Evaluating Augmented Reality Assembly Instructions Delivered via Microsoft HoloLens

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ABSTRACT

To keep up with the maintenance demands of a dynamic fleet of equipment, military personnel are constantly learning new repair skills. However, this constant training can be time consuming and cost prohibitive. In fact, United States Military spending on operation and maintenance equaled $200 billion in 2015. One method of reducing these costs is to employ more efficient methods of delivering work instructions, such as Augmented Reality (AR). Studies on the use of AR work instructions have shown reductions in task duration and errors by as much as 50%. Although previous research has confirmed the advantages of AR over traditional 2D work instructions, little research has been conducted to evaluate the advantages of emerging AR hardware, such as the Microsoft HoloLens for delivering maintenance and assembly information.

This paper presents the results of a comprehensive user study comparing four work instruction delivery methods. Users were asked to perform a mock wing assembly task with work instructions using one of 4 methods: 2D instructions on a desktop computer, 2D tablet instructions, AR tablet instructions, and AR instructions on the Microsoft HoloLens head-mounted display (HMD). Results of the study showed that viewing the AR instructions using the HMD yielded faster assembly times than the other three instructional methods. The study also showed that users made very few errors when using AR methods in general. However, net promoter scores (a measure of user satisfaction) and qualitative feedback from the users showed that some improvements in comfort and 3D registration may be necessary before the HoloLens can be successfully employed for widespread military maintenance use. Despite this subjective feedback, the HoloLens HMD has the potential to provide warfighters with quick access to work instructions that will decrease the need for expert assisted training and increase readiness of military equipment.

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Eliot Winer, Ph.D., is an associate director of the Virtual Reality Applications Center and professor of Mechanical Engineering at Iowa State University. He has led numerous projects for the D0D including development of a next-

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INTRODUCTION

In order to keep equipment working effectively and maintain combat readiness, the U.S. Military spends as much as $200 billion on operations and maintenance costs annually (Congressional Budget Office, 2017). Keeping these machines in optimum condition is not a simple task because it requires the consistent maintenance of a constantly changing arsenal of military vehicles and machines. To this end, the maintenance personnel performing repairs must be continually trained in new maintenance procedures. Traditionally, maintenance training is done using digital or paper manuals or by expert-guided training in the field. These methods are not ideal because they can be time consuming and expensive. Additionally, an expert's time valuable and better spent working on complicated repairs rather than training. Recent developments in Augmented Reality (AR) technology have the potential to make military maintenance training faster, more effective, and limit the need for expert supervision during training.

In the past, researchers have proven the advantages of AR work instructions for manual assembly tasks. These advantages include faster assembly times, lower error rates, and lower mental work load (Hou, Wang, & Truijens, 2015). These benefits have been found in studies using a wide variety of AR hardware including AR Head-Mounted Displays (HMDs), tablets, and projectors. The hands-free nature and mobility of HMDs makes them a unique AR hardware option that is ideal for large-scale maintenance applications. However, past AR HMDs had severe limitations such as latency, lag in real-time tracking, and user comfort, which prevented them from being widely used outside of a lab environment (Feiner, Macintyre, & Seligmann, 1993). If these limitations could be overcome, the benefits of AR delivered work instructions to maintenance personnel could be realized, increasing fleet readiness and reducing operations and maintenance costs for the U.S. Military.

Recently, new AR HMDs such as the Microsoft HoloLens, Daqri Smart Glasses, and the Meta 2, have become available to the public ("DAQRI Smart Glasses," 2018; "Meta Augmented Reality," 2017; Microsoft, 2018). These new AR hardware devices aim to solve some of the inherent problems with early AR HMDs. However, little research has been done to confirm the benefits of these new AR systems for assembly and maintenance tasks. Therefore, more research is needed to understand how modern HMDs can augment military operations and maintenance.

This paper presents a comparative study of user performance in a manual assembly task using AR instructions presented on the Microsoft HoloLens HMD. The data collected using the Microsoft HoloLens was then compared to data from previous research studies using three different instructional conditions: Tablet AR, Tablet Model-Based Instructions (MBI), and Desktop MBI (Hoover et al., 2016; MacAllister et al., 2017; Richardson et al., 2014). The Tablet AR instructions represent the previous state-of-the art in AR hardware, while the Tablet MBI and Desktop MBI conditions represent current instructional practices using 2D images and text. This study will help exemplify the advantages of using new AR HMD technology to provide assembly instructions for military maintenance.

BACKGROUND

The field of AR research has grown a great deal since the early 1990s, covering AR guided instructions for applications in many industries such as aerospace (Caudell & Mizell, 1992), automotive (Echtler et al., 2004; Wiedenmaier, Oehme, Schmidt, & Luczak, 2003), and medicine (Nilsson & Johansson, 2007). Of these works in AR for manufacturing, 30% of published research has studied the use of AR for guided assembly and disassembly tasks (Palmarini, Erkoyuncu, Roy, & Torabmostaedi, 2018). Many of the previous publications on AR instructions for assembly tasks reported advantages such as fewer errors and reduced assembly time when compared to traditional instructional methods (Hou et al., 2015).

