Investigating different Augmented Reality Approaches in Circuit Assembly: a User Study

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Abstract

Augmented Reality (AR) has been considered as having great potential in assisting performance and training of complex tasks. Assembling electronic circuits is such a task, since many errors may occur, as wrong choice or positioning of components or incorrect wiring and thus using AR approaches may be beneficial. This paper describes a controlled experiment aimed at comparing usability and acceptance of two AR-based approaches (one based on a single device and another approach using two interconnected devices), with a traditional approach using a paper manual in the assembly of an electronic circuit. Participants were significantly faster and made fewer errors while using the AR approaches, and most preferred the multi-device approach.

CCS Concepts

• ***Human-centered computing*** → ***Mixed / augmented reality; Empirical studies in HCI;***

1. Introduction

Augmented Reality (AR) refers to the superposition of virtual layers over the real world to provide additional contextual information. What makes AR so attractive in assisting the performance of complex tasks is its potential to reduce cognitive load, task duration, errors, and facilitate effective training over most current practices [KBB*18]. These advantages combined with the emergence of more affordable and powerful devices with compact computer chips, cameras, and sensors, such as mobile devices and AR headsets [CBHH17] make AR especially suitable for maintenance and repair of complex equipment, as well as assembly of electronic circuits [Azu16, KBB*18].

Dunser et al. (2008) surveyed evaluation methods used in AR studies reported in 165 publications between 1993 and 2007, focusing on objective methods as formal qualitative analysis and the use of more general usability evaluation techniques. According to the authors there was a growing understanding of the need to formalise the evaluation process and conduct properly designed user studies [DGB08]. This trend is confirmed by Kim et al. (2018) and Dey et al. (2018) in their recent surveys, reporting a dramatic increase of evaluation research [KBB*18, DBLS18], which might be due to the fact that AR technology is getting mature and used, and thus new methods and systems need to be evaluated with real users.

In this vein we performed a study aimed at comparing the usability and acceptance of two AR-based approaches for electronic circuit assembly (one based on a single mobile device and a another novel approach using two interconnected devices) to a conventional approach based on paper documentation. In the rest of this paper we describe the setup, design and procedure used in a controlled experiment, present and discuss the results obtained by 24 participants, and draw conclusions and ideas for future work.

2. Related Work

Most current research focus on software-related issues and tools for easing the development of electronic circuits; nevertheless, understanding how to properly support inexperienced users with electronic circuit construction is emerging as a recent topic of research [BSBJ16].

Hahn et al. (2015) proposed an AR-based assistance for teaching the assembly process of printed circuit boards to workers using smart glasses. The system detected QR-Codes, highlighted the location of components and installation point in the user's field of view. A study performed in a production line of an Electronics Manufacturing company with 30 participants resulted in an errorless performance of the participants equipped with the system. Almost all participants acknowledged that the assistance contributed to the learning process and that a permanent deployment in the production line could be a relevant asset [HLW15].

Loch et al. (2016) evaluated an AR-based assistance system integrated in a manual workstation to perform assembly tasks using hardware components. A study was conducted with 17 students. The AR-based solution was compared with video-based assistance regarding performance, user acceptance and mental workload. Results showed improvements in accuracy as the number of errors was

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significantly reduced. There was no significant reduction of time as time to fix errors was not measured. If it had been considered, the AR-based system would provide further benefit. Moreover, a significant effect of perceived ease of use was observed [LQB16].

Recently, Bellucci et al. (2018) studied the effectiveness, usability, and cognitive load of AR visual instructions to guide novice users in building electronic circuits. A mobile-based AR tool was compared to traditional media, such as paper-based and monitor-displayed electronic drawings. Results of a between-subjects experiment with twenty four participants show that superimposing components and instructions through AR reduces the number of errors, allowing users to easily troubleshoot them, while reducing their mental workload [BRDA18].

These works show AR-based technologies provide interesting tools to minimise errors while decreasing mental workload. Nevertheless, the device screen may be too small to display all the information without obstructing the region of interest, and thus an extra screen may be useful. Yet, to the best of the authors' knowledge, a multi-device AR-based approach, able to present distributed and customizable information among devices, has never been explored. Hence, there is a need to compare it with traditional and other AR approaches to better understand their benefits and limitations.

3. The Study

This study aimed to compare the usability and acceptance of two AR-based electronic circuit assembly approaches with presenting instructions and help using paper documentation. These three methods were selected after an exploratory test performed to help elicit feedback about the approaches to compare, select the task as well as the experiment procedure.

3.1. Task

The task was designed as to have the main features of assembly tasks (beyond circuit assembly). Usually, these tasks have several steps with different goals and require the usage of different components. In this task the participants had to identify the component to be used in each situation, arising the need of understanding the proper position and orientation of each component in a breadboard. The initial circuit configuration (Figure 1) was the same for all participants in every experimental condition. It consisted in a breadboard with a few components already in place and other components, needed for the task or not, organised on the table within reach of the user. The task included the following six steps: 1- connect the PIC to the ground using a blue cable; 2- supply power to the PIC using a red cable; 3- connect a LED to a specific line and ground; 4- connect three resistors to the LEDs; 5- connect a dip-switch; 6- connect a resistor for each switch.

