Evaluating the User Experience of Microsoft HoloLens and Mobile device Using an Augmented Reality Application

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Abstract

Context. In recent years, every one is completely relying on using computers and smart phones in our daily activities. Augmented Reality will superimpose virtual and computer generated information on top of the real world. Volvo Construction Equipment (VCE) team is planning to use Augmented Reality applications on a real construction site to track the details of the vehicles without going to the laboratory. An Augmented reality application is developed for Microsoft HoloLens and Mobile device and the user experience is evaluated. This research has been conducted at PDRL-BTH, in collaboration with VCE.

Objectives. In this research, the key attributes are collected, which should be displayed in both the devices and compare the user experience using user satisfaction score. Furthermore, this research involves exploring and evaluating the difference in the user experience between both the devices.

Methods In this study first an interview is carried out with the design engineers of VCE team. Some open-ended questions were asked to the VCE team. The information required from the VCE team is collected and documented and further an experiment on the user experience has been conducted to calculate the User Satisfaction Score between the Microsoft HoloLens and Mobile device. After the experiment, significant difference has been measured using statistical techniques among the two devices. To measure the size of the difference Cohen’s D effect size is used.

Results. The significant difference on the User Satisfaction Score of two devices has been done using T-test. The results state that the significant value is less than 0.05 and hence the null hypothesis is rejected. The measurable difference states that Microsoft HoloLens has better user interface than the Mobile device with respect to the User Satisfaction Score.

Conclusions. After obtaining the results and analyzing the data, we conclude that there is a significant difference in the user experience of Microsoft HoloLens when compared to Mobile device. We also conclude that Microsoft HoloLens has better user experience when compared the Mobile device.

Keywords: Microsoft HoloLens, Augmented Reality, Mixed Reality, Mobile device, User Experience, User Satisfaction Score.

ACM classification: H.5.1[Information Systems]:Human Computer Interaction - Mixed / Augmented Reality
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Finally I want to dedicate this thesis to my family.
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List of Abbreviations

- **AR** - Augmented Reality
- **AV** - Augmented Virtuality
- **CAD** - Computer Aided Design
- **HHD** - Hand-Held Display
- **HMD** - Head Mounted Device
- **HMPD** - Head Mounted Projective Display
- **HCI** - Human Computer Interaction
- **IDE** - Integrated Development Environment
- **MR** - Mixed Reality
- **OST** - Optical See through
- **PDRL** - Project Development research Lab
- **ST-HMD** - See-Through Head-Mounted Display
- **SDK** - Software Development Kit
- **UI** - User Interface
- **VST** - Video See Through
- **VCE** - Volvo Construction Equipment
- **VR** - Virtual Reality
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Chapter 1

Introduction

Augmented Reality (AR) can be represented as an enhanced view of the real-world by augmenting the surroundings with some virtual objects or computer-generated data[1].

Virtual Reality (VR) is a term which is often used to describe the systems that replace a user’s surroundings with a virtual world in the aspects of vision and sound and completely immerse the user in the virtual environment [2]. Whereas in AR the real world can be visible and audible, the user will not lose the sight of the physical world. AR augments the real world rather than completely replacing it [3]. A transparent 2-D screen will be overlaid on top of the real world which can be anything from pictures and text to symbols, displayed from an AR Head-mounted device [2]. Mixed Reality (MR) is a combination of both VR and AR. One of the common similarity between AR and VR is represented as Reality-Virtuality continuum by Paul Milgram [4].

![Figure 1.1: Simplified representation of Reality-Virtuality continuum by Paul Milgram [4]](image)

As we can see in Figure 1.1, Paul Milgram described MR as a continuum that ranges between the real world environment and virtual environment which contains Augmented Reality and Augmented Virtuality (AV) in between them, where AR is adjacent to real-world environment and AV is adjacent to virtual
world environment [1]. MR is very similar to AR. In AR, 2D transparent screen with virtual objects will be overlaid on it. MR not only overlays the virtual objects but also carries the 3D virtual objects in the real world where the user can interact with these 3D objects using hand gestures and voice commands. Microsoft HoloLens is considered to be one of the first Mixed Reality Devices, which is created and developed by the Microsoft Company [5]. It enables a 3D virtual object over a traditional 2D virtual object in the real world environment [6]. It is a lightweight Mixed Reality Head-mounted device that projects 3-D holograms onto the user’s view and enables the user to interact with those holograms using hand gestures and voice commands [6]. Microsoft HoloLens can be useful in many ways. The device can be considered as a portable mini-computer, as it can be operated without connecting it to an external machine [6].

In huge construction sites, there will be many vehicles working around. So, to monitor the data such as the task assigned to the vehicle, the load it is carrying or the fuel that has been consumed by the vehicle, etc., is quite a tedious task [5].

Developing an AR application for the Microsoft HoloLens or a Mobile device to monitor the data of the vehicles in the construction field will allow the person responsible at the site to recognize the vehicle and see the status of the vehicle while looking through the AR devices. One of the main motives of this thesis is to develop an AR application to display the user interface of an automated machine while looking at the machine through Microsoft HoloLens or a Mobile device.

1.1 Problem Statement

There is impressive growth in the field of Augmented Reality technology in recent years. It is a technological concept which was introduced in 1968 by Ivan Sutherland [7][8].

AR significantly depends crucially on the hardware equipment parts that can capture and record the data about the real world, such as location data, video data, and can play a live-video presentation that mixes live content in a virtual way without any delay i.e., user-friendly.[9]

In recent years, almost everyone has a smartphone which means that everyone is having AR capability in their pockets. This led to an increase in interest in AR development.[9]

A real construction site is very large and the machines at the construction area perform several tasks and it is important to track the work details of every machine and it is difficult to manage complex tasks at the site using a computer. The main problem at a construction site is that there might be many machines and vehicles working, and to be able to see the information like the fuel, efficiency values, and even the load weight of the machine and other tasks one must use the highly efficient computers and also these computers might be located far away

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from the working area and hence it is not efficient and difficult to track the details of the machines at the site.

In this research, an application will be developed for Microsoft HoloLens and Mobile device that displays the information panels about automated machines. Then the user-experience with the displayed data in Microsoft HoloLens and Mobile device will be compared. Research must be conducted to check if its worth having to use such devices.

The proposed thesis should develop an application that displays the user interface of an automated machine for Microsoft HoloLens and a Mobile device. Then the user experience with the displayed data in Microsoft HoloLens will be compared with the displayed data in the Mobile device.

1.2 Aims and Objectives

The aim of this thesis is defined as follows as per the requirements of VCE and PDRL-BTH:

1. Comparison of display techniques to display the User-Interface of an automated machine using Microsoft HoloLens and Mobile device.

Thus the following objectives are identified which have to be fulfilled in order to achieve the aim of this thesis work:

1. To identify the key attributes or information that should be displayed in the user interface of an automated machine.

2. To compare See through Head-mounted Display (Microsoft HoloLens) and Hand-held Display (Mobile device) techniques and display the user interface of an automated machine in both the devices.

3. To examine and evaluate the user experience in interacting with the displayed information of an automated machine in both devices (See through Head-mounted Display and Hand-held Display).

1.3 Research Questions

Based on the objectives, research questions are formulated as follows:

- **RQ1**: How should the user interface be displayed for best user experience and what are the key attributes that should be displayed?
Motivation: To identify and select the main features of an automated machine that should be added to the display panel and to develop an interface to interact with an automated machine using Microsoft HoloLens. Thus fulfilling Objective 1.

- RQ2: How is the user experience with the developed user interface in Microsoft HoloLens compared to Mobile device.

Motivation: To build an AR application that displays the information panel of an automated machine in Microsoft HoloLens and in a Mobile device and compares the user interface of both the devices by evaluating the user experience. Thus fulfilling Objective 2 and Objective 3.

1.4 Thesis Outline

The Thesis is structured as follows:

- Chapter 2 covers background and related work on AR technology and the devices used for the development of AR applications. It highlights the methods used for the development of applications for Microsoft HoloLens and Mobile device.

- Chapter 3 describes the methods adopted in the research. Interview and experiment are selected as a research methods which are well explained in detail how they have been conducted and analyzed.

