EXTENDED REALITY TECHNOLOGY FOR MAINTENANCE OF COMPLEX MACHINE IN MANUFACTURING TRAINING

EXTENDED REALITY TECHNOLOGY FOR MAINTENANCE OF COMPLEX MACHINE IN MANUFACTURING TRAINING

A Thesis Presented to

The Graduate School of Bangkok University

In Partial Fulfillment

of the Requirements for the Degree of

Master of Engineering in Electrical and Computer Engineering

by

Dissapoom Siyapong

2020

This thesis has been approved by

School of Engineering

Bangkok University

Title : Extended Reality Technology for Maintenance of Complex Machine in Manufacturing Training

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15 / 03 / 2022

Dissapoom Siyapong, Master of Engineