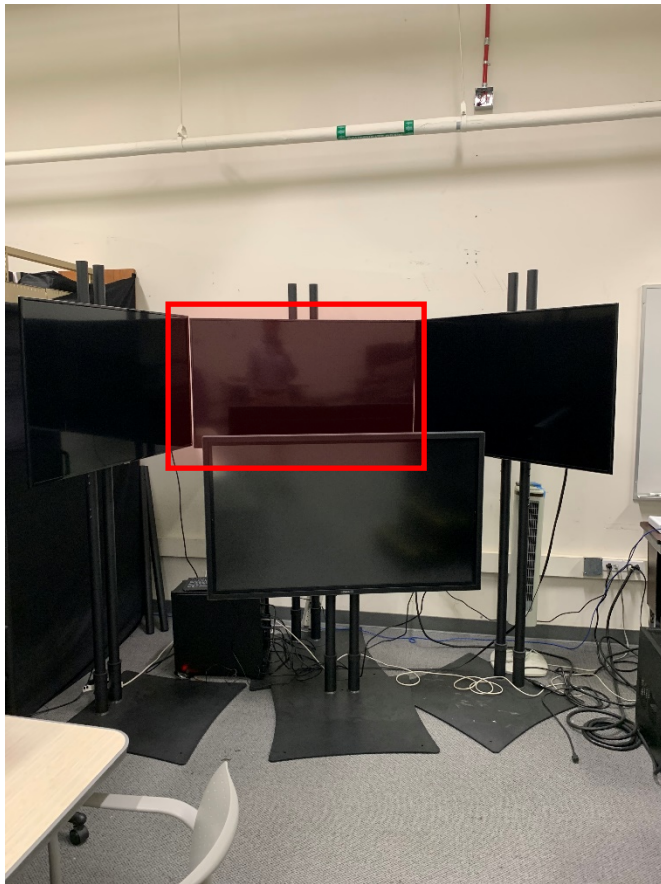
Assigned Component ID: 884



Item: Power Panel

Description: This Power Panel is one of two within the space. They are both located on the right bulkhead of the space. This particular power panel is labeled “L2A”.

Assigned Component ID: 298



Item: Flight Simulator TV Monitor

Description: This TV Monitor is approximately 42 inches in size. It is a part of a cluster of 4 Monitors of the same size located near the Flight Simulator within the space. This particular monitor is the middle TV of the highest tier.

Assigned Component ID: 242



Item: HTG Hot Water Return Piping

Description: This piping is located in overhead of the far left corner of the space. This HTG How Water Return Piping is one of two in the same location. It's labeling is green with white letters reading "HTG HOT WATER RETURN". This specific pipe is the closest to the bulkhead.

Assigned Component ID: 551



Item: Floor Stain

Description: This floor stain is one of many within the space, but located approximately in the center of the space. It's approximately the diameter of a quarter. To locate this stain it is approximately 12 paces or 10 yds when walking directly into the space. It is black in color.

Assigned Component ID: 291

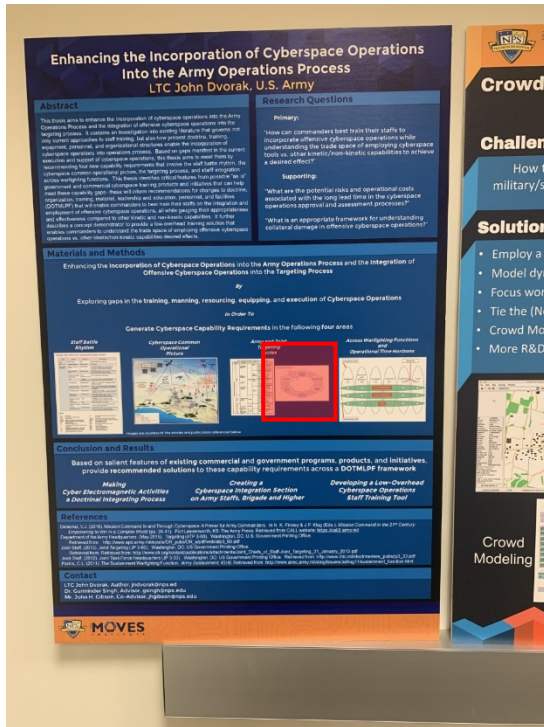


Item: Tool Box Drawer

Description: A drawer style toolbox is located to the immediate left corner of the space upon entering. It is a light green in color. This toolbox has 6 rows and 6 columns of drawers. The specific drawer to be identified is labeled "Allens" and is the 3rd column 2nd row.