- Chapter 4 presents the results obtained from the experiment conducted on the user experience for the test subjects.

- Chapter 5 covers the findings of the results. The results obtained in the experiment are analyzed and well explained.

- Chapter 6 describes the discussion and the limitations while considering the research. The threats to validity are also discussed in this chapter.

- Chapter 7 presents the findings of the experiment and concludes the results while discussing future work.
Chapter 2

Background and Related Work

2.1 Background

2.1.1 Human Computer Interaction

Human-Computer Interaction (HCI) deals with the implementation and evaluation of the ways that humans interact and use a computer and other electronic devices [10]. AR has importance in the development of applications for user interaction [11]. HCI focuses on the user experience between the human and the computer. HCI plays an important role in studying in the fields of VR, AR and MR which are some of the important classifications of information system in the field of computer science [12]. AR has gained a lot of importance in recent years, but the methods of information exchange between AR devices and users are still not clear [13].

The main interactive objects for the users in AR devices are the surrounding environment and the virtual objects. The active participants are the users i.e. the people who do interactive actions with the virtual objects in the real world with hand gestures and voice commands [12]. The users play an important role in the human-computer interaction cycle [13].

2.1.2 Augmented Reality

AR is the terminology which is used to merge real-time direct or indirect view of the real world with virtual data in it. The idea is to mix the virtual data which is really not visible to the user and augment the surroundings around them with a head-mounted device or a Mobile device [9].

2.1.3 Mixed Reality

Mixed Reality is similar to Augmented Reality. AR overlays virtual objects into the user’s view whereas, MR not only overlays but also holds the 3-D virtual objects to the real world and the user can interact with the 3D virtual objects using hand gestures and voice commands.
2.2 Related Work

In the research [5], the user experience on the quality of visualization and interaction with automated machines using an AR application in Microsoft HoloLens were discussed and furthermore, a survey was conducted on the idea of controlling vehicles using Microsoft HoloLens in the real world and the user experience on controlling automated vehicles using Microsoft HoloLens through voice commands was also investigated [5].

Jacob Lites in [14] proposed an implementation that scans the QR code and gathers information from the environment and stores it in the database to access and display the information on Google glasses. For a more in-depth and detailed analysis of data, this information was mirrored by the web interface to bring real-time info-graphic information related to the scanned QR code [14].

An Arilyn mobile application was converted to an AR application for Microsoft HoloLens in the article [15]. The data-types like image, sound, and video will be displayed simultaneously in the Microsoft HoloLens if multiple targets are set on the Arilyn application. There is a scanning instruction button on the target to display the content which was set on Arilyn application. This application uses spatial mapping function which now used in Microsoft HoloLens. But the 3-Dimensional data-types were not displayed [15].

An investigation on the human factors and the development in the mobile augmented reality research has been done by Gervaut et al [16]. An AR application was developed and a part of the user interface by 3D interaction with the user was investigated. Interaction with handheld AR was explored by considering the factors like visualization, localization and tracking [16].

Kerr et al. [17] evaluated the outdoor user experience on wearable Mobile AR application. This research explored the user experience on acceptability of using a wearable head mounted display in an outdoor urban environment. The wearable system developed by Steven Kerr et al [17] consists of a monocular See-through head-mounted display with visual graphics and information transferred from an attachable Mobile device. The user study on investigation of wearable HMD in the real world environment using the hand gestures input to know the information about how the system alters the user experience was discussed in this research [17]. This research further highlights the problems faced in using the gesture inputs and rendering the graphics form the device.

Furthermore, a review was conducted by Feng Zhou et al [18], on emerging trends and technologies in AR and MR on the last ten years development of the work that was presented at the ISMAR conference. This research was mainly focused on recent developments and the problems in AR/MR field. They also discussed the tracking, interaction and display techniques in AR/MR field. Feng et al [18] also explained about the types of display technologies like See-Through Head-Mounted Display, projection-based display and Hand-Held Display.

This paper provides a future map for the researchers who want to explore
something about AR/MR and its relative technologies in this area.

Analyzing the paper [18], the display technologies mainly focuses on three types: (i) See-through head-mounted display, (ii) Projection based display and (iii) Hand-held Display.

1. See-through Head-mounted display:
According to Feng et al [18], "See-through HMDs are mostly employed to allow the user to see the real world with virtual objects or images superimposed on it by optical or video technologies". The See-through HMD's are divided into two categories: (i) Optical See-Through (OST) HMD and (ii) Video See-Through (VST) HMD. Optical see-through displays allow the user to view the real world directly with the user's eyes and overlays the graphics onto the users view by making use of a holographic optical element, half-silvered mirror technology [18].
Video see-through Head Mounted Displays (VHMD) are those in which the user has a video view of the real world with graphics overlaid on it.
Examples for See-through Head-mounted displays are Google glasses, Microsoft HoloLens.

2. Projection based display:
Projection based display or Head-mounted Projective Displays (HMPD) is an alternative to HMDs [19]. They typically make use of a pair of miniature projectors mounted on the head which projects images onto retro-reflective material which then is reflected into the users' eyes [18].
A projection-based display is a nice option for applications that do not require several users to wear anything, providing minimal intrusiveness [18].

3. Hand-held Display:
A Handheld Display is a small display that fits in a user's hand. The two main advantages of Handheld AR are the ubiquitous nature of camera phones and the portable nature of handheld devices [18].
"Handheld displays are a good alternative to HMD and HMPD systems for AR applications because they are easily maintained, affordable and easy to handle, readily available, minimally intrusive, and highly mobile." Examples of handheld devices are Tablets, Laptops, PCs and smart mobile phones [18].

There are many previous works which are related to AR field, for example an AR application for heads up display technology, where HMD is combined with head position sensing to display computer-generated diagram in to the real world, [20] an AR application to detect images and objects using Mobile device [9] another application is to draw outlines in the mid-air using hand-gestures [21].
and a lot more applications were done for Mobile devices \cite{22, 23}. A lot of work can be done using augmented reality applications.

The main motive was to select an AR device that enables the Volvo Construction Equipment (VCE) engineers to have access to all the information associated with the autonomous vehicle instead of depending on laptops which are difficult to carry in the construction site. There are two types of AR devices that can be used in our study: 1. Head-Mounted Display device and 2. Handheld Display device.

Microsoft HoloLens is selected among all other head-mounted display devices. Motivation: Microsoft HoloLens is one of the best head-mounted display device which is currently available in the market with and the device is provided by the company.

Mobile device (Samsung Galaxy s8+) is selected among all other Handheld display devices. Motivation: The Mobile device is easy to use, carry and is faster when compared to other handheld devices. Nowadays everyone has a smartphone and has experience in using mobile AR technologies like Instagram, snapchat etc. Samsung Galaxy S8+ is selected as a Mobile device because it has a big screen (has the best display in the market). It has the latest android specifications and is provided by the company.

As per our existing Knowledge, in previous studies, works have been done on the development of head-mounted display, hand-held display and projection based display devices individually. This research is focused on the comparison of two display devices i.e. see through-head mounted display device and handheld display device by evaluating the user experience from the rating points given by the users. This thesis is intended to measure the user satisfaction score between the users of the Mobile device and Microsoft HoloLens. So, the main aim of this research is to bridge the gap and the results obtained in this research would serve as a base for the future researchers in this area.

The proposed thesis should develop an application that displays the information of an automated machine for Microsoft HoloLens and Mobile device. Then the user interaction with the displayed data developed in Microsoft HoloLens will be compared with the displayed data developed in the Mobile device.
Chapter 3

Method

This chapter describes the research method that has been used to accomplish the aims and objectives which are described in chapter 1.

3.1 Interview

Motivation for selecting Interview:

Interviews are defined as a qualitative research technique which are designed to collect a rich information regarding various elements such as attributes, preferences, behaviour, knowledge, opinion from small set of respondents [24][25]. Interviews are said to be the most effective method for data collection in qualitative research [25]. Apart from interviews, questionnaire and observation can also be used as data collection techniques.

Questionnaire method of collecting data is carried out by emailing or manually delivering the questionnaire to the selected respondents in a written format. A questionnaire typically consists of a series of questions along with the choice of answers for each question, among which the respondents are supposed to choose one or many depending on the requirement of the researcher [26].