3.2. Experimental setup

The three methods compared correspond to different types of information support provided to the user: one paper-based and two AR-based. The former presented the instructions in a conventional paper document (Figure 2). The other two used one and two mobile devices respectively, using an AR setup described in a previous work [MAE*18]. In both cases an AR application overlaid indicative virtual objects on the image of the circuit as shown in Figure 3. The second AR condition included another device to display synchronised information to help performing the task (Figure 4). The virtual information overlaid depends on the type of component to be used in each step. Virtual objects are aligned with the intended position of the components; however, it can be difficult to identify their correct place on the breadboard due to its small size. To help the user in this perception task visual guidance is provided regarding the name of the slot. Also, blue and red lines are superimposed on the power rails.

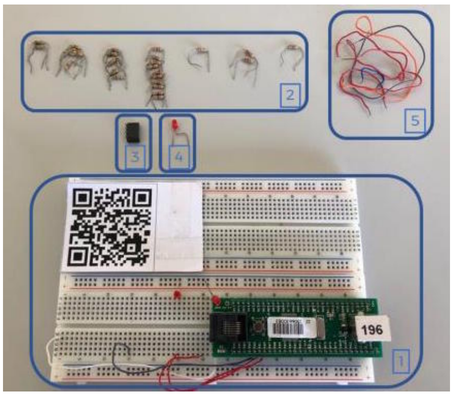

Figure 1: *Initial situation: 1 - breadboard with QR code and some components in place; 2 - resistors organised according to colour code; 3 - dip-switch; 4 - LEDs; 5 - cables of different colours.*

3.3. Experimental design

The null hypothesis (H_0) considered was that the three methods (experimental conditions) are equally usable to perform the task. The independent variable was the type of information support provided to the user, with three levels corresponding to the three methods/ experimental conditions: 1- Paper documentation: The user performed the assembly using the instructions presented in a conventional paper document (Figure 2). 2- Single device AR approach (ARSd): The user performed the assembly using visual instructions, presented on the screen of a mobile device (smartphone) regarding the place of intervention and the components required, in each step (Figure 3). These instructions are overlaid on a live stream captured from a mobile device camera. 3- Multi-device AR approach (ARMd): The user performed the assembly using the instructions presented in two distinct devices. This approach uses one device (smartphone) to display aligned information and another one (tablet) to present detailed (synchronised) information regarding the task being performed, thus freeing space on the device presenting aligned content (Figure 4).

Performance measures and participants' opinion were the dependent (output) variables. The performance measures were: 1- Time (seconds): time taken to complete each step (logged by the application), and total assembly time. 2- Errors: number of errors made by the participant in each step, and number of errors that the participant rectified. Participants' opinion was obtained through a post-task questionnaire. A within-group experimental design was used;

all participants used the three experimental conditions, but the order was varied among participants to avoid bias due to learning effects. The order in which the conditions were used, as well as participants' demographic data and previous experience with AR and circuit assembly, were registered as secondary variables.

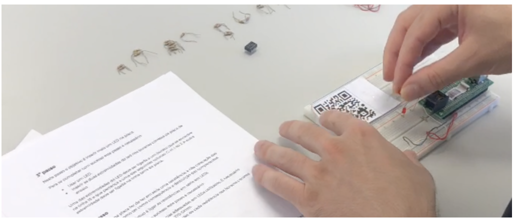

Figure 2: *Condition 1- Circuit assembling using the conventional paper documentation approach.*

Figure 3: *Condition 2- Circuit assembling using the AR single-device approach.*

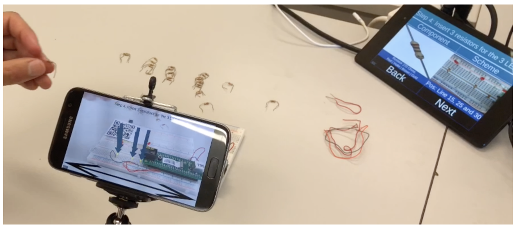

Figure 4: *Condition 3- Circuit assembling using the AR multi-device approach.*

3.4. Experimental procedure

At the beginning of the experiment each participant was briefed about the experimental setup and the task and gave their informed consent. Then they were asked to consider two levels of priorities: first minimize errors, and then minimize assembly time. Participants were observed by an experimenter who assisted them if they asked for help and used a standard form to make annotations (e.g. the number and type of errors: wrong connection, wrong resistor values, etc.). After completing the task using the three conditions, participants answered a questionnaire with general questions about age, gender and previous experience with AR, as well as with electronic circuits. Moreover, questions concerning the three methods were also asked in order to assess the acceptance and ease of use of each method, as well the participants' preferences.

3.5. Participants

Twenty four participants (9 female) aged from 17 to 47 years old, performed the assembly task and completed the questionnaire. Participants had various professions (e.g. students, programmers, health professionals and factory workers); 17 participants had never assembled an electronic circuit and 14 had never used AR before.