Assigned Component ID: 608

C. INTRODUCTORY/WARM-UP SPACE



Item: Poster Board Image (Army Joint Targeting Cycle)

Description: This image can be found on the poster “Enhancing the Incorporation of Cyberspace Operations into the Army Operations Process” which is located in the immediate left-hand corner of the space. When looking at this poster this particular image is found within the Materials and Methods section of the poster. Within that section it is the image that is of a donut shape and serves as a visual for “Army and Joint Targeting Cycles”.

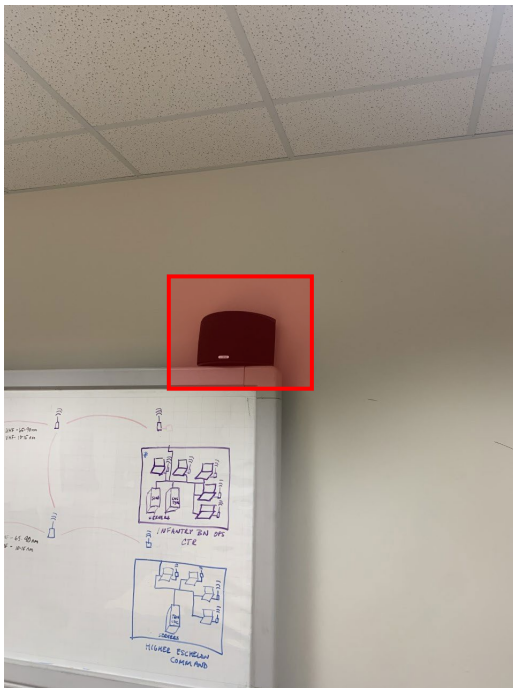
Assigned Component ID: 108



Item: Poster Board Picture (30 Years of VR at NPS)

Description: This image can be found on the poster “30 Years of Virtual Reality (VR) at Naval Postgraduate School”. This poster is found on the bulkhead to the immediate left upon entering the space. The image can be found on the 5th row of images. It is the image of a man in a khaki uniform using a computer. Visibly you can see the left-hand side of his body. Within this image he is wearing a black watch on his left wrist.

Assigned Component ID: 650



Item: Presentation Speaker

Description: This is 1 of 2 elevated speakers within this space. This speaker is located on the bulkhead immediately to the right upon entering the space. It is above a grided white board. When facing this white board, it is the speaker on the top right. It is all black in color.

Assigned Component ID: 340

APPENDIX C. MAINTENANCE ITEM DESCRIPTIONS (CONTROL)

A. LEAST COMPLEX SPACE

Item Name: Classroom Thermostat

Location Description:

This classroom thermostat is approximately 3” by 2” in size. Located on the left bulkhead of the classroom upon entry and near the secondary exit of the space. It is labeled “VAV-203.”

Item Name: Light switch

Location Description:

This classroom light switch is located on the left bulkhead of the space upon entry. It is located above waist height near the secondary entrance of the space. It is off-white and is labelled “L-12.”

Item Name: Overhead Sprinkler

Location Description:

This overhead sprinkler is 1 of 6 located within the space. It is the middle of three sprinkler heads on the right-hand side of the space upon entry. It is located in the overhead and one ceiling tile forward and three ceiling tiles to the right of the space’s projector.

Item Name: Project Screen Up and Down Switch

Location Description:

This switch controls the up and down movement of the projector screen. It is located on the furthest bulkhead from the entry point of the space. Height on the wall is approximately 4 feet above the deck. This switch is black and is behind the instructor’s desk.

Item Name: Fire Alarm

Location Description:

Description: This fire alarm is 1 of 1 located within the space. It has an orange covering and is approximately 7 feet above the deck. It is located on the bulkhead to the immediate right upon entering the space. On each side of this alarm the label “ALERT” can be seen.

Item Name: Wall Panel

Location Description:

Description: This wall panel is 1 of 8 located within the classroom. All wall panels make up the right bulkhead of this space. Upon entry of the space this panel is the third from the front side of the room.