AR is an intuitive medium for providing work instructions because it fuses real and computer-generated information together. It does this by super imposing 3D objects onto the user's view of the real world. Additionally, AR allows the virtual information to be spatially registered with the real-world space and updates in real-time (Ronald Azuma, 1997). This allows users to understand the physical relationship between real and virtual objects in the scene independent of their relative viewing angle and position. The concept of using AR to display work instructions was first proposed by Caudell and Mizell in 1992 (Caudell & Mizell, 1992). In their seminal paper, they suggested that a tracked, transparent head-mounted display could be used to provide dynamic graphical and text-based instructions to aircraft manufacturers, thereby reducing the need for physical design instructions like paper manuals.

Advantages of AR for Guided Assembly Instructions

Time savings is one of the most cited benefits of AR instructions. By reducing assembly time, stakeholders can reduce labor costs by as much as 50% (Hou et al., 2015). Additionally, many studies have found that users of AR instructions complete manual assembly tasks significantly faster than those who use traditional paper instructions (Friedrich, 2002). For example, Baird and Barfield compared two different types of AR instructions to paper and digital 2D instructions for a motherboard assembly task (Baird & Barfield, 1999). The researchers found that both AR methods effectively reduced task completion times over the traditional paper and computer instructions. The time savings associated with the use of AR work instructions has also been observed for military applications. In 2011, Henderson and Feiner found that using AR work instructions reduced the time spent searching for parts in a military maintenance task (Henderson & Feiner, 2011).

Error reduction is another significant benefit for employing AR work instructions for maintenance and assembly because this helps to eliminate rework time (Hou et al., 2015). Many studies to date have reported reductions in errors when using AR technology to present work instructions as opposed to traditional 2D instructions (Baird & Barfield, 1999; Loch, Quint, & Brishtel, 2016). For example, Tactić and Tešić created an AR maintenance instruction system to replace traditional paper check lists in a factory environment. They found that the AR instructions reduced the number of errors in the work procedures compared to the traditional method (Tatić & Tešić, 2017). Additionally, they found that the AR system helped prevent the user from skipping steps or completing them in an incorrect order. Error reductions have also been found when using AR instructions for training applications. Gavish et al. assessed the effectiveness of AR training with respect to a control group using an instructional video. The study found that technicians who were trained using the AR system performed industrial maintenance and assembly tasks with fewer errors than their traditionally trained counterparts (Gavish, Gutiérrez, & Webel, 2013). These error reductions could result in higher readiness rates if AR is applied to military maintenance processes increasing overall military preparedness and reducing time spent correcting errors.

Another benefit of AR which is less widely studied is its potential to reduce mental workload on the user. Mental workload measures the mental strain that results from a particular task, in this case interpreting the assembly instructions (Wickens, Gordon, Liu, & Lee, 1998). AR instructions can provide sequential task instructions, rather than using a paper manual. This reduces mental workload by providing information in context instead of forcing the user to recall information or find it in documentation. Crescenzio et al. demonstrated this advantage with an AR system for checking the oil levels in a small aircraft (De Crescenzio et al., 2011). Their research showed that an AR system increased task efficiency when compared to paper instructions and reduced the mental workload on the maintenance personnel. Reductions in mental workload can result in fewer errors and less stress on maintenance personnel.

Augmented Reality Hardware

One of the first contributions to the development of AR HMDs was made by Feiner et al. in 1993. They developed a see-through HMD to provide instructions for servicing a laser printer (Feiner et al., 1993). In this work, they recognized that the available technology of the time limited the benefits of AR. They concluded that improvements in portability, field of view, and resolution would greatly improve the effectiveness of AR work instructions in the future. Since then, new systems have been developed that seek to eliminate the limitations of earlier AR hardware. With the release of commodity AR devices like the Microsoft HoloLens, Daqri Smart Glasses, and Meta 2, optical see-through HMDs have become readily available to consumers. The Microsoft HoloLens was chosen as the display device for the AR work instructions in this study because representative of these modern AR HMDs. However, any of these devices could have been used for this purpose. These devices aim to improve upon the limitations of their predecessors by providing improved tracking capabilities, reduced latency, and a more comfortable experience for the user. These features, along with the increased availability of AR hardware could increase the feasibility of using these devices for military maintenance applications. However, little research exists which investigates the impacts of these new HMDs on human performance in maintenance or assembly tasks.

Hand-Held Displays (HHDs), such as tablets and smart phones, offer a cheaper alternative to HMDs for providing AR instructions. These devices provide AR content by overlaying computer-generated graphics onto real-time video from the device's camera. This type of AR creates a "window" through which the user can see the AR content (R Azuma, Baillot, & Behringer, 2001). HHDs can also be advantageous because they are more familiar to most users. However, they can also interfere with the performance of operations and maintenance tasks because they are not hands-free devices. As a result, some users have even reported that HHD AR instructions may interrupt their work flow for manual tasks (Aromaa, Aaltonen, Kaasinen, Elo, & Parkkinen, 2016).

