MOBILE AUGMENTED REALITY FOR MOBILE ROBOT ASSEMBLY MANUAL

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# MOBILE AUGMENTED REALITY FOR MOBILE ROBOT ASSEMBLY MANUAL

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**ABSTRACT**

In industrial operations such as assembly tasks, manuals or guidebooks are commonly used to convey information via visual methods in the form of text, pictures or videos and more recently Augmented Reality (AR) which has gained traction in recent years. However, several researchers highlighted their studies may not accurately represent actual assembly scenarios in terms of complexity as they use toys such as LEGO or puzzles or short assembly durations which may not show the effects of AR on the participant for longer assembly processes. The objective of this research is to design a developers-based algorithmic conversion of content in paper manual to AR-based manual, to develop a modified paper manual and AR-based manual for mobile robot assembly, and to evaluate the performance of paper manual, modified paper manual, and AR-based manual in mobile robot assembly. In this research, the mobile robot Turtlebot was used as the testbench which is a widely used mobile robot in research and requires approximately 3 hours for assembly. To develop the content for AR-based manual, a developers-based algorithmic technique from literature was adopted for textual instructions and modified to extract and convert visual information from paper manual. A study was then conducted to evaluate the effectiveness of three types of manuals which are paper manual, modified paper manual, and AR-based manual on participants' assembly performance. Overall, participants using AR-based manual completed the assembly faster by 21.72% while modified paper manual have an improvement of 7.5% compared to paper manual. In terms of number of assembly errors, AR-based manual and modified paper manual were found to have similar performance where the number of assembly errors is at 2.25 and 2 respectively while average assembly errors for paper manual is 5. NASA- TLX scoring showed higher mental workloads but lower frustration and effort from AR-based manual participants compared to other manuals. User satisfaction score is also highest for AR-based manual participants from the Likert-scale questionnaire. The contribution of this study is on the introduction of buffer steps during conversion of paper to AR-based manual which can be adopted for other paper manuals and the evaluation of participants' performance using longer and more complex assembly tasks. AR-based manual participants were also concluded to have an overall better performance.

# ABSTRAK

Dalam operasi industri seperti tugas pemasangan, buku panduan biasa digunakan untuk menyampaikan maklumat melalui kaedah visual seperti teks, gambar atau video dan kebelakangan ini menerusi kaedah realiti terimbuh (AR). Namun, beberapa penyelidik menyatakan bahawa kajian mereka tidak mewakili senario pemasangan sebenar dari segi kerumitan kerana mereka menggunakan alat permainan seperti LEGO ataupun mempunyai tempoh operasi pemasangan yang singkat dan tidak dapat menonjolkan kesan AR terhadap peserta dalam tempoh operasi pemasangan yang lebih panjang. Objektif penyelidikan ini ialah mereka bentuk cara "*developers-based algorithmic"* untuk penukaran kandungan buku panduan kertas (BPK) kepada buku panduan berbentuk AR (BPAR), membangunkan buku panduan kertas yang diubah suai (BPUS) dan BPAR untuk pemasangan robot mudah alih, dan menyiasat prestasi BPK, BPUS, dan BPAR untuk pemasangan robot mudah alih. Dalam penyelidikan ini, robot mudah alih Turtlebot digunakan sebagai alat ujian dengan purata tempoh pemasangan sebanyak 3 jam dan sering digunakan dalam bidang penyelidikan. Kandungan BPAR dihasilkan menerusi maklumat berbentuk teks dalam BPK diekstrak menggunakan cara "*developers-based algorithmic"* daripada kajian literatur dan diubah suai untuk ekstrak maklumat berbentuk visual. Seterusnya, keberkesanan antara BPK, BPUS, dan BPAR terhadap prestasi pemasangan peserta dikaji. Secara keseluruhannya, tempoh pemasangan pengguna BPAR dan BPUS lebih singkat dengan pengurangan tempoh pemasangan sebanyak 21.72% dan 7.5% masing-masing berbanding dengan BPK. Dari segi bilangan ralat pemasangan (BRP), BPAR dan BPUS didapati mempunyai prestasi yang hampir sama sebanyak 2.25 dan 2 masing-masing manakala BRP BPK ialah 5. Daripada pemarkahan NASA-TLX, peserta BPAR mempunyai persepsi beban kerja mental yang paling tinggi tetapi tahap kekecewaan dan usaha paling rendah berbanding dengan BPK dan BPUS. Skor kepuasan pengguna juga adalah tertinggi untuk peserta BPAR daripada soal selidik skala Likert. Sumbangan penyelidikan adalah penggunaan langkah penampan semasa penukaran BPK kepada BPAR yang boleh digunakan untuk buku panduan yang lain dan penilaian prestasi peserta dalam tugas pemasangan yang lebih lama dan kompleks. Pengguna BPAR didapati mempunyai prestasi yang baik secara keseluruhannya.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AR | - | Augmented Reality |
| SAR | - | Spatial Augmented Reality |
| MAR | - | Mobile Augmented Reality |
| NASA-TLX | - | NASA Task Load Index |
| QUESI | - | Questionnaire for intuitive use |
| SART | - | Situational awareness rating technique |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Augmented reality (AR) is one of the pillars of Industry 4.0 that can revolutionize interactive technology. It is a technology that spatially places digital objects to provide additional information by overlaying the digital objects with the physical world. In recent years, advancements in AR for mobile and web-based applications have led to greater research interests in this field [1]. The possibilities of AR had been shown in various applications in industry, medical, education, and entertainment [2]–[6]. The field of AR have also been a topic of interest for academic research for more than 50 years [7].