4. Results and Discussion

This section presents and discusses the main results obtained from performance measures and opinion. As a first step, an Exploratory Data Analysis of the task completion times and errors for each experimental condition was performed to obtain insight concerning their range and symmetry. Then, a Contingency table was used to assess the influence of the participants' previous experience with AR and circuit assembly on their performance. A Fisher test did not reject the independence (p-value=0,075 > 0,05), suggesting that the participants profile did not influence their performance. Times and errors were analysed using a Friedman test (non-parametric ANOVA), because there were three conditions, the experimental design was within-group, and the normality or the homoscedasticity of these data was rejected using Shapiro-Wilk or Levene tests. Finally, the participants' preferences were tested using a χ^2 test.

Figure 5 shows the boxplots of the time required to complete the circuit assembly for each experimental condition. Participants were slower when they used the Paper condition (median=603,5s) than when using the AR conditions: ARSd (276,0s), and ARMd (263,5s). As a Friedman test rejected the equality hypothesis H_0 (with p-value=0.000), multiple comparisons pair tests were used to find the pair(s) responsible for rejecting the equality of medians. These tests show that the median of the time for the Paper condition is different from the medians of both AR conditions, yet there is no significant difference between the median times for ARSd and ARMd.

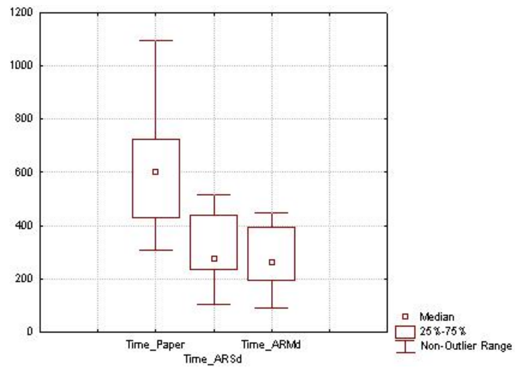

Figure 5: *Boxplots of the time (s) for the three conditions.*

Figure 6 shows the boxplots of the participants' errors for each experimental condition. Participants made more errors when they used the Paper condition (median=2) than when using the AR conditions: ARSd (0), and ARMd (0). As in the case of times, a Friedman test rejected the equality hypothesis H_0 (with p-value=0.000) and multiple comparisons tests showed that the median of the errors for the Paper condition is different from the medians of both

AR conditions, but there is no significant difference between the medians for ARSd and ARMd.

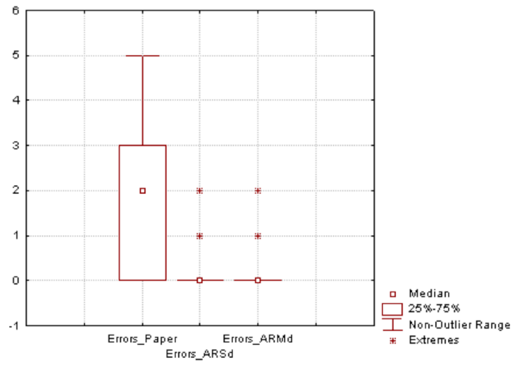

Figure 6: *Boxplots of the errors for the three conditions.*

The answers to the post-task questionnaire show that all participants preferred one of the AR approaches; 18 preferred the multi-device approach and 6 preferred the single device approach, which is a statistically significant result (χ^2 test, p-value=0,02). These answers also show that participants recognized the advantage of using the main device to understand where they should place specific components on the breadboard, while more detailed information was presented in the second device. However, participants also recognized that the multi-device approach would be more beneficial for more complex tasks. Thus, in a future study it is important to address the complexity of assembling tasks.

Although the AR approaches did not present significant differences in user performance according to the statistical analysis, we argue that the multi-device approach may have more advantages. For example, it offers the possibility of exploring different types of content in the second device as animations and videos (preventing clutter of the main device screen) while the main device is used to present information aligned with the breadboard. In addition, a predefined layout to visualize information can be available for each device. However, it is important to explore how users can customize the layout to understand what type of information can be more relevant, and how to better present it, since a fixed design can be restrictive. It is also relevant to define guidelines concerning when and how to use an AR-based multi-device approach. In a future study, besides including more complex tasks, it is important to involve a larger group of participants trying to obtain significant differences and more insight concerning the proposed approaches.

5. Conclusions and Future Work

The main contribution of this paper is a formal study comparing two AR-based approaches for electronic circuit assembly (one based on a single mobile device and another novel approach based on two interconnected devices) with a traditional paper-based approach. Participants performed significantly better with the AR-based approaches (with lower completion task time and number of errors) when compared to the paper-based approach. While these performance results do not allow to differentiate between the AR-based approaches, participants preferred the multi-device approach. Nevertheless they identified the need to have tasks with enough complexity to justify its use.

Work will continue through the definition of guidelines concerning how to present information in a multi-device scenario. In addition, the current prototypes will be improved, making them more suitable for large scale user-testing, allowing to explore the potential of the multi-device approach in terms of reducing the cognitive load required to perform circuit assembly. Besides, future experimental designs must be addressed to tackle learning effects.

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