On the other hand, observations are carried out to investigate how a task is conducted, typically by an engineer. Observations in meetings is another technique where attendants of a meeting elicit information about the studied object by interacting with each other in a meeting [27].

Analyzing these three techniques, observation technique is ruled out since it is not apt for data collection in this case. Among the other two methods, Interview has been selected over questionnaire because questionnaire is objective in nature and only supports close-ended questions, while Interviews are subjective in nature and enable the researcher to collect rich and analytic information through open-ended questions [26].

Generally, in Interviews, the selected respondents are asked a series of questions based on the research questions formulated. These questions can either be open-ended or close-ended. Open-ended questions allow a wide range of answers from the respondents while for close-ended questions, the respondents are allowed to chose only from a limited set of answers. Interviews can be further divided into
three categories – Unstructured interviews, Semi-structured interviews and Fully structured interviews [27].

In an unstructured interview, the researcher formulates the interview questions based on his general concerns and the conversation during the interview develops based on interest of the subject as well as the researcher. Therefore, this type of interview comprises mainly open-ended questions. In contrary to unstructured interviews, all the questions are planned in advance in a fully structured interview and are asked in the same order as devised in the plan. Therefore, these questions comprise only of close-ended questions [27].

In a semi-structured interview, all the questions are pre-planned like in the case of fully structured interviews, but they need not be asked in the same order as planned and the interviewer has the flexibility to decide the order depending on the development of the conversation in the interview, also making sure at the same time that all the questions have been covered.

The semi-structured interviews mainly provide room for the researcher to improve and explore the area of study and enable the researcher to change questions accordingly. Therefore, these interviews comprise both open-ended as well as close-ended questions [27].

Semi-structured interview has been selected to answer the RQ1 since it is the most appropriate method to understand and elicit the requirements from the respondents. A series of questions consisting of both open-ended as well as close-ended questions have been prepared and a semi-structured interview was conducted. A semi-structured interview is more suitable in this case because the questions were not asked in a specific manner or as listed in the document, allowing the respondents to answer their own form of opinion, rather than answering 'YES' or 'NO' for pre-framed questions [28]. So, the semi-structured interview will be a more suitable method to gather information from the respondents.

Three subjects - two design engineers from the Volvo Construction Equipment (VCE) team and our external supervisor provided by Volvo CE have been selected as the respondents for the interview. Face-to-face interviews were conducted to collect the data from the respondents. The main purpose of this interview is to collect the information of an automated machine that the VCE team wants to interact with and display that information in Microsoft HoloLens. Audio of the discussions during the interview sessions were recorded and then transcribed into text and later tabulated for further work. The subjects who participated in the interview were also notified that a recording of the interview was being made for academic purposes before the commencement of the interview [27].

The main reason for conducting this interview was to collect qualitative data from the respondents i.e. the key attributes that are to be displayed in the device. As a result, richer and deeper information was gathered from the Volvo team regarding how the interface should be designed for the Microsoft HoloLens and Mobile device, if they would like to use it in the real construction site.
Chapter 3. Method

3.2 Experiment

Motivation for selecting experiment:

Experiments are conducted to compare and study various trends, techniques and methods etc [29]. In experimental studies, users can be variables of the experiment which is being conducted [30]. This allows many types of measurement methods which will give more details about the estimation of computational methods. Statistical analysis can be conducted by measuring the effect of the manipulation [29]. In this research study, statistical significance difference is measured by calculating the user satisfaction score. Therefore an experiment is selected as a research method. Alternatively, a case study or a survey can also be used a research methodology.

A case study can be used for monitoring the projects or assignments. The level of control in the case study is comparatively low than in experiment [29]. A case study is an observational research study i.e., The research is done by observation of an on-going activity or a task. The disadvantages of case studies are it is difficult to generalize and interpret the results and they are expected to exploratory studies and time-consuming [29]. In this research, we are evaluating the user experience by comparing Mobile device with Microsoft Hololens which cannot be done by exploratory observation. Therefore a case study is not selected as a research method.

A survey is generally referred to as a research-in-the-large i.e. required to take interview for a large group of people [29]. They are used as opinion polls in the market area researches [12]. In this research, the participants should answer the questionnaire while interacting with the display devices which cannot be done for a large population and may lead to biased solutions. Therefore survey is not selected as a research method.

Therefore, experiment has been chosen as the research method to answer RQ2. As it is required to work with quantitative data, an experiment is selected as the best approach than the other descriptive methods like Case Study or Survey [31].

The goal of this experiment is to compare the user satisfaction score with the displayed data in Microsoft HoloLens and Mobile device between the two groups. In this experiment, an application will be developed to display the user interface of an automated machine. Then the user interface developed for Microsoft HoloLens will be compared with the user interface developed in the Mobile device.

3.2.1 Experimental Design

The guidelines stated by Wohlin et al. [32] are being used for experimental design.

Independent variables: AR device, background and lighting conditions.
Dependent variable: User Satisfaction Score.
Experimental Design Type: One factor more than two treatments.

Test Subjects: 20 students having related background and experience in Human-Computer interaction/ Usability Interaction, and Computer Science are selected as test subjects in this experiment. The test subjects have no previous experience of using Microsoft HoloLens as most of the current generation people have experienced AR technology using mobiles. i.e Instagram has AR filters. Assuming that the target population has experienced AR technology using Mobile devices.

Treatments:
1. Treatment 1: Using Mobile device (Samsung s8 plus) as AR device.
2. Treatment 2: Using Microsoft HoloLens as AR device.

Hypothesis Formulation

The hypothesis is declared in such a way that they have to be assessed by the desired statistical technique. There are two types of hypothesis concerned in this hypothesis testing which are more suitable to most of the statistical techniques. The null hypothesis is the hypothesis that needed to be tested, which is represented as $H_0$ and the alternate hypothesis is a statement of which we believe to be true if our data sample motivate us to reject the null hypothesis and it is represented as $H_a$[33].

Both the hypothesis are stated below:
Null Hypothesis($H_0$): There is no significant difference in the user experience while interacting with the displayed data between both the devices with respect to the User Satisfaction Score.
Alternate Hypothesis($H_a$): There is a significant difference in the user experience while interacting with the displayed data between both the devices with respect to the User Satisfaction Score.

The results obtained from the test can be interpreted by comparing the p-value as declared below:

- If the obtained P-value is less than or equal to 0.05(p-value $\leq$ 0.05), the null hypothesis will be rejected and alternate hypothesis is accepted i.e. there is a significant difference in the user experience.
- If the obtained P-value is greater than 0.05(p-value $>$ 0.05) then it is failed to reject null hypothesis i.e. there is no significant difference in the user experience between both the groups.

We can simply state that if $H_0$ is rejected, $H_a$ is true. If $H_0$ is not rejected, $H_0$ might be true.
3.2.2 Experiment setup

Experimental Process:

1. Implemented an application to display the information in Microsoft HoloLens and Mobile device.

2. The results of this experiment are measured by taking the User Satisfaction Score from the test subjects.

3. Test Subjects: 20 students having related background and experience in Human-Computer interaction/ Usability Interaction, and Computer Science are selected as test subjects in this experiment.

4. The test subjects are interacted with displayed data in Microsoft HoloLens and Mobile device and are asked some pre-determined questions on the User-Interface in both the devices.

5. The test subjects were asked to rate this questionnaire from 1 (Strongly disagree) - 5 (Strongly agree) and the questionnaire procedure carried out around 15-20 minutes for each test subject.

6. The Feedback from the test subjects was taken and tabulated.

7. User Satisfaction Score: User Satisfaction Score for each test subject is calculated by taking the average of all question’s score given by each test subject.

8. Statistical significance difference was evaluated by comparing the User Satisfaction Score of Microsoft HoloLens with the User Satisfaction Score of Mobile device.

9. Effect size is calculated using Cohen’s D effect size method to measure the difference in the size of User Satisfaction Score between the two devices.

3.2.3 Selection of Display Devices

Microsoft HoloLens and Mobile device are selected as the display devices for evaluating the user experience.

Hardware Specifications

Hardware specification of both Microsoft Hololens and Android device are tabulated individually. We used the Vuforia SDK to develop augmented reality applications. These two augmented reality applications have the same features, that is to display information related to the automated vehicles.
<table>
<thead>
<tr>
<th></th>
<th>Connectivity</th>
<th>Wi-Fi 802.11ac, Bluetooth 4.1 LE, Micro-USB 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Processor</td>
<td>Intel 32-bit</td>
</tr>
<tr>
<td>3</td>
<td>Display</td>
<td>See-through holographic lenses (wave-guides) 2x HD 16:9 light engines Automatic papillary distance calibration 2.3M total light points holographic resolution, 2.5k light points per radian</td>
</tr>
<tr>
<td>4</td>
<td>Storage</td>
<td>64 GB</td>
</tr>
<tr>
<td>5</td>
<td>Ram</td>
<td>2 GB</td>
</tr>
<tr>
<td>6</td>
<td>Camera</td>
<td>2 MP</td>
</tr>
<tr>
<td>7</td>
<td>Sensors</td>
<td>Inertial Measurement Unit, 4x environment understanding cameras, mixed reality capture, 4x microphones, ambient light sensor</td>
</tr>
</tbody>
</table>

Table 3.1: Hardware specifications of Microsoft HoloLens AR device

<table>
<thead>
<tr>
<th></th>
<th>Connectivity</th>
<th>Wi-Fi 802.11ac MIMO Bluetooth 5.0 NFC, GPS, Glonass, Galileo, BeiDou LTE Cat.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Processor</td>
<td>Qualcomm Snapdragon 835 or Samsung Exynos 8895</td>
</tr>
<tr>
<td>3</td>
<td>Display</td>
<td>5.8-inch AMOLED 2960x1440 (570 ppi)</td>
</tr>
<tr>
<td>4</td>
<td>Storage</td>
<td>64GB (UFS 2.1)</td>
</tr>
<tr>
<td>5</td>
<td>RAM</td>
<td>4GB</td>
</tr>
<tr>
<td>6</td>
<td>Rear Camera</td>
<td>12MP Dual Pixel, f/1.7 1.4-micron pixels OIS</td>
</tr>
<tr>
<td>7</td>
<td>Operating system</td>
<td>Android 7.0 Nougat</td>
</tr>
</tbody>
</table>

Table 3.2: Hardware specifications of Samsung Galaxy s8+ Mobile device
3.2.4 Initial Setup

Here, we implement a augmented reality application for Microsoft Hololens and for Mobile device (Samsung Galaxy s8+).
Unity 3D game engine IDE is used for building AR applications because Unity supports all the platforms required to develop AR/VR applications and furthermore, it easy to deploy the applications for all platforms [15].

3.3 Implementation

3.3.1 Application development for Microsoft HoloLens

The approach of interaction for Microsoft HoloLens is different from that of a Mobile device. It requires gestures or voice commands to interact with the virtual objects.[15]. The major differences between application development for HoloLens and Mobile device are:
Microsoft HoloLens requires solid black colour as the background and because of
the transparency, it may be difficult to observe dark colours while using Microsoft HoloLens [15]. Vuforia Augmented reality SDK was used to create augmented reality applications in Unity. MixedRealityToolKit repository was used to develop an application for Microsoft HoloLens which contains a set of components and codes for the application development in Unity3D IDE. An information panel was created. It uses gaze to know where the user is looking and it is easy to focus on the object that the user wants to interact with his/her hand gestures. The size of Gaze increases when it is pointed on any object. HoloLensCamera extracted from MixedRealityToolKit was used as the main Camera input.
The 2D and 3D objects used in Unity for Microsoft HoloLens are:

- Information panel
- 3D CAD Models
- 3D buttons (Restart and Exit)

Figure 3.2: Microsoft HoloLens application development in Unity 3D IDE
Information Panel

A panel was created to display the information about the automated machine. The key attributes that are obtained from the semi-structured interview from the design engineers of Volvo Construction Equipment (VCE) were used in the information panel of Microsoft HoloLens. The attributes that this information panel consists of are (see Figure 4.1):
1. Truck ID
2. Status
3. Load
4. Battery

To change the values in the information panel dynamically MySql Database was used. When the values in the database are changed from the system then the values in the information panel will be changed dynamically.

3D CAD Model

In this research two automated miniature models, Hauler (HX01) and Wheel Loader (LX01) were used. so, the 3D CAD Models of those vehicles were used to display in the user interface. Auto rotation script was implemented for the CAD models. The CAD Models will rotate automatically when the application starts so, the user can interact with the models from all sides (see Figures 4.2 and 4.3).
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3D Buttons

Restart and Exit buttons were created and corresponding scripts were implemented for these buttons to work functionally (see Figures ?? and ??).

The buttons are designed in such a way that if the user is looking at the restart button the color of the restart button will change from blue to green and when the user taps on the restart button or selects using voice commands the color of the restart button changes to white. so that, the user can know that the action was performed.

When the user is looking at the exit button the color of Exit button will change from yellow to green and when the user taps on the exit button or selects using voice command the color from green changes to red. So that, the user can know that the action was performed.

Application development for Mobile device

The application developed for Mobile device is similar to the application developed for Microsoft HoloLens.

Unity 3D IDE is used to develop the Mobile application. Vuforia augmented reality SDK and android studio SDK are used to create an augmented reality application for Mobile device.

Figure 3.4: Mobile device application development in unity 3D IDE

Same information panel and 3D CAD model were used for Mobile device. 2D Restart and Exit buttons were created for the Mobile device (see Figure4.8).

The experimental procedure conducted in this research has been discussed by following the steps mentioned:
Chapter 3. Method

- Selection of Test Subjects
- Questionnaire Development
- Procedure
- Result and Data Analysis

3.3.2 Selection of Test subjects

The participants are the primary conception of statistics. The participants can be identified as a set of individual persons who are fundamentally investigated during the research [34]. The test subjects in this research are the participants who are selected by conducting a closed interview with a fixed set of predefined questions [35]. A closed interview is chosen for selecting the test subjects because closed interview does not allow modification to the interview questions depending on the responses from the subjects of the experiment, therefore closed interview has an advantage over open interviews [35]. The closed interview may be more suitable when there are statistical methods involved to analyze the results in the experiment [12].

The test subjects chosen were 20 students with age between 20-30. The questions asked to the test subjects were about their experience in the Usability interaction/Human-Computer Interaction and the department they are studying in and any previous experience in using the AR/VR head-mounted devices for the experiment in the research. The selected test subjects were from the computer science department or having experience in Usability interaction design principle and the test subjects were randomly segregated into two equal groups for the questionnaire process as all the test subjects have no previous experience in using Microsoft HoloLens and other AR head-mounted devices.

10 test subjects were assigned to interact with the Microsoft HoloLens and the remaining other 10 test subjects were asked to interact with the Mobile device. This sampling method is chosen because it improves the accuracy of results by decreasing the sampling bias in the experiment. These samples are taken out from the same test subjects which shows a normal distribution. "Normal distribution is defined as the distribution of a sample which is characterized by its mean (μ) and standard deviation (σ) having a symmetric curve" [12].

3.3.3 Questionnaire Development

The questionnaire that has been used in this research is developed from the findings based on the 10 Usability Heuristics for User Interface developed by J. Nielsen [36] and Usability Heuristics to evaluate patient safety developed by Zhang J [37]. As this research is focused on the user experience, the following heuristics related to this aspect are chosen from the findings Nielsen [36] and
Chapter 3. Method

Zhang [37].

1. Consistency and Standards: This principle states that "the user should not have to wonder whether in a different situation or different actions mean the same thing. Follow platform conventions" [36].

   The standards and conventions in product design should be followed are[36] [37]:
   - Sequence of actions
   - Color
   - Layout and position
   - Terminology
   - Standards

2. Visibility of system state: This principle states that the user should always informed about what is going on inside the system [36] [37].
   - What is the current state of the system?
   - What is the visibility of the system?
   - What is going on with the system?

3. Match between system and the real world: The system should follow the real world conventions. The images or objects perceived in the system by the users should match with the real world models [36] [37].
   - User models matches the real world
   - Actions provided by the system should match actions performed by the system.
   - Objects on the system should match objects of the tasks.

4. Flexibility and efficiency: The user interface should be flexible and the system should be able to perform actions for both experienced and novice users.
   - Allow the user to customize repeated activities [36] [37].

5. User control and freedom: The user often makes mistakes in the system functions and should need a button to exit the tasks and leave the current state. The user should control the system [36] [37].

   The questionnaire development process has a total of 5 questions with 5-point Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). The test subjects for Microsoft HoloLens and Mobile device were asked to answer this question using a 5-point Likert scale by describing their experience in using the devices. These questions have been analyzed to calculate the User Satisfaction Score.
User Satisfaction Score

User Satisfaction Score for each test subject is calculated by taking the average value from the ratings of each test subject in the questionnaire. The results obtained in the questionnaire process has been verified and analyzed by conducting the statistical technique [12].

3.3.4 Procedure

All the participants were individually asked to visit the PDRL Lab and participate in the experiment. Since it is a closed project each participant was given directions only about the user interface in the device which did not disclose any information regarding the research.

The total number of test subjects involved in this research is 20. All the test subjects were randomly divided into two groups and were asked to interact with each device separately. A group of 10 students were assigned for interacting with the user-interface developed in Microsoft HoloLens and another group of 10 students were asked to interact with the user-interface developed in the Mobile device.

Test subjects interacting with Microsoft HoloLens was chosen first to conduct the experimental process and a brief overview was provided to the subjects about various operations (Gestures using Microsoft HoloLens) before the experiment was conducted. They were given the training to use various functionalities of the Microsoft HoloLens such as opening the windows menu, opening and closing an application, selecting the buttons etc., using hand gestures and voice commands and the test subjects for Mobile device was selected next. The test subjects were asked to interact with the user-interface developed in Microsoft HoloLens and Mobile device individually and answer the questionnaire by rating each question from 1 to 5 i.e. Strongly disagree to Strongly agree.

Each test subjects has interacted with the device separately and the interview lasted around 10 to 15 minutes. Therefore every test subject had a chance to interact with the Microsoft HoloLens and Mobile device individually while conducting the experiment. After the interview, the participants were asked about their experience in using the devices and they have admitted that they answered the questionnaire from their experience of whole interaction process with the displayed data, not just from physical view and interaction of devices.

3.3.5 Result and Data Analysis

The answers obtained through the questionnaire process were analyzed and evaluated by using a statistical technique for this experiment. In general, we can state that Statistical technique is a procedure of collecting, understanding, experimenting, obtaining results and analyzing and formulating conclusions from
the experiment [34].

Data analysis is a collection of various characteristics of a people and is inferred through the observations made from the population [12]. The main objective of data analysis is to make the process of the research more productive and efficient to help gain insights into the data [38]. Therefore, a statistical technique needs to be implemented to check whether there is a significant difference between user satisfaction scores of the two groups.

**Normality Check**

In order to perform a parametric test, first, we need to check the normality of the data. The data can be approximately normally distributed to perform a parametric test and need not to be perfectly normally distributed [39]. In our case, we use the following to check the normality of data:

1. Check the Skewness and Kurtosis z-values [40, 41].
2. Perform a Shapiro Wilk test [42].

We can say that the data is approximately normally distributed if the z-values of Skewness and Kurtosis and between -1.96 and +1.96. The p-value obtained in the Shapiro Wilk test should be above 0.05 to say that the data is approximately normally distributed [39].

**Selection of statistical test**

Assuming that the data obtained to be approximately normally distributed. Here, we select a suitable parametric test to check the following:

- Whether there is a significant difference between the user satisfaction scores of the two groups? if yes, then how much is the difference?

T-test has been selected as the parametric test over other parametric tests, as the sample size is less than 30 (small sample)[43]. Among the different t-tests, we select independent sample t-test.

The motivation for the selection of independent sample t-test:

Independent-Samples T-Test compares two sample means from different populations regarding the same variable to determine whether the difference between the two means is statistically significant. In our case, we have samples obtained from two different groups on the same variable (user satisfaction score). A parametric test provides information about the existence of significant difference or not and does not provide any information about how much is the difference. To know how much is the difference we use the effect size technique.
Independent Samples T-Test

The statistical technique selected in this research is Independent Samples T-Test [44]. The samples in the experiment are assumed to follow a normal distribution. Independent Samples T-Test can be used to compare the means of two sample groups. This test is used to compare the mean values of two sample groups which are independent to each other in order to decide that there is a statistical proof that the mean values of the two sample groups are significantly different. This sample test was conducted to find out whether there is a significant difference between the User Satisfaction Scores of the two groups. There are two samples in this research they are: one group is for interacting with the user interface developed in Microsoft HoloLens and the other group is for interacting with the developed application in Mobile device. In this research, the test subjects are taken as two independent samples. The difference in the mean is calculated from the values given by the test subjects from the questionnaire [12]. The difference in the mean of this user experience is calculated and analyzed by using statistical t-test [44] [45].

In this research, the user experience is measured by calculating the User Satisfaction Score between both the sample groups. A t-test is conducted for evaluating the User Satisfaction Score of test subjects. The mean difference and the standard deviation of both device user experience are measured and analyzed. Furthermore, the comparison of mean between both the devices is performed by carrying out the hypothesis testing.

Effect Size

The t-test can only reveal the user about whether there is a significant difference or not in the user experience and does not provide how much significant is the difference between the two groups. So, in order to know the difference in the size between both the groups’ effect size is used.

The purpose of the Effect size is to measure the quantity of the difference between the two groups i.e. the size of the effect after finding that there is a significant difference in the user experience between the two groups[46]. It provides a power calculation to the statistical significance tests, which emphasizes the size of the difference instead of confounding with the sample size. Effect size evaluates the difference in the size between two groups and it may be therefore said to be a true comparison for the significant difference[46, 47].

In statistical techniques the effect size can be measured in three types [46]:

- Standardized mean difference: When a research study is based on the comparison of the population mean and its standard deviation. When the outcome of the experiment is a continuous measure of comparing two groups This method is used[47].
• Odd ratio: Odd ratio method is used when the data values are in binary format. It is calculated by the ratio of odds of success in the treatment group with odds of success in the control group of the experiment[46].

• Correlation coefficient: Pearson correlation coefficient is used to measure the linear correlation between the variance of two variables.

This research is based on the comparison of mean and the standard deviation of two independent groups so, the standardized mean difference method is used to calculate the effect size.

This effect size can be known by dividing the obtained two mean differences by their standard deviation [46] When the obtained values are calculated by using a 5-point scale, 7-point scale or 9-point scale Cohen’s D effect method is used to compare across the studies [48]. In this experiment User Satisfaction Score is measured by using 5-point Likert scale which needs to be validated and analyzed to state the difference in the mean, therefore Cohen’s D effect size method is used in this research to measure the significant difference in the user experience between two devices. The effect size signifies which device has more user experience in interacting with the displayed data than the other device. Cohen’s D effect size is calculated by subtracting the means of two display devices and then dividing it with the common standard deviation. If the obtained Cohen’s D value is less than 0.20 then the effect size is small, if it is near to 0.50 the effect size is medium and if the obtained value is near to 0.80 the effect size is large which allows the researcher to measure the experiment’s effect size to known standards[12][47]. The formulae for mean standard deviation and Cohen’s D effect are as follows:

To calculate mean:
\[
\bar{x} = \frac{1}{n} \sum_{i=0}^{n} \bar{x}_i
\]

where,
• \( \bar{x} \) = mean,
• n is the total number of test subjects.

To calculate Cohen’s D effect :
\[
d = \frac{\bar{x}_H - \bar{x}_M}{\sigma}
\]

where,
• d = Cohen’s D effect size
• \( \bar{x}_H \) = mean value of user satisfactory score for Microsoft HoloLens,
• \( \bar{x}_M \) = mean value of user satisfactory score for Mobile device,
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- $\sigma$ common/pooled standard deviation.

$\sigma$ is calculated by

$$\sigma = \sqrt{\frac{s_H^2(n_H - 1) + s_M^2(n_M - 1)}{n_H + n_M}}$$

where, $s_H$ is the standard deviation of user satisfactory score Microsoft HoloLens and,

$s_M$ is the standard deviation of user satisfactory score for Mobile device.