AR comes in many different forms, such as Spatial AR (SAR) that uses projector to superimpose digital assets on the real world. Another approach is called indirect AR where a camera is used to capture images from real world environment to be augmented with digital assets before being visualized on a monitor for the user. Head Mounted Devices (HMDs) such as Hololens on the other hand directly augments the image and projects them directly in front of the user which can provide a more immersive experience. Recent newer approaches also see Mobile AR (MAR) where mobile devices such as smartphones and tablets were used to augment and visualize the image on screen. This has made AR more accessible via MAR as mobile devices are ubiquitous in the current day and age. MAR also has the advantage of being less bulky and less complex to setup. MAR is used in this research as it is able to provide a suitable AR experience.

In contrast to conventional printed manuals and handbooks, AR can be used to project visual information or content on the physical environment which can provide clearer information than a printed manual [8]. The location and the necessary procedures to assemble/disassemble parts can be indicated by AR in a step-by-step manner to reduce the possibility of errors. Furthermore, AR can visualize interactive 3D models that can be more intuitive for the user to understand the assembly task especially if animated [9]. The 3D graphical models can also reduce ambiguity in instructions that may occur due to missing information from 2D graphical information.

Several researches had been conducted on the conversion of conventional manuals to AR-based manuals for maintenance. For instance, some research reused existing manuals to be converted for AR [9], [10]. Another research was conducted to represent common maintenance actions using 2D symbols to be visualized in AR [11]. Although these studies can provide consistency in the conversion process for AR manual, most of them utilize 2D graphics instead of 3D graphics to represent the information. Furthermore, some of them focus on the conversion of existing textual information and use images as references instead [9].

Participants' performance with AR-based manual is usually evaluated using total assembly duration and questionnaires. This is usually done by comparing these metrics between participants that use conventional manual and AR-based manual. Another approach evaluates participants' performance between three manuals instead. For instance, one research evaluated three manuals where the first manual was from their proposed conversion methodology which can be used for AR and labelled as visual. The second and third manual were original paper manual labelled as PDF, and paper manual using textual information and reference images from their proposed methodology but do not incorporate symbols and is labelled as iFixit respectively [9]. In this evaluation, it was found that both visual and iFixit manuals performed better than the PDF manual [9]. Information in the visual and iFixit manual was also found to be clearer compared to PDF in their study [9]. A similar approach for the iFixit manual was adopted in this research in the form of modified paper manual. The modified paper manual utilized the same information as the AR-based manual and was used to evaluate the effectiveness of AR when both manuals contain the same information. A comparison between paper manual, modified paper manual, and AR-based manual is also conducted in this research.

## 1.2 Problem Statement

As the world actively adopts the principles of Industry 4.0, the Malaysian government has also begun the process to transform the current manufacturing sector towards industry 4.0 via Industry4WRD policy [12]. This policy highlights several enabling technologies that drives the digitalization of the manufacturing sectors. One of the enabling technologies for this is AR. An industrial application of AR lies in assembly guidance where an AR application can be used to support or guide the user when performing assembly tasks.