Item Name: Computer Monitor

Location Description:

This computer monitor is 1 of 1 located within the space. Located near the forward most bulkhead of the space on top of the instructor's desk. It is an all black "Dell" monitor.

Item Name: Ceiling Tile

Location Description:

This ceiling tile is closest to the right bulkhead of the space. If counting the columns of ceiling tiles from the intersection of the right and rear bulkhead of the space this ceiling tile is three full columns to the right and 11 ceiling tiles towards the front of the space.

Item Name: Presentation Speaker

Location Description:

This is 1 of 2 speakers located within the space. There are two speakers that located on the forward most bulkhead of the space. These speakers are above the projector screen. This speaker is the left speaker of the projector screen. It is white and JBL brand. There is a water stain located to the left of this speaker on a ceiling tile above it.

Item Name: Floor Outlet

Location Description:

This is one of many floor outlets within this space. This floor outlet has a brass covering that covers 3 of 4 outlets. This outlet is located in front of the instructor's desk approximately 5 inches from the front end of its base.

B. MOST COMPLEX SPACE

Item Name: Overhead Junction Box

Location Description:

This exposed junction box is located in the overhead approximately in the center of the space. It is located on ventilation ducting and its cover faces the right bulkhead of the room. This junction box has exposed wires of red and blue colors, its sides are black and interior is dark green. It is approximately 6 inches by 3 inches and has two electric conduits that lead into the junction box.

Item Name: Flight Simulator Joy Stick

Location Description:

This joy-stick is a part of the flight simulator within the space. It's all black with buttons colored red. It's on the right hand side of the flight simulator, to the right of the pilot seat.

Item Name: Overhead Sprinkler Head

Location Description:

This over-head sprinkler is located towards the middle of the space. It is located in the overhead and the lowest hanging of the others. It has a red colored wire guard encasing it. It is located under a large overhead air duct.

Item Name: Fan Coil Assembly

Location Description:

This component is nearest the right-hand side of the space. It is located above the projector screen mount and approximately 1 foot above the "Condensate Drain" overhead piping. This Fan Coil Assembly is all white and rectangular in shape, it also has a black label "FC-2-15."

Item Name: Damper Solenoid

Location Description:

This Damper Solenoid is located in the overhead and rectangular in shape. It is orange in color and has a metal rod protruding out from its body. This component is located towards the intersection of the back and left walls. There are three of these solenoids located in its general vicinity. This one faces the right wall of the space.

Item Name: Large Computer Monitor

Location Description:

This large computer monitor is located at one of the workspaces towards the back wall of this space. This monitor is elevated above the workspace. Counting these elevated monitors from right to left within the space it is third

Item Name: Wall Outlet

Location Description:

There are multiple wall outlets throughout this space. This wall outlet is on the right bulkhead of the space right before the first workstation. This outlet consists of two adjacent outlets as well as a 440 Outlet. They are all white in color. There is no equipment plugged into them.

Item Name: Power Panel

Location Description:

This Power Panel is one of two within the space. They are both located on the right bulkhead of the space. This particular power panel is labeled “L2A.”

Item Name: HTG Hot Water Return Piping

Location Description:

This piping is located in overhead of the far left corner of the space. This HTG How Water Return Piping is one of two in the same location. It’s labeling is green with white letters reading “HTG HOT WATER RETURN.” This specific pipe is the closest to the bulkhead.

Item Name: Floor Stain

Location Description:

This floor stain is one of many within the space, but located approximately in the center of the space. It’s approximately the diameter of a quarter. To locate this stain it is approximately 12 paces or 10 yds when walking directly into the space. It is black in color.

Item Name: Tool Box Drawer

Location Description:

A drawer style toolbox is located to the immediate left corner of the space upon entering. It is a light green in color. This toolbox has 6 rows and 6 columns of drawers. The specific drawer to be identified is labeled “Allens” and is the 3rd column 2nd row.

Item Name: Flight Simulator TV Monitor

Location Description:

This TV Monitor is approximately 42 inches in size. It is a part of a cluster of 4 Monitors of the same size located near the Flight Simulator within the space. This particular monitor is the middle TV of the highest tier.

