Usability and performance assessment of augmented reality assistive tool

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Kurzfassung: Augmented reality (AR) technology has been widely applied in our daily life and work environments nowadays. From the general public to professional operators, after being exposed to and getting familiar with various types of information, users have gradually changed their operation patterns. Many traditional instruction interfaces and the operating modes may no longer meet the expectations and needs of modern users. In this study, we have investigated the performance of an electronics manual assembly task conducted under a paper-based instruction procedure and an AR-based assistive tool. Under these two instruction modes, the task completion time and accuracy have been measured, in addition, SUS (System Usability Scale) and TAM (Technology Acceptance Model) questionnaires have been applied to the participants. Results of 42 participants have shown that the order of using different instruction modes may influence the task completion time, highlighting the importance of prior AR experience and the advanced nature of AR technology. As for the TAM results, participants have expressed a positive attitude towards the AR assistive tool, perceiving it as valuable. During semi-structured interviews, participants have provided suggestions and feedback for improving the AR assistive system and user experience, which is highly valuable for future development.

Schlüsselwörter: AR (augmented reality) assistive tool, usability evaluation, task performance, TAM (Technology Acceptance Model)

1. Introduction

Considering the nature of work environment and condition in modern industries, the operator at the manufacturing site would require his/her both hands for performing some manual tasks with minimum constraints and loads. Therefore, modern see-through devices have been facilitating fast growth and advances in ergonomic research and is supposed to progress in improving the quality of our work and life. Concerning high mental workload, faulty operation, occupational injury, and accidents that happen frequently in manufacturing sites, it has become a valuable key solution if we could apply AR applications sufficiently for training, instructing, and supervising purposes in a hybrid simulated work environment. Such an immersive medium could help the operator to get into the use scenario and workflow more easily (or more likely). Utilizing the advantages of AR technology into the workplace may improve efficiency and reduce human errors. For example, Pesca et al. (2021) proposed a method for improving AR in the production line, focusing on the interaction between users and the system. The purpose of AR assistive tools is to generate value in reducing the frequency of human errors, reducing the time for operator training, and improving operating procedures.

AR technology has gradually scaled into the market and gained a significant commercial foothold. For an operator in a factory environment, the use of AR devices enables receiving the assistance of virtual technology and operating machines in the real environment at the same time. Therefore, the interface design should be simple and intuitive, so that users can quickly understand how to use it and use it effectively. (Vaughan-Nichols 2009). AR technology is applied in production maintenance and maintenance training systems, which results in better training effects and satisfaction levels. Besides, better user experience is found for indoors applications with the stable light and small environment scale (Leach et al. 2018).

2. Method

The main purpose of this study is to investigate the usability of an AR assistive tool, whether the introduction of AR tool may reduce the mental load of on-site personnel and shorten the operating time. In this experimental study, we have constructed and implemented an AR-based instruction tool following ergonomics principles and the development of human-computer interaction systems for smart manufacturing industries.

In this proposed AR assistive tool, we have included the image detection module, which allows for real-time detection of target status and therefore enables reporting of abnormal conditions and/or faulty operations, triggering guiding procedures in a visualized manner. The integrated interactive digital information includes aligning references, guiding procedures, judgment standards, operation process prompts, etc., and is realized on a HoloLens 2 (Microsoft, USA) AR device. A comparison study has been carried out by performing same manual tasks with our AR-based assistive tool and with a paper-based instruction brochure. Based on the operation procedures and instructions prompted by the AR interactive system or by the printed-out brochures, participants are asked to inspect or perform functional operations on a breadboard to complete the manual electronics assembly tasks. Task completion time and operation accuracy have been recorded during the manual tasks. SUS (System Usability Scale) (Brooke 1996) and TAM (Technology Acceptance Model) (Davis et al. 1989) are applied after performing the manual tasks.

Each participant has conducted a total of two experiments, one for performing tasks based on the paper-based instruction, and the other for wearing HoloLens2 based on AR-assistive system, and the order is randomized. Participants have been asked to perform two electronics assembly tasks as shown in Fig. 1. Two assembly tasks have the same amounts of required electronic elements and similar difficulty levels.