$n_H = \text{Total number of test subjects for Microsoft HoloLens}$ and $n_M = \text{Total number of test subjects for Mobile device.}$
Chapter 4

Results

4.1 Interview

The research question is answered by collecting the feedback from the Volvo Construction Equipment (VCE) design engineers from an interview. Various qualitative analysis techniques have been studied and it has been noted that these techniques are effective when large data is collected. The data collected in this case is small and the answers given by the respondents are straightforward and directly related to the terminology used in the development of the applications for Microsoft HoloLens and mobile device. Therefore, a data analysis technique with minimal structure known as Immersion approach has been used to analyze the data collected from the interviews. The immersion approach of data analysis depends majorly on the “intuition and interpretive skills of the researcher” [49]. Therefore this approach has been selected as it is easy to implement this analysis method on simple and straightforward data unlike other approaches such as editing approach, template approach and quasi-statistical approach which are ideal for large and complex data [49]. As stated earlier, the entire conversation of the interviews has been recorded and transcribed into text. The text has been studied carefully and using the interpretive skills of the researcher, the following information has been sorted, deduced and aggregated as follows:

Components to be included in the User Interface:

- 3D model of the machine,
- restart and exit features,
- gaze,
- information panel.

The information panel should further consist of attributes namely:

- machine id,
• machine status,
• battery of the device,
• machine fuel level,
• machine load efficiency,
• name of the site manager,
• name of the operator.
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The snapshots of the user interface of the Microsoft HoloLens and Mobile device are shown in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8

![Figure 4.1: Information Panel developed for Microsoft HoloLens](image1)

![Figure 4.2: 3D CAD Model of Hauler machine HX01](image2)

*Figure 4.1: Information Panel developed for Microsoft HoloLens*

*Figure 4.2: 3D CAD Model of Hauler machine HX01*
Figure 4.3: 3D CAD Model of Wheeled-Loader LX01
Chapter 4. Results

4.2 Experiment

After conducting the experiment, the User Satisfaction Score was calculated by the answers given by the test subjects who have participated in this experiment which is interacting with Microsoft HoloLens and Mobile device. After interpreting the values all the statistical analysis were performed using R Studio software to find out the p-value. The User Satisfaction Score was calculated by taking
Figure 4.8: User-Interface developed in Mobile device, 3D model of the automated machine on the top left, information panel for the hauler on the top right, restart and exit buttons in the middle

the average values from the ratings given by the test subjects based on the Likert scale. The answer to the questions is rated from 1-5 and 1 being strongly disagreed and 5 being strongly agreed by the test subjects. This typical scaling system is called a Likert-type scale [50].

User Satisfaction Score

The format of this Likert type scale is:

- 1- Strongly Disagree
- 2- Disagree
- 3- Neither Agree nor Disagree
- 4- Agree
- 5- Strongly Agree
Table 4.1: Ratings given by the test subjects for user experience of Microsoft HoloLens

**Results of Microsoft HoloLens**

The User Satisfaction Score for the Microsoft HoloLens group is calculated for the user experience. The obtained individual values of the User Satisfaction Score for Microsoft HoloLens is presented in Table 4.1.
Chapter 4. Results

The total User Satisfaction Score for the user experience of Microsoft HoloLens is graphically represented below. Figure 1 shows the User Satisfaction score for each test subject when the test subject is looking at the displayed data using Microsoft HoloLens. In general, it can be seen that the average user satisfaction score for all the test subjects together is very high (i.e nearly 4).

The User Satisfaction Score for Microsoft HoloLens was presented in a graph (Figure 4.7) for a clear pictorial understanding.

![User Satisfaction Score for Microsoft HoloLens](image)

Figure 4.9: User Satisfaction Score for the User experience of Microsoft HoloLens given by the test subjects of Microsoft HoloLens group

The graphs were drawn for 10 test subjects according to the User Satisfaction Score calculated. The test subjects 2 and 5 shown lower User Satisfaction Score comparatively other test subjects as shown in Figure 4.7.

From the formulated result, the User Satisfaction Score interprets the overall value of the user experience for each test subject. Many participants agreed and strongly agreed that the user interface developed is impressive when rendering the information panels with buttons and 3D CAD models. Some of the participants agreed that the interaction which contains both voice commands and hand gestures were very clear and the response was almost spontaneous. As they were 10 subjects for this experiment, each one will have their own experience with both the treatments which can have an impact on their answers to the questions. Many of the participants have felt that Microsoft Hololens is not very comfortable to wear and also strenuous on the eyes.
### Table 4.2: Ratings given by the test subjects for the user experience of Mobile device

<table>
<thead>
<tr>
<th>Test Subjects</th>
<th>Rating for ques 1</th>
<th>Rating for ques 2</th>
<th>Rating for ques 3</th>
<th>Rating for ques 4</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Subject 11</td>
<td>4</td>
<td>4</td>
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</tr>
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<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3.00</td>
</tr>
</tbody>
</table>

### Results of Mobile device

The User Satisfaction Score for Mobile device group of test subjects is calculated for the user experience and results were displayed in Figure 4.9. The obtained individual values of the User Satisfaction Score for Mobile device test subjects is presented in Table 4.2.

The User Satisfaction Score for Mobile device is graphically presented in Figure 4.8 for a clear pictorial understanding.

![User Satisfaction Score graph for the User Experience of Mobile device by the test subjects of Mobile device](image)
Chapter 4. Results

Figure 4.8 shows the user satisfaction score given by each test subject when the test subject is interacting with the user interface using Mobile device, in general, it can be seen that the total average user satisfaction score for all the questions together is moderate (i.e. nearly 3).

The graphs were drawn for 10 test subjects according to the User Satisfaction Score calculated for the test subjects. The test subjects 4 and 8 shown lower User Satisfaction Score compared to other test subjects respectively as shown in Figure 4.8.

From the formulated result of a Mobile device, the User Satisfaction Score interprets the overall value of the user experience for each test subject using the Mobile device. Some of the test subjects agreed and some of them neither agreed nor disagreed that the visualization aspect is noticeable when rendering the information panels with buttons and 3D CAD models. Many participants felt that carrying a Mobile device is easy and safe compared to Microsoft HoloLens.

After obtaining the results of Microsoft HoloLens and Mobile device the comparison between the User Satisfaction Score of these two sample groups has been presented in the line graph (Figure 4.9). The User Satisfaction Score for Mobile device is approximately less when compared to the Microsoft HoloLens. The significant difference is calculated and analyzed in the next chapter.

![Figure 4.11: Comparison line graph of User Satisfaction Score of test subjects from Microsoft HoloLens group and Mobile device group](image)

The Skewness, Kurtosis and z-values obtained using descriptive statistics for Mobile device and HoloLens are tabulated in Table 4.3. We can see the Shapiro
Table 4.3: Skewness, Kurtosis and z-values

wilk test results obtained using IBM SPSS in the Figure 4.2.

<table>
<thead>
<tr>
<th>Device</th>
<th>Statistic</th>
<th>Std.Error</th>
<th>z-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skewness Mobile</td>
<td>0.07</td>
<td>0.687</td>
<td>0.101</td>
</tr>
<tr>
<td>Kurtosis Mobile</td>
<td>-0.777</td>
<td>+1.33</td>
<td>-0.584</td>
</tr>
<tr>
<td>Skewness Hololens</td>
<td>-0.34</td>
<td>0.687</td>
<td>-0.584</td>
</tr>
<tr>
<td>Kurtosis Hololens</td>
<td>-0.333</td>
<td>+1.33</td>
<td>-0.250</td>
</tr>
</tbody>
</table>

Tests of Normality

<table>
<thead>
<tr>
<th>Kolmogorov-Smirnov(^a)</th>
<th>Shapiro-Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>mobile device</td>
<td>.169</td>
</tr>
<tr>
<td>Hololens</td>
<td>.200</td>
</tr>
</tbody>
</table>

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Figure 4.12: Shapiro wilk test using IBM'S SPSS
5.1 Data Analysis for obtained Results

Data analysis generally refers to the systematic assessment of data against the objectives of the research[35]. This chapter gives the description of results obtained from the experiment and answers to the research questions. The user satisfaction scores obtained in this research are presented in chapter 4.