C. INTRODUCTORY/WARM-UP SPACE

Item Name: Poster Board Image (Army Joint Targeting Cycle)

Location Description:

This image can be found on the poster “Enhancing the Incorporation of Cyberspace Operations into the Army Operations Process” which is located in the immediate left-hand corner of the space. When looking at this poster this particular image is found within the Materials and Methods section of the poster. Within that section it is the image that is of a donut shape and serves as a visual for “Army and Joint Targeting Cycles.”

Item Name: Poster Board Image (30 Years of VR at NPS)

Location Description:

This image can be found on the poster “30 Years of Virtual Reality (VR) at Naval Postgraduate School.” This poster is found on the bulkhead to the immediate left upon entering the space. The image can be found on the 5th row of images. It is the image of a man in a khaki uniform using a computer. Visibly you can see the left-hand side of his body. Within this image he is wearing a black watch on his left wrist.

Item Name: Presentation Speaker

Location Description:

This is 1 of 2 elevated speakers within this space. This speaker is located on the bulkhead immediately to the right upon entering the space. It is above a grided white board. When facing this white board, it is the speaker on the top right. It is all black in color.

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APPENDIX D. MAINTENANCE ITEM DESCRIPTIONS (EXPERIMENTAL)

A. LEAST COMPLEX SPACE

Item 1: Classroom Thermostat

Item 2: Light Switch

Item 3: Overhead Sprinkler Head

Item 4: Projector Screen Up and Down Switch

Item 5: Fire Alarm

Item 6: Wall Panel

Item 7: Computer Monitor

Item 8: Ceiling Tile

Item 9: Presentation Speaker

Item 10: Floor Outlet

B. MOST COMPLEX SPACE

Item 1: Overhead Junction Box

Item 2: Flight Simulator Joystick

Item 3: Overhead Sprinkler Head

Item 4: Fan Coil Assembly

Item 5: Damper Solenoid

Item 6: Large Computer Monitor

Item 7: Wall Outlet

Item 8: Power Panel

Item 9: HTG Hot Water Return Piping

Item 10: Floor Stain

Item 11: Toolbox Drawer

Item 12: Flight Simulator TV Monitor

C. INTRODUCTORY/WARM UP SPACE

Item 1: Poster Board Image (Army Joint Targeting Cycle)

Item 2: Poster Board Image (30 Years of VR at NPS)

Item 3: Presentation Speaker

APPENDIX E. DEMOGRAPHIC SURVEY

Augmented Reality Object Location Experiment

Demographic Survey

Subject Number: _____

Date: _____

1. Age: _____

2. Gender: Female Male

3. Preferred writing hand: Left Right

4. Do you wear any corrective lenses: Yes No

a. If yes: what is your uncorrected vision: _____ (example 20/400)

5. Are you currently serving in the Armed Forces: Yes No

a. Which branch: USA USN USMC USAF

USCG

b. Years of Service: _____ (years, example 2.4)

c. Highest Rank: _____ (example O3)

d. Rating/MOS: _____ (example AN, AE; or service equivalent)

6. Has your job or military occupation required you to identify components for preventative or corrective maintenance? Yes No

7. Years involved with military maintenance to include supervision or management :

(years, example 1.3)

8. How many hours a week do you play computer games? _____ (hours, ex. 1.2)

9. Have you ever experienced a virtual environment? Yes No

b. If Yes: About how many times? _____

10. Are you prone to motion sickness? Yes No

APPENDIX F. POST TASK SURVEY

A. TRADITIONALLY GUIDED TASK (CONTROL GROUP)

Augmented Reality Object Location Experiment

Post-task Survey

Subject Number: _____

Date: _____

Traditionally guided task:

1. Indicate how easy it was to complete the task by circling one of the options listed below:

Very Easy - Easy - Moderately Easy - Average - Moderately Difficult - Difficult - Very Difficult

2. Indicate how easy it was to understand the location descriptions of each object?

Very Easy - Easy - Moderately Easy - Average - Moderately Difficult - Difficult - Very Difficult

- a. If you found it Moderately Difficult to Very Difficult to understand, why?

3. What was the most difficult object to find for each room?

4. What was the least difficult object to find for each space?

5. Any other comments?

B. AR GUIDED TASK (EXPERIMENTAL GROUP)

Augmented Reality Object Location Experiment

Post-task Survey

Subject Number: _____

Date: _____

AR guided task:

1. Indicate how easy it was to complete the task by circling one of the options listed below:

Very Easy - Easy - Moderately Easy - Average - Moderately Difficult - Difficult - Very Difficult

2. Did the use of the AR headset help you identify the items throughout the space without confusion?

- a. If not, why?