Although research had been conducted for guidelines on the conversion process from paper manual to AR-based manual, most of them utilize 2D graphics such as symbols to represent the information [9], [11]. However, animated 3D graphics can provide a more immersive and intuitive experience in comparison with 2D graphics such as symbols [9]. Furthermore, the usage of symbols would require the users to learn the symbols beforehand which may be less intuitive. Existing research also focus on the conversion of existing textual information in the paper manual and use images as references instead [9].

Several researches have highlighted the benefits of AR for assembly operations but these researches generally perform tests for short durations [13]–[17] which range from a few minutes to forty minutes or uses toy puzzles or similar [18]–[20] as testbench. As the tests are performed for relatively short durations, the effects of AR on longer assembly processes in actual industrial assembly scenarios may not be accurately represented in terms mental workload and assembly complexity. Some research only utilized a subassembly or toy puzzle as testbench which also do not accurately represent actual industrial assembly complexity. Alves et al. [21] had also highlighted that Lego was widely used in research as a testbench but may not represent actual industrial complexity.

## 1.3 Objectives

The objectives of this research are as follows:

(a) To design the conversion of content in paper manual to AR-based manual for mobile robot assembly using developers-based algorithmic method

(b) To develop a modified paper manual and AR-based manual for mobile robot assembly

(c) To evaluate the performance of paper manual, modified paper manual, and AR-based manual in mobile robot assembly

## 1.4 Research Scope

The research is on the design and development of conversion of content in paper manuals to AR-based manuals process using developers-based algorithmic method. The AR-based manual consists of 3D graphical information that is used to guide the participant in performing step-by-step assembly instructions by providing textual information and animations. Animations were created based on the existing visual instructions in the paper manual while textual information were created based on the adopted developers-based algorithmic method from literature. The assembly task used to evaluate the participants' performance will only consist of mechanical assembly tasks that can be assembled by hand with screwdrivers. Turtlebot was used as the mobile robot to be assembled by participants using different manuals as it contains mechanical assemblies similar with industrial assemblies and takes an average assembly time of 3 hours. Using the Turtlebot mobile robot as testbench, the performance of the different manuals was evaluated with metrics such as assembly duration, number of assembly errors, NASA-Task Load Index (NASA-TLX) scoring, and Likert scale questionnaires.

## 1.5 Thesis Structure

Chapter 1 is an introduction on background, problem statement, objectives, and research scope on effects of AR for mobile robot assembly. The following chapter reviewed the literatures, works and theories that are related to this research. Research framework and proposed methods are then further described in Chapter 3. Chapter 4 showed and discussed about the obtained results from the three experiments conducted. In the last chapter, a concise conclusion about the outcome of this research was highlighted.

## 1.6 Research contribution

The hypothesis of this study is participants' that use AR-based manual will perform better than participants' for paper manual and modified paper manual. To test this hypothesis, a developers-based algorithmic conversion process inspired by Gattullo et al. [9] was adopted for the existing Turtlebot paper manual to create the AR-based manual to answer the first and second objective. In the adopted conversion process, this research proposed the usage of buffer steps and guidelines to create animated 3D graphics in the AR manual. Buffer steps were used when discontinuities occur between instructions that may not convey the required information fully and can be adopted for other manuals with similar problems. Participants' performance using paper manual, modified paper manual, and AR-based manual were then evaluated with Turtlebot mobile robot assembly tasks to answer the third objective. As highlighted earlier, several research utilized less complex assembly tasks and tasks with shorter assembly durations. In this research, the evaluation was conducted on Turtlebot mobile robot which shares similarities with industrial assembly tasks and have a longer average assembly duration of 3 hours.

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## LIST OF PUBLICATIONS

Ye Sheng Koh, Kai Woon Goh, Marvin Dares, Che Fai Yeong, Eileen Su Lee Ming, Mohd. Shahrizal Sunar, Yik Shin Tey., Dec. 2020, "A REVIEW ON AUGMENTED REALITY TRACKING METHODS FOR MAINTENANCE OF ROBOTS," JURNAL TEKNOLOGI, vol. 83, no. 1 SE-, pp. 37–43, (0.82)