Although HMDs and hand-held devices are the most frequently studied hardware for presenting AR instructions, other methods of displaying AR have been tested as well. These include stationary monitors and projectors. Both methods work well in small, isolated work areas. However, they are not adaptable to dynamic work environments because of their immobility. This makes them a less desirable option for larger, more dynamic work environments.

Existing Comparisons of AR Hardware

Despite detailed research into the advantages of AR guided-assembly instructions over traditional instructional methods like paper manuals, little research has been conducted to measure the relative advantage of using different types of AR hardware for assembly and maintenance applications. Moreover, the majority of published work that does exist on this topic uses simplified assembly tasks using Legos or wood blocks (Funk, Kosch, Greenwald, & Schmidt, 2015). This is because they require little to no training before the task begins and eliminate bias due to different levels of experience or expertise (Tang, Owen, Biocca, & Mou, 2003). One such study used a Lego Duplo assembly task outlined by Funk et al. to test AR instructions presented on both a smart phone device and a Microsoft HoloLens HMD. This study found that the HoloLens improved performance in part finding tasks, like choosing the correct Lego from a parts bin, and significantly improved task completion times over paper and smart phone AR conditions (Blattgerste, Strenge, Renner, Pfeiffer, & Essig, 2017). Although this work is promising, a more rigorous study with a more complex assembly task is needed to understand how these results apply to more realistic scenarios.

Other studies have compared AR hardware for more complicated assembly tasks but fail to evaluate state-of-the-art AR hardware. For example, Zheng et al. compared the effects of two different types of AR eyewear, as well as tablet and paper instructions for an automotive maintenance task (Zheng et al., 2015). Although the results of this study are interesting, the application of these findings to spatially registered AR HMDs like the HoloLens is limited because the hardware used in this study was only capable of 2D imagery. Therefore, a study of the newest HMDs using a realistic, large-scale assembly task is needed to gain further understanding of the trade-offs between modern AR HMDs and HHDs in assembly and maintenance applications.

By conducting a user study that combines both state-of-the-art AR hardware, and a realistic assembly task, this research will help further understanding of the human performance benefits of AR guided assembly instructions. Additionally, this work will evaluate user attitudes towards current AR HMD technology, specifically the Microsoft HoloLens, for manual assembly applications. Ultimately, this work will provide more insight into how new AR technology can be applied to reduce operations and maintenance costs and increase readiness of military equipment.

METHODS

For this work, a user study was conducted using the Microsoft HoloLens to display AR work instructions for assembling a mock aircraft wing. The data from this user study was compared to data from three previously published works using the same assembly task. The previously collected data included samples from users who viewed instructions using 2D Desktop Model-Based Instructions (MBI), Tablet MBI, and Tablet AR instructions. The Desktop MBI condition represents the traditional 2D instructions for this research. These instructions were shown on an immobile, touch screen display located in the work area. Data from the Tablet MBI condition, taken from the same study, featured 2D instructions displayed on a touch-screen tablet mounted on a mobile stand (Richardson et al., 2014). Additionally, data from two previous studies, which collected data using the same AR application on a mobile tablet, were combined to create one Tablet AR condition (Hoover et al., 2016; MacAllister et al., 2017). More information about the features and development of these three conditions can be found by referencing the previous works.

HoloLens Application Development

The HoloLens AR guided-assembly application for this study was developed using Unity3D and Vuforia (Unity Technologies, n.d.). Unity3D allowed for simple authoring of the AR content and interactions for the Microsoft HoloLens. 2D image targets were used with Vuforia to initialize the locations of virtual objects in the scene. The internal tracking system of the Microsoft HoloLens was used to provide accurate 3D tracking in the work environment.

The application features were designed to be as similar as possible to the AR application used for the Tablet AR condition (MacAllister et al., 2017). To this end, the application featured green highlights for identifying parts, blue model animations for depicting assembly locations, and square yellow "gates" to help the user navigate around the work space. However, the Microsoft HoloLens required a different method of interaction compared to the Tablet AR condition. To limit training time, a small Bluetooth clicker attached to the user's non-dominant wrist was used to select virtual buttons in a menu. Using these buttons, the user could easily navigate forward and backward between steps or select a specific step they would like to visit from a dropdown menu (Figure 1). After selecting a step, yellow navigational cues led the user to the location of their next task. Once there, a green box would appear to indicate which part to retrieve, or a blue model animation showed the user where to place a previously obtained part.