3. What was the most difficult object to find for each room?

4. What was the least difficult object to find for each space?

5. Could you see the **virtual images** clearly? Yes No

- b. If not, were you wearing corrective lenses? Yes No

- c. Why could you not see the virtual images clearly?

6. Did you experience any discomfort? If so, describe.

7. Any other comments?

APPENDIX G. SUBJECT EXPERIMENT CONSENT FORM

Naval Postgraduate School Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled, “AR Technology effect on efficiency of shipboard maintenance.” The purpose of the research is to determine the effect of Augmented Reality (AR) technology on the efficiency of shipboard maintenance. Total participation time is approximately 1 hr to 1 hr 25 min, in which you will be asked to find and identify several components in two different rooms, a demographics questionnaire, and a post-task questionnaire. This study is being conducted at NPS. Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you would otherwise be entitled, and you may discontinue participation at any time without penalty or loss of benefits to which you otherwise would be entitled.

The potential risks of participating in this study are very minor nausea and a breach of confidentiality. If your participation involves AR technology, it is possible but not probable, that exposure to Microsoft HoloLens environment can induce very minor nausea. After onset, the discomfort should resolve itself within 30 minutes. Potential general benefits are evidence-based recommendations to leadership about whether or not AR technology can aid the efficiency of shipboard maintenance. You will receive no benefits. The alternative to participating will be not to participate.

Procedures: We are asking **20 - 50** volunteers to participate in this study. You will be asked to find and identify several components in two different rooms. To assist you in finding and identifying components, you will be provided with either a written description of the component or visual indicators provided from an augmented reality headset. You also will be asked to complete a demographic questionnaire and a post-task questionnaire. The procedures for the experiment are completely new, designed specifically for this research, and will serve no purpose other than research. Total participation time is approximately 1 hr to 1 hr 25 min. Your performance during these tasks will be assessed based on time completed, accuracy and confidence level. The subject will not be required to provide any PII information throughout the duration of this experiment. The data collected for their participation will only be used for the research purposes outlined within this study.

Location: The experiment will take place in Watkins Hall at the Naval Postgraduate School.

Cost. There is no cost to participate in this research study.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. The research team will collect no personal information throughout testing. Any personal information used for scheduling purposes will be destroyed at the completion of

the experiment. In accordance with NPS data storage instruction, data collected at NPS only will be stored on approved NPS systems. Hard copies of informed consent forms and questionnaires will be kept separately in a locked cabinet in a locked room at NPS. Hard copies of data will be associated only with a randomly selected subject identification number. Your participation data does not intentionally identify you. Your information collected as part of the research, even if identifiers are removed, will not be used or distributed for future research studies.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Quinn Kennedy, mqkenned@nps.edu Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831-656-2473, lgshattu@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