5.1.1 Checking for normality of data

From the Table 4.3 we can say that all the z-values are between -1.96 and +1.96 and the p-value obtained from Shapiro Wilk test for Hololens (0.500) and mobile (0.798) is greater than 0.05. Hence, we can say that the data is approximately normally distributed.

5.1.2 Statistical test

It is clear for the normality check that the data of user satisfaction scores of the two display devices is approximately normally distributed, a parametric test is performed using IMB’S SPSS package to check whether there is a significant difference between the user satisfaction scores of the two groups.

Independent Samples T-Test

Independent Samples T-Test is selected to investigate that if there is any significant mean value difference in the user satisfaction score in the sample groups of two display devices. All the statistical calculations were performed by using IBM’S SPSS software. The hypothesis test was performed by using R studio software for calculating the p-value for the user satisfaction score of sample groups for both the devices. A normal distribution is assumed and the parameters for this distribution are mean value and standard deviation [12].

The T-test was conducted with 95% confidence interval of the difference an the significance level as 0.05.
Table 5.1: The mean and standard deviation values of two sample groups

<table>
<thead>
<tr>
<th>Test subjects</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard error of the mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft HoloLens group</td>
<td>4</td>
<td>0.485912</td>
<td>0.1536</td>
</tr>
<tr>
<td>Mobile device Group</td>
<td>3.35</td>
<td>0.542627</td>
<td>0.1715</td>
</tr>
</tbody>
</table>

Hypothesis Testing

The hypothesis test was conducted by Independent Samples T-Test to compare the mean and standard deviation of User Satisfaction Score for the test subjects of Microsoft HoloLens and Mobile device.

The mean and standard deviation values of both the groups after conducting the t-test are displayed in the table 5.1:

From Figure 5.1 we can state that the obtained mean value for the sample group of Microsoft HoloLens is 4.0 and the mean value for the sample group of the Mobile device is 3.35 respectively.

The obtained standard deviation for Microsoft HoloLens is 0.4859 and Mobile device is 0.5426 respectively. The values obtained from the hypothesis test conducted with 95% confidence interval and 0.05 significance level is presented in Figure 5.1:

Figure 5.1: Output of T-test obtained from R studio

The obtained p-value from the t-test was 0.01139 for the two sample groups of display devices which are less than the significance level (0.05) i.e. (0.01139 < 0.05), from this, we can conclude that null hypothesis (H₀) is rejected i.e. alternate hypothesis (Hₐ) is true. That means, the statement that "there is no significant difference in the user experience between both the groups with respect to the User Satisfaction Score" is been rejected.

From this hypothesis, we can conclude that there is a significant difference in the user experience between both the sample groups of Microsoft HoloLens and
Chapter 5. Analysis

### Test Subjects

<table>
<thead>
<tr>
<th>Test Subject 1</th>
<th>User Satisfaction Score for Microsoft HoloLens</th>
<th>Test Subject 11</th>
<th>User Satisfaction Score for Mobile device</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75</td>
<td></td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>3.25</td>
<td></td>
<td>4.25</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>3.75</td>
<td></td>
<td>2.75</td>
<td></td>
</tr>
<tr>
<td>3.25</td>
<td></td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>4.25</td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td></td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>4.25</td>
<td></td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2: User Satisfaction Score for the test subjects of Microsoft HoloLens and Mobile device

<table>
<thead>
<tr>
<th>Total User Satisfaction Score</th>
<th>Microsoft HoloLens</th>
<th>Mobile device</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td></td>
<td>33.5</td>
</tr>
</tbody>
</table>

Table 5.3: Total User Satisfaction Score for sample groups of Microsoft HoloLens and Mobile device

Mobile device with respect to the User Satisfaction Score.

The difference in the User Satisfaction Score of both groups has been identified. To know the level of significant difference between both the devices Cohen’s D effect method was chosen and it is presented in the next section.

#### 5.1.3 Comparison of User Satisfaction Scores

The average of scores are calculated and tabulated in Table 5.2. The difference in the mean value of User Satisfaction Score for sample groups of Microsoft HoloLens and Mobile device is shown in pictorial representation in the Figure 5.2:
5.1.4 Effect Size

Effect size is the statistical evaluation that calculates the difference between the two variables in an analytical way [46]. The hypothesis testing can only state that there is a significant difference in the mean values between the two sample groups of Microsoft HoloLens and Mobile device but the t-test will not state the size of the difference in between the groups. To evaluate the difference in size between two values Cohen’s D effect method is chosen.

Cohen’s D effect size is elucidated as small, medium and large. If Cohen’s D value is nearer to 0.2 then the effect size is small,
If the value is nearer to 0.5 then the effect size is medium,
If the value is nearer to 0.8 then the effect size is large [12] [48].

Cohen’s D effect Size

The effect size is measured by Cohen’s D method. The difference in the User Satisfaction Score between the groups of Microsoft HoloLens and Mobile device has been measured by subtracting the mean value of Microsoft HoloLens with Mobile device and then dividing the obtained value with pooled standard deviation. The formula for this calculation is mentioned in chapter 3.1.6. The Cohen’s D value obtained by this method was 1.22 which is greater than 0.8 (1.22 > 0.8). Hence we can deduce that the effect size measured by considering the mean values of user satisfaction scores of both the device groups is large which means there is a difference in the user experience of the devices to a great extent.
Chapter 6
Discussions and Limitations

6.1 Discussions

This chapter interprets the findings and results of the previous chapters by briefly summarizing the results.

The main aim of this research is to evaluate the User Satisfaction Score and investigate the user experience of the sample groups between both the devices i.e. Microsoft HoloLens and Mobile device. The answers to the research questions are discussed below:

Research Question 1: How the user interface should be displayed and what are the key attributes that should be displayed?

A semi-structured interview is considered as a research method to obtain the required information that should be displayed in the user interface from the design engineers. The required information is collected and tabulated. Then requirements are prioritized based on the expert’s advise. The prioritized attributes are used to develop the user interface for Microsoft HoloLens and Mobile device. The developed user interface is then compared and evaluated.

Research Question 2: How is the user experience with the developed user-interface in Microsoft HoloLens compared to Mobile device? To answer this research question an experiment was chosen as a research method. An experiment was conducted to find the difference in the user experience by evaluating the User Satisfaction Score between the sample group of Mobile device and Microsoft HoloLens.

The User Satisfaction Score has been measured and calculated for the test subjects of the Mobile device and Microsoft HoloLens and is segregated based on the Usability Heuristics Principles. After evaluating the User Satisfaction Score Independent Samples T-Test was conducted to know the significant difference in the user experience in the sample groups between Microsoft HoloLens and Mobile device. In chapter 4, it was found that the null hypothesis was rejected and further the hypothesis shows that there is a significant difference in user experience between the sample groups of both the devices with respect to the User Satisfaction Score.

And furthermore, Cohen’s D effect size method is used to measure the difference...
in the size of User Satisfaction Score between the two sample groups. The Co-
hen’s D effect size for Microsoft HoloLens and Mobile device was 1.2 which is
greater than $0.8 (1.2 > 0.8)$ [48]. so, it can be interpreted from the obtained value
that the effect size is large. Therefore, the significant difference in the user expe-
rience between Mobile device and Microsoft HoloLens is large. The results show
that the User Satisfaction Score for Microsoft HoloLens is high compared to the
Mobile device.

6.2 Limitations:

Microsoft HoloLens

- Microsoft HoloLens is not comfortable to wear for longer time while working
in a construction site.

- Sometimes lighting conditions may effect the visibility of the user.

- It is difficult for a new user to interact with the Microsoft Hololens user-
interface.

Mobile device

- Mobile devices have limited display size, a lot of modules have to be built in
the user interface to display data associated with large information systems.

- Difficult to develop a good enough interface for Augmented reality applica-
tion because of size

6.3 Validity Threats

To evaluate the validity of results some of the threats that might impact our
experiment and their mitigation strategies are identified and listed below:

6.3.1 Internal Validity

The threats to internal validity include the selection and instrumentation [51].
Selection bias is mitigated by randomly assigning the test subjects into two test
groups rather than conducting the experiment sequentially to the same test sub-
jects for both the devices. If the test subjects were arranged sequentially there
might be a chance of receiving biased results which strengthens the risk of inter-
nal validity. To avoid this, test subjects were randomly assigned into two groups
for better results.