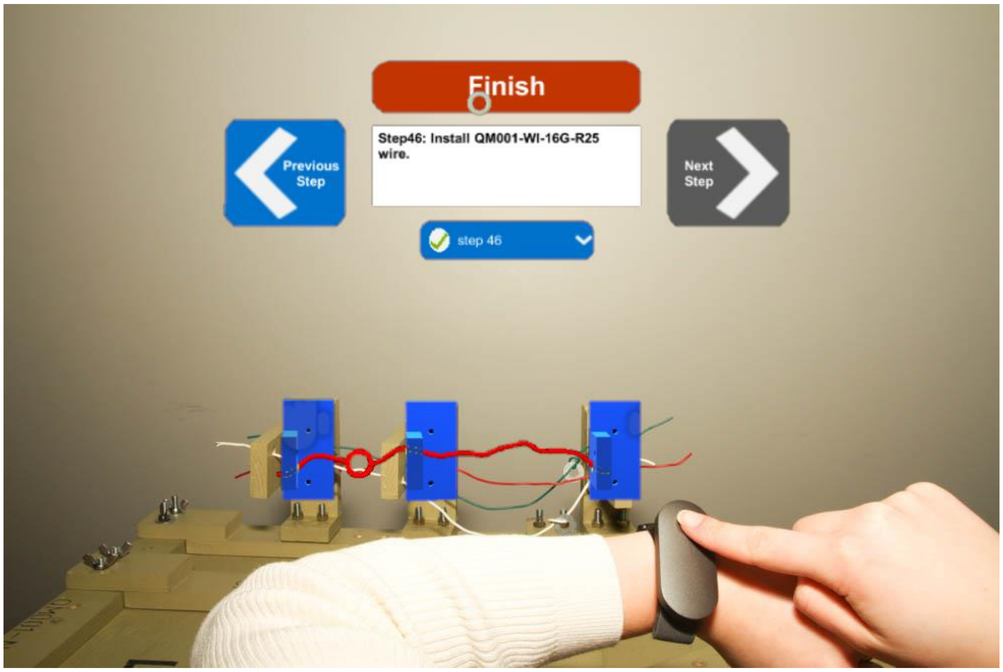

Figure 1. HoloLens interface with Bluetooth clicker.

Task

During the user study, participants were asked to complete a mock aircraft wing assembly task. This task was designed in collaboration with The Boeing Company to simulate a typical factory floor assembly scenario. The assembly consisted of wooden parts which were assembled on a table using metal bolts, nuts, washers, and wires. All parts were assembled by hand during the assembly process to eliminate individual difference due to previous experience with tools. During the task, users were directed to retrieve labeled parts from the parts table, or metal fasteners and wires from the fastener bins. These parts were then used to assemble the mock aircraft wing on the wing table shown in Figure 2.

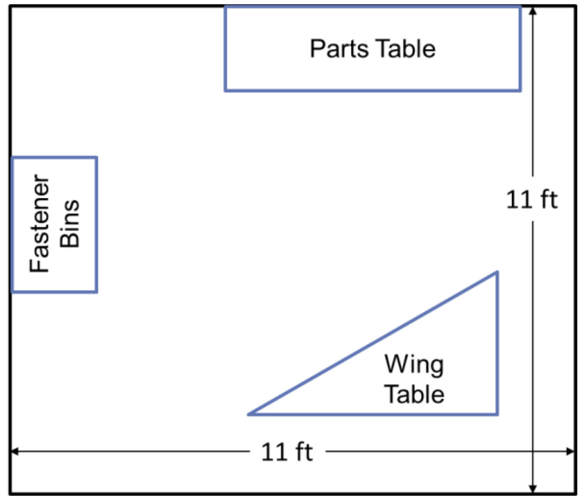

Figure 2. Task environment layout.

Procedure

The same procedure was used to gather data using the HoloLens AR guided-assembly instructions as previous studies using the Desktop MBI, Tablet MBI, and Tablet AR conditions. Users signed an informed consent document which outlined the purpose of the study and their rights as a participant. When the participant arrived at the study location, they were asked to complete an initial demographics survey. After the survey, they were instructed on how to use the HoloLens device, the Bluetooth clicker, and the AR guided-assembly instruction application. Next, they were briefed on the task and the environment. When the briefing was complete, the participant was asked to complete a short practice assembly to acclimate themselves to the procedure. During the practice assembly, the participant was encouraged to ask clarifying questions. Upon finishing the practice assembly, the participant completed the first trial of the wing assembly task, after which the assembly was graded and disassembled for the second trial. During this time, the participant filled out a paper-folding questionnaire for measuring spatial thinking ability. Next, a second identical wing assembly trial was completed and graded. Lastly, the participant was given a short survey to gather feedback about their experience. The entire study lasted about 2 hours and participants were compensated $20 for their time.

Measures

For this study, the time required for the participant to complete each trial was recorded as well as the number of errors made during the assembly process. Errors included incorrect, misplaced, extra, and missing parts. These measures were used to evaluate human performance for the wing assembly task. After the user study, subjective, feedback was obtained via electronic questionnaire in the form of a Net Promoter Score (NPS) and free response questions inquiring about the user's experience using the AR instructions. A detailed analysis of each of these measures can be found in the following section.

RESULTS

Because the data for the Desktop MBI (n=13), Tablet MBI (n=15), and Tablet AR (n=40) conditions were taken from previous work, the sample sizes for each condition were different from the HoloLens AR condition (n=35). Therefore, non-parametric tests were used to compensate for the dissimilar sample sizes.