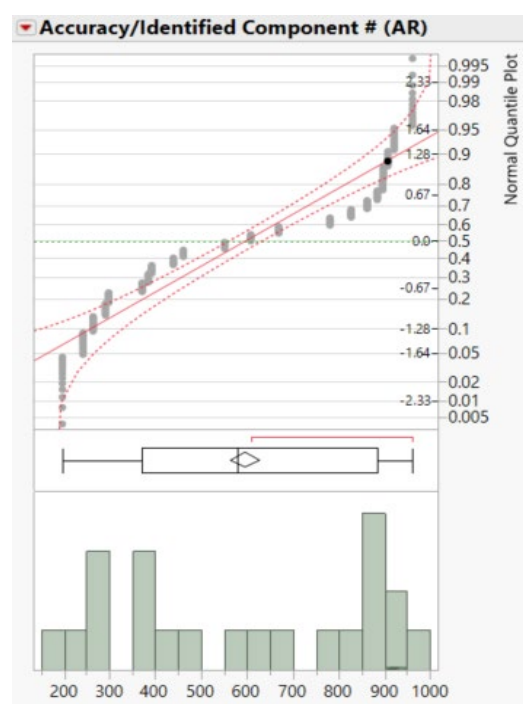
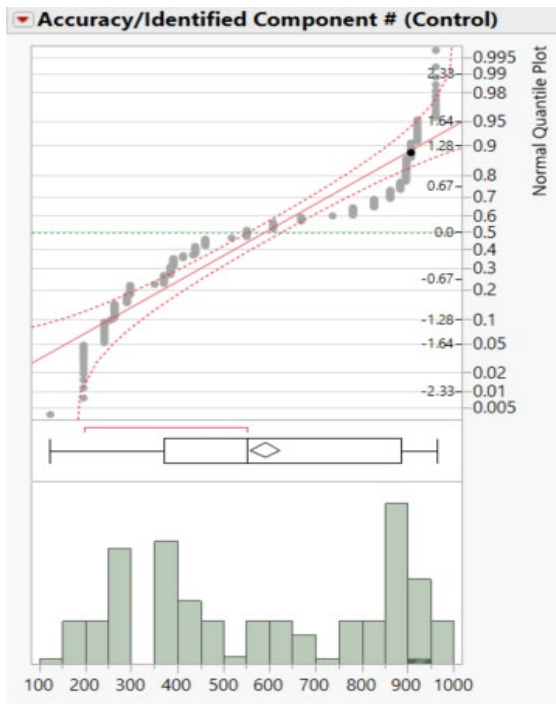
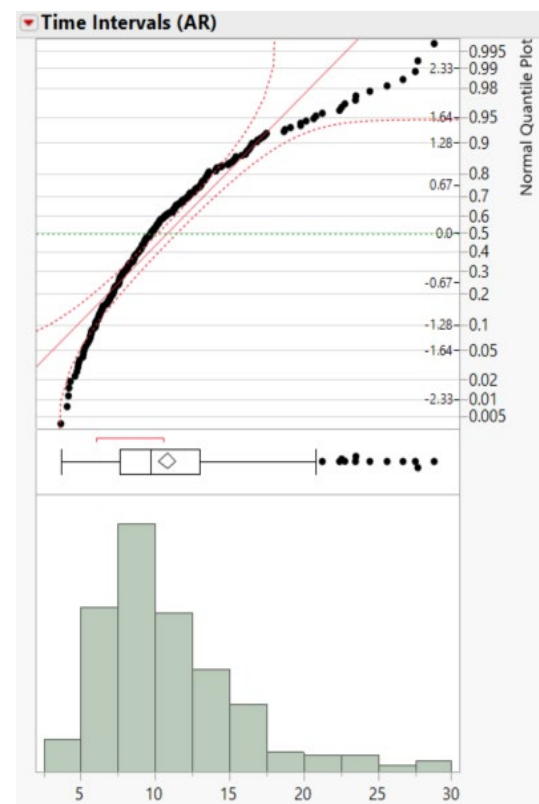
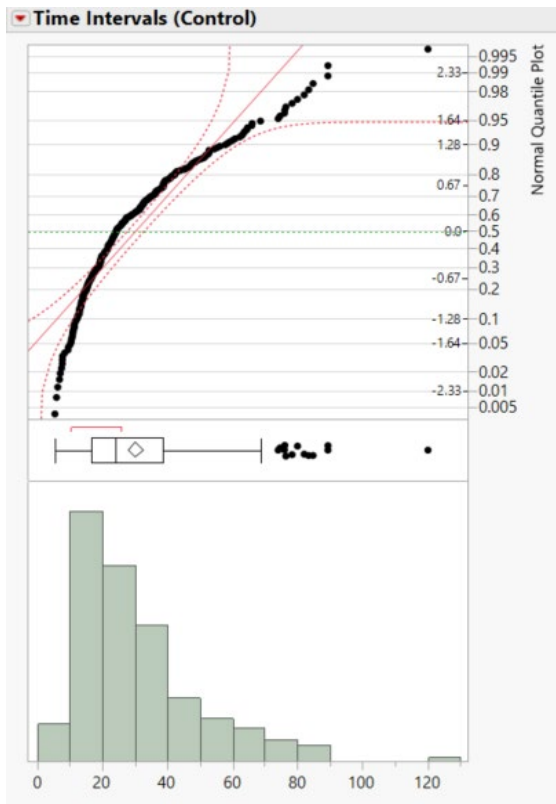
☐ I consent to participate in the research study.

☐ I do not consent to participate in the research study.

Signature of Participant

Date

APPENDIX H. NORMALITY PLOTS OF DATA COLLECTED



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