Instrumentation refers to the measurements type that has been considered in
this research which were properly validated before conducting the questionnaire.
Having previous experience of using AR/VR head-mounted device will influence the outcome of the experiment and the results would be biased. This problem is mitigated by adding a confounding factor and while selecting the test subjects only the subjects with no previous experience of AR/VR head-mounted devices technology are selected.

6.3.2 External Validity
External validity can be stated as "The extent to which the findings can be generalized to a larger or applied to the larger populations" [52, 53]. In this research, we achieve this validity by selecting the test subjects with the same characteristics as the population, accessible to generalise the results (i.e. no previous experience in using Microsoft HoloLens).

The test subjects in this experiment were chosen in such a way that the characteristics of students resemble the characteristics of Volvo employees so that this research can be replicated to the large construction site. The selected test subjects were randomly assigned into two groups to avoid biased results. Therefore the results of the experiment are generalisable to the entire population.

6.3.3 Construct Validity
Construct Validity is considered as "how well the outcome of the study is linked to the concepts or theory behind the experiment and what is measured and affected" [54][29]. The questionnaire procedure which was used to measure the user satisfaction score for the user experience is the construct in this research. The concepts of this questionnaire were defined clearly enough before defining the calculation part of the experiment. The questions that have been used in this research is developed from the findings developed by Nielsen [36] and Zhang et al. [37] which were valid to be used for calculating the user experience to mitigate this threat.

6.3.4 Conclusion Validity
Conclusion Validity verifies the treatments used in the experiment and the results obtained are actually valid and justified or not. This threat will be raised when an experiment is carried without following the proper procedure. To mitigate this threat, statistical analysis of the results were performed by using Independent samples t-test in the experiment.
Chapter 7

Conclusions and Future Work

7.1 Conclusion

In this research, the significant difference in the user experience between the two groups of a Mobile device and Microsoft HoloLens has been measured using User Satisfaction Scores given by the test subjects. The research has been conducted for the two devices, Microsoft HoloLens and Mobile device. The test subjects have been asked to interact with the devices individually and answer the questionnaire on the developed user interface. The questionnaire has been evaluated and validated to calculate User Satisfaction Scores for both the devices.

Independent Samples T-test has been conducted to find a significant difference between the two devices. The results show that there is a difference in the user experience and user interaction between the users of both devices. Furthermore, Cohen’s D effect size method was used to calculate the significant difference size between Microsoft HoloLens and Mobile device. The results obtained concludes that there is a large difference in the user experience between Microsoft HoloLens and Mobile device. An overall conclusion that can be drawn through the research is that there is a significant difference in the user experience in interacting with Microsoft HoloLens and Mobile device, and interacting with Microsoft HoloLens has better user experience than interacting with Mobile device.

7.2 Future Work

1. An interesting research would be controlling the movements of the automated machines with Microsoft HoloLens and Mobile device and evaluating the user experience.

2. Other interesting research would be trying to display incoming vehicles information, which helps in increasing the safety in construction sites.

3. Research can be done on how to interact with 3-D CAD models of the automotive vehicles and enable the user to interact with each and every individual parts of the CAD model in the virtual environment.
Bibliography


[38] Arnaud Delorme. “San Diego California, CA92093-0961, La Jolla, USA. Email: arno@salk.edu.” In: (2005).


8.1 Interview questions asked for the respondents

The information obtained from the semi structured interview is tabulated in Table 8.1
<table>
<thead>
<tr>
<th>Interview Questions</th>
<th>Respondent 1</th>
<th>Respondent 2</th>
<th>Respondent 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you like the user interface to be displayed?</td>
<td>The user interface should be more user friendly, flexible and efficient</td>
<td>User friendly, consistent and use of voice commands.</td>
<td>Avoid complexity, make sure that the UI has better contrast and should be convenient for a new user to use.</td>
</tr>
<tr>
<td>Would you like to have the 3D models of the automated machine in the user interface?</td>
<td>Yes, of course the 3D models of an automated machine could be needed.</td>
<td>3D models of that machine would help the user which machine they are using.</td>
<td>Yes, it would be great if the 3D models rotate and a user could see the whole model by standing in a single location.</td>
</tr>
<tr>
<td>Would you like to have an information panel with buttons for the application?</td>
<td>Yes, one or two information panels would be better for the user to know the information.</td>
<td>Yes, one information panel with all information and buttons should be developed.</td>
<td>Yes, please create an information panel with the contrast shown in the demo video of the automated Hauler (HX02).</td>
</tr>
<tr>
<td>What are the key attributes that should be displayed?</td>
<td>The details that the site manager needs are - the vehicles status, load carried by the vehicle, information of the vehicle</td>
<td>The user should know all the information that is monitored in the system. The main attributes are - ID of the vehicle, fuel level in the vehicle, the tasks assigned to the vehicle, name and details of the site manager and the operator.</td>
<td>The information panel should provide Automotive machine ID, the assigned task, current site details, load details and manager details.</td>
</tr>
</tbody>
</table>

Table 8.1: Semi-structured interview with the respondents
8.2 Questionnaire for Microsoft HoloLens

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate your satisfaction level with the following aspects of the User-Interface:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Strongly Agree) 1 - - 2 - - 3 - - 4 - - 5 (Strongly Agree)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To what extent is the quality of visualization and the visibility status of Microsoft HoloLens?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To what extent did you feel was the user control of the application for the Microsoft HoloLens?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To what extent did you find the Voice commands to be useful?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To what extent were you able to notice the flexibility and efficiency of use of the Microsoft HoloLens?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.1: The questionnaire for the sample groups of Microsoft HoloLens

8.2.1 Questionnaire for Mobile device
Figure 8.2: Questionnaire for the sample groups of Mobile device

8.3 Test Subjects and their age

20 students between the age of 20 to 30 and having related background and experience in Human-Computer interaction/Usability Interaction, and Computer Science are selected as test subjects in this experiment.
Table 8.2: Test subjects with their Age

<table>
<thead>
<tr>
<th>Test Subjects for Microsoft HoloLens</th>
<th>Age of the Test subjects</th>
<th>Test Subjects for Mobile device</th>
<th>Age of the Test subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Subject 1</td>
<td>29</td>
<td>Test Subject 11</td>
<td>23</td>
</tr>
<tr>
<td>Test Subject 2</td>
<td>25</td>
<td>Test Subject 12</td>
<td>23</td>
</tr>
<tr>
<td>Test Subject 3</td>
<td>23</td>
<td>Test Subject 13</td>
<td>22</td>
</tr>
<tr>
<td>Test Subject 4</td>
<td>22</td>
<td>Test Subject 14</td>
<td>24</td>
</tr>
<tr>
<td>Test Subject 5</td>
<td>24</td>
<td>Test Subject 15</td>
<td>20</td>
</tr>
<tr>
<td>Test Subject 6</td>
<td>23</td>
<td>Test Subject 16</td>
<td>21</td>
</tr>
<tr>
<td>Test Subject 7</td>
<td>23</td>
<td>Test Subject 17</td>
<td>22</td>
</tr>
<tr>
<td>Test Subject 8</td>
<td>22</td>
<td>Test Subject 18</td>
<td>20</td>
</tr>
<tr>
<td>Test Subject 9</td>
<td>22</td>
<td>Test Subject 19</td>
<td>21</td>
</tr>
<tr>
<td>Test Subject 10</td>
<td>24</td>
<td>Test Subject 20</td>
<td>21</td>
</tr>
</tbody>
</table>

8.4 Screenshots

8.4.1 User interface developed for Microsoft HoloLens

Figure 8.3: See through experience provided by Microsoft Hololens (Displaying data related to the automotive vehicle)
8.4.2  user interface developed for Mobile device

Figure 8.4: User-Interface developed for Mobile device for the Wheeled-loader LX01 automated machine)

8.4.3  Mobile application development in unity IDE
Figure 8.5: Application deployment in unity engine IDE for Mobile device