Across all four conditions, the majority of participants for this study were recruited from the College of Engineering at Iowa State University. Therefore, most of participants (79%) had obtained, or were actively pursuing a degree in engineering, which gave them some necessary background knowledge of basic machines. This recruitment method also resulted in a large percentage of male participants (72%) as opposed to females (28%). This ratio is similar to the current ratio of genders in the US Military (Parker, Cilluffo, & Stepler, 2017).

Time

A Kruskal-Wallis test (α=0.5) was used to determine if there were differences in median task durations between the four instructional conditions: Desktop MBI, Tablet MBI, Tablet AR, and HoloLens AR. The statistical test showed that there was a statistically significant difference in Trial 1 times between the four groups, $\chi^2(3) = 30.670$, $p < .0005$ These graphs can be found in Figure 3 on the following page. A pairwise comparison revealed there to be a significant difference between the median errors for the HoloLens AR (1.0) and the Tablet MBI (*Mdn* = 3.0) ($p = .029$) and the HoloLens and Desktop MBI (*Mdn* = 7.0) ($p < .0005$). The pairwise comparison also showed significant difference between the tablet AR condition (*Mdn* = 1.0) and Desktop MBI (*Mdn* = 7.0) ($p < .0005$).

The same statistical test also showed a significant difference in median completion times for trial 2, $\chi^2(3) = 29.303$, $p < .0005$ (Figure 4 on the next page). The pairwise comparison revealed that there was, once again, a significant difference between the median errors for the HoloLens AR (*Mdn* = 0.0) and the Tablet MBI (*Mdn* = 1.0) ($p = .025$) and the HoloLens and Desktop MBI (*Mdn* = 4.0) ($p < .0005$). And the median number of errors for tablet AR condition (*Mdn* = 0.5) was also significantly different than that of the Desktop MBI (*Mdn* = 4.0) ($p < .0005$).

Errors

A Kruskal-Wallis test (α=0.5) was also used to determine if differences in median number of errors for Trial 1 existed between the four instructional conditions. The test showed that some differences existed among the groups, $\chi^2(3) = 25.990$, $p < .0005$, as seen in Figure 5 later in this text. Further post hoc analysis showed that there was a significant difference between the median completion time for the HoloLens AR (*Mdn* = 1328 s) and Tablet AR (*Mdn* = 1572 s) ($p = .004$), HoloLens and Tablet MBI (*Mdn* = 1801 s) ($p =.001$), and the HoloLens and Desktop MBI (*Mdn* = 1868 s) ($p < .0005$).

A similar analysis of Trial 2 errors also revealed a statistically significant difference, $\chi^2(3) = 12.364$, $p = .006$, shown later in the text in Figure 6. And the post hoc analysis showed significant differences between the HoloLens AR (*Mdn* = 1026 s) and the Desktop MBI conditions (*Mdn* = 1259 s) ($p = .013$). The Tablet AR (*Mdn* = 1182 s) and Tablet MBI (*Mdn* = 1193 s) conditions were not significantly different from the other groups.

Net Promoter Score (NPS)

NPS measures the likelihood that a user of a product would recommend the product in question to a friend. For this survey question, the user was asked to give their response on a five-point scale with one being the least likely to recommend, and five being the most likely. To calculate the overall NPS for each instructional condition, the percentage of detractors (responses of 1, 2, or 3) were subtracted from the percentage of promoters (responses of 5). According to Reichheld, an average NPS is around 16% (Reichheld, 2003). Using this formula, the Tablet AR condition received an NPS of 53%, while the HoloLens AR condition had an NPS of 14%. These positive values show the both of the AR conditions have more promoters than detractors. Conversely, the Tablet MBI condition had an NPS of -31% and the NPS of the Desktop MBI condition was -47%. This means both MBI conditions had more detractors than promoters overall.

Qualitative Feedback

After the study, HoloLens AR participants were asked to comment on their experience with the AR guided-assembly instructions in an electronic questionnaire. These responses were then broken down into their main ideas and categorized according to the theme of the statement. Three positive and three negative themes emerged during this process. First, 26% of the HoloLens users reported that the 3D tracking was not always precise. 14% of participants commented that they experienced some discomfort while wearing the HoloLens HMD. And 11% of the participants did not like that the AR graphics were constantly in their field of view. On the other hand, 29% of participants reported that they felt the HoloLens instructions were easy to use and 11% said they thought the HoloLens instructions would be easier to use than paper instructions. Lastly, 11% of participants mentioned that the HoloLens instructions helped reduce their mental work load in some way.