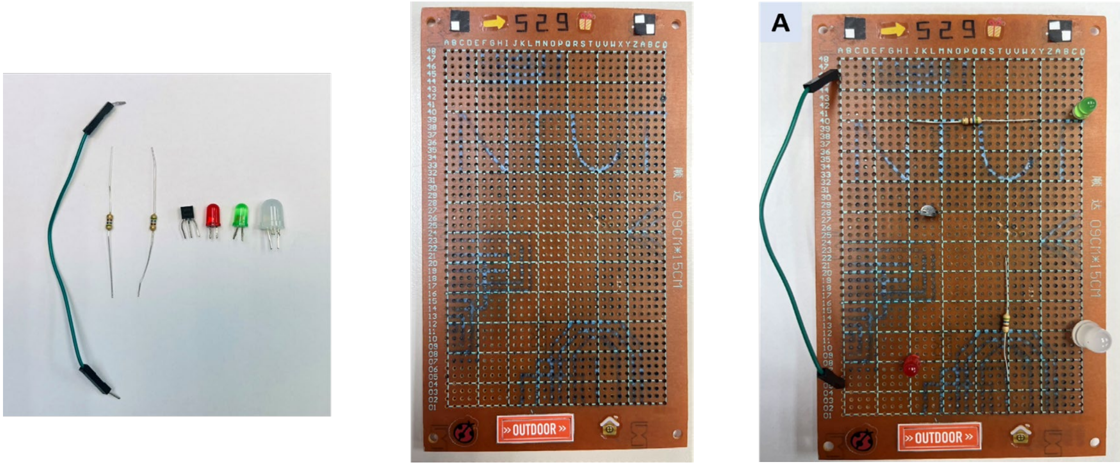

***Figure 1**: Electronics assembly task – (left) electronic elements used in the assembly tasks, (middle) front side of the circuit board, (right) final circuit layout of Task A.*

In the paper-based instruction mode, the assembly procedures consisting of step numbers, names and colored-pictures of circuit elements, X-Y coordinate on the circuit board of each element are provided to the participant on a print-out booklet. As for the AR mode, we have developed the AR assistive system based on Unity 2021.3.4f1 with MRTK module for user interaction features and integrated with Vuforia Engine 10.15.4 module for image detection features. In the AR mode, in addition to the information abovementioned in the paper-based mode, the image detection function would identify the circuit board layout and indicate the exact position for the electronic element to be assembled as shown in Fig. 2.

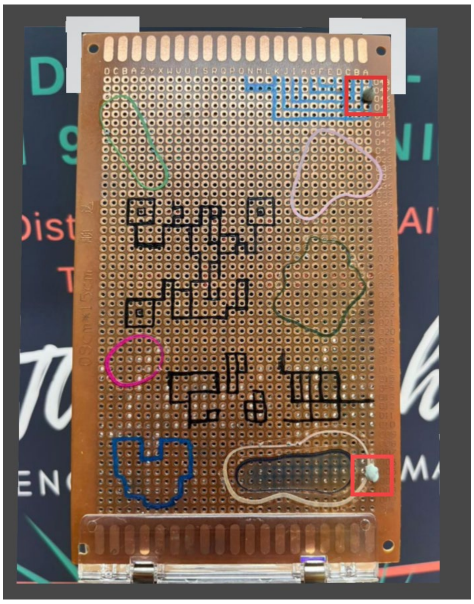

***Figure 2**: Demonstration of the image detection feature of the AR-assistive tool – the corresponding red rectangles are shown in HoloLens2 during the assembly task for each electronic element.*

3. Results and discussions

42 participants (21y - 28y, mean age = 24.02y, SD = 1.52y, 19f & 23m) are included in this study. Results of task completion time are 605.55s (mean, SD = 196.61s) in paper-based mode and 635.02s (mean, SD = 190.40s) in AR mode. Paired T-test reveals no significant difference (T(41) = -.769, p = .446). Results of task accuracy are 0.8402 (mean, SD = .2077) in paper-based mode and 0.7621 (mean, SD = .2598) in AR mode. Paired T-test reveals no significant difference (T(41) = 1.774, p = .084).

Results reveal that the sequence of using the different instruction tools influence the task completion time. In addition, participants with prior AR experience exhibit significantly better performance in task completion time and operation accuracy, and higher SUS scores. As for the TAM results, participants have shown a positive attitude towards the AR assistive tool. We hope that through the development of such AR-assisted tools, appropriate auxiliary information can be used to reduce operators’ mental workload, improve efficiency, and reduce the possibility of human errors.

4. Conclusion

The results of 42 participants have shown that the order of using different instruction modes may influence the task completion time, highlighting the importance of prior AR experience and the advanced nature of AR technology. Participants with prior AR experience have exhibited significant differences in completion time and accuracy, with higher SUS scores compared to others, indicating the impact of AR experience on satisfaction and acceptance.

Based on the TAM analysis, participants expressed a positive attitude towards the AR assistance system, perceiving it as valuable. During interviews, participants provided specific suggestions and feedback to improve the system and enhance the user experience, which is highly valuable for future development. In conclusion, the findings demonstrate the potential wide-ranging applications of AR technology in real-world scenarios. However, it is essential to consider the limitations and appropriate timing for implementing AR technology, as well as the necessity of prior training to fully experience the convenience and benefits of AR technology.

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