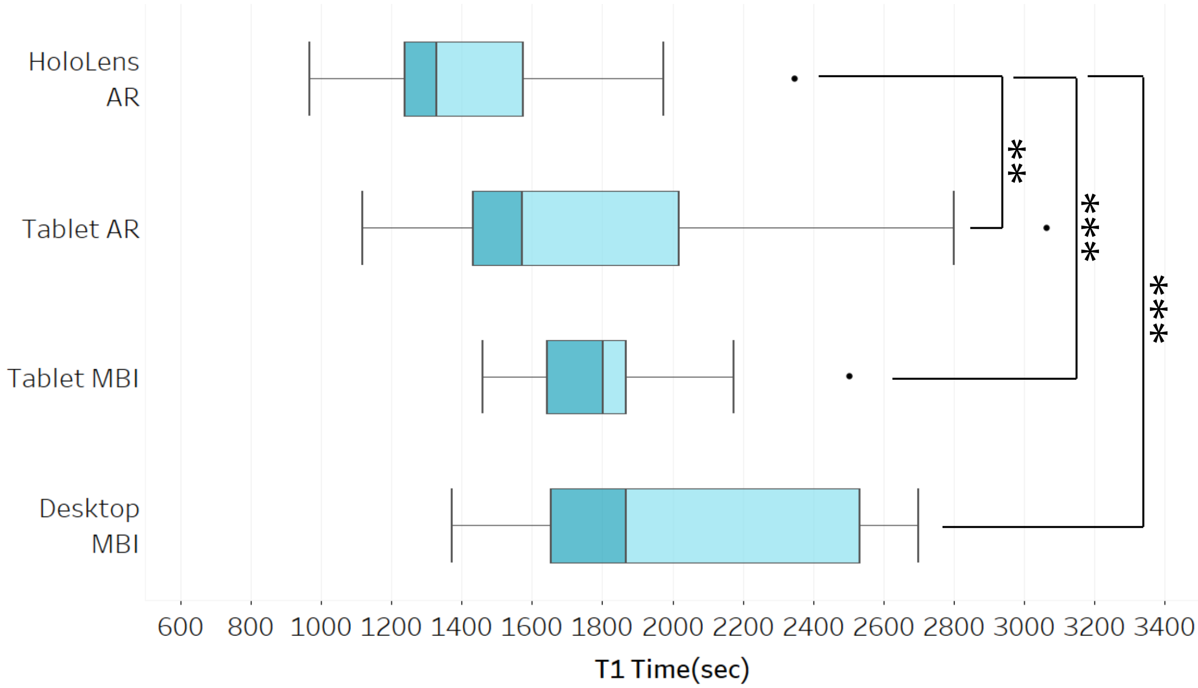

Figure 3. Box plots of Trial 1 completion times. (* indicates p ≤ 0.05, ** indicates p ≤ 0.01, * indicates p ≤ 0.001)**

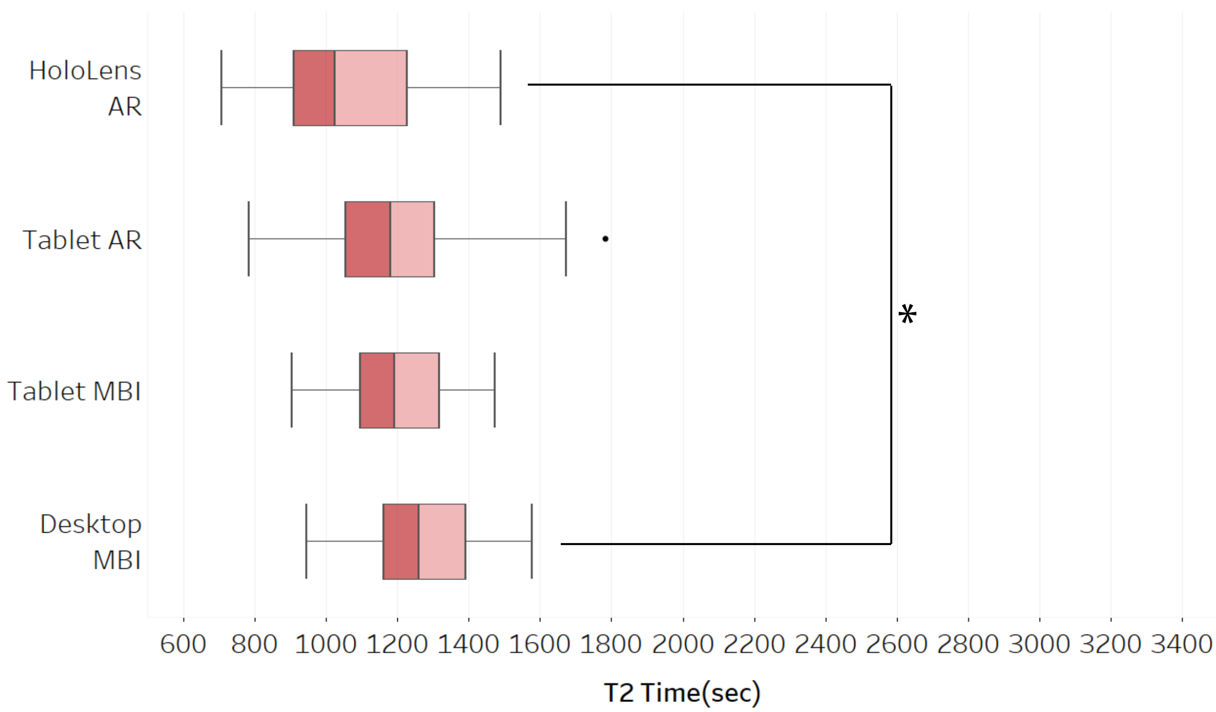

Figure 4. Box plots of Trial 2 completion times. (* indicates p ≤ 0.05, ** indicates p ≤ 0.01, * indicates p ≤ 0.001)**

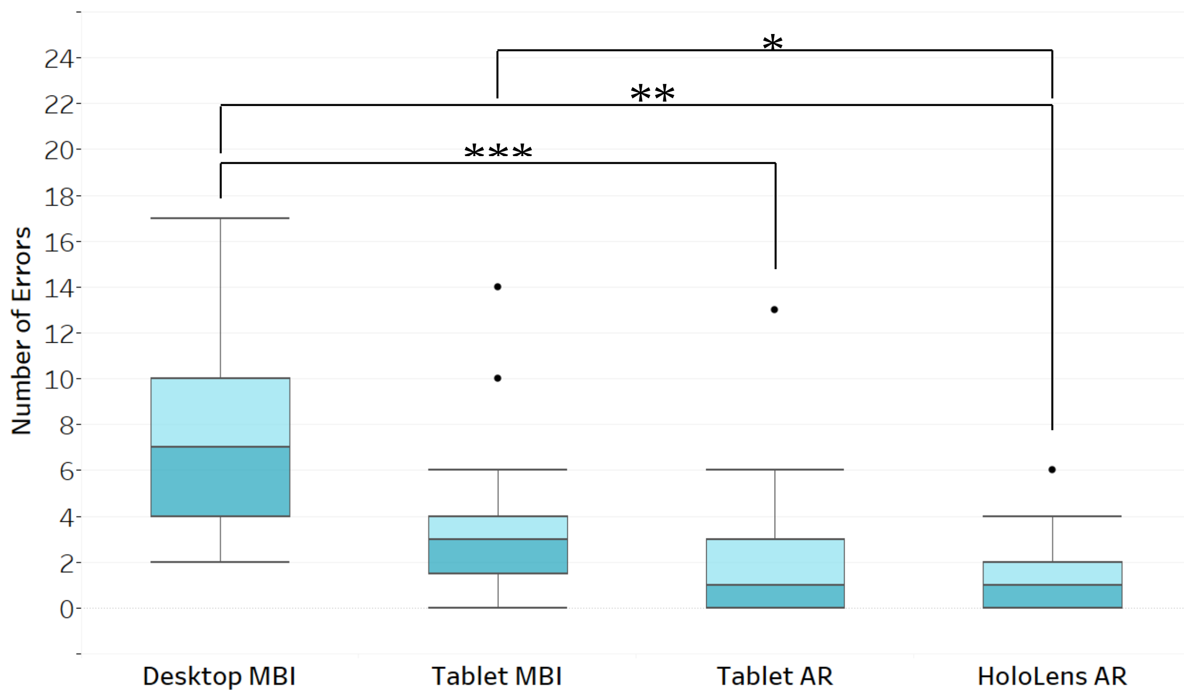

Figure 5. Bar charts of Trial 1 errors. (* indicates p ≤ 0.05, ** indicates p ≤ 0.01, * indicates p ≤ 0.001)**

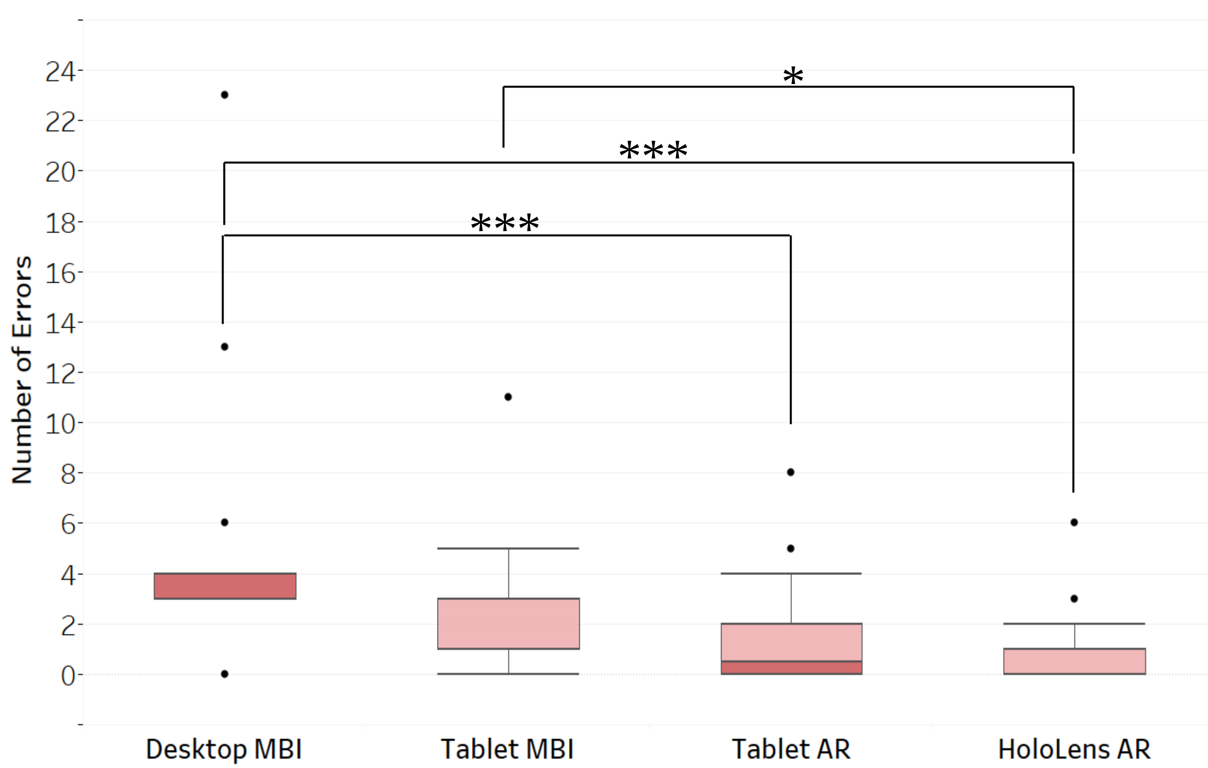

Figure 6. Bar charts of Trial 2 errors. (* indicates p ≤ 0.05, ** indicates p ≤ 0.01, * indicates p ≤ 0.001)**

DISCUSSION

Based on the results shown in the previous section, the HoloLens AR condition yielded better overall human performance than the Tablet AR, Tablet MBI, and Desktop MBI conditions. The advantages of the Microsoft HoloLens AR instructions are most evident in Trial 1 times. In the first trial, the median completion time for the HoloLens AR group was 16% faster than the Tablet AR group, 26% faster than the Tablet MBI group, and 29% faster than the Desktop MBI group. The completion times for Trial 2 were more similar. In this trial, the HoloLens AR condition was only somewhat faster than the Desktop MBI condition. This shows that this HoloLens AR instructions are very effective for reducing first-time task duration, but less effective for more repetitive tasks. This effect could be advantageous for military maintenance personnel who must frequently learn new maintenance procedures on the job.

The second measure of human performance, number of errors, showed that HoloLens AR users had lower median error rates than users of both the Desktop MBI and Tablet MBI conditions for both Trial 1 and Trial 2. No significant differences were noted between the HoloLens AR and Tablet AR groups for either trial. However, the error rates for both AR conditions were very low, equal to or near zero. This trend shows that a floor effect may have prevented the emergence of differences in this data. Therefore, it cannot be concluded whether there is a difference in the number of errors between the HoloLens and Tablet AR groups.

The NPS was used to measure user preference for the four instructional conditions. Despite the relatively higher performance characteristics associated with the HoloLens AR group, the HoloLens NPS of 14% was much lower than that of the Tablet AR condition (53%). However, both AR conditions greatly outperformed the Tablet MBI and Desktop MBI conditions in term of NPS showing that the AR instructions were preferable to the non-AR instructions. However, this result was unexpected. Some of this NPS gap could be explained by the lag in time between studies. During the interim period of about two years between the collection of the Tablet AR and HoloLens AR data, AR applications for mobile phones and tablets became much more popular, with the rise of games such as Pokemon Go. This new prevalence of AR technology to the general public could have desensitized users to the novelty of the technology resulting in lower NPS ratings.

The qualitative responses showed that although human performance was augmented using the HoloLens AR work instructions, there are still some limitations of the HoloLens that could be resolved. For example, some users reported that seeing the AR graphics constantly was distracting. This could be resolved by allowing the user to toggle the AR layer on and off. Another limitation mentioned by some participants was a lack of 3D tracking precision. However, the low error rate and significantly faster completion times observed by HoloLens users contradict this feedback and showed that any tracking errors which may have been present did not negatively affect their ability to perform the task quickly and accurately. Lastly, some users reported some discomfort when wearing the headset. Without further inquiry, it is not clear whether this discomfort was a result of the shape and weight of the headset or the way in which the HMD was adjusted.

CONCLUSIONS

The goal of this research was to expand upon previous work by analyzing the use of a modern HMD in a realistic assembly task. By conducting this user study, the authors were able to give a more thorough analysis of how the Microsoft HoloLens and its contemporaries can help augment human performance in realistic assembly and maintenance tasks. The results of the comprehensive user study showed that the use of the HoloLens AR guided-assembly instructions led to better human performance characteristics when compared to AR instructions shown on a mobile tablet device. The users of the HoloLens AR instructions also outperformed those who used traditional 2D text and image instructions presented on both a stationary and mobile platform, which is concurrent with the results of previous studies comparing AR and traditional work instructions.

This study exclusively studied the use of AR instructions for assembly tasks. Though this work showed that modern HMDs provide a significant benefit to human performance in assembly tasks, more research is needed to understand the benefits of these new AR technologies to disassembly and inspection tasks. However, the results described in this paper show promise for military maintenance applications. Specifically, the application of AR guided instructions using modern HMDs like the Microsoft HoloLens could result in cost savings and increased combat readiness if applied to military maintenance procedures. This technology can be especially beneficial for on the job training and applications in which maintenance personnel are constantly performing different procedures on a variety of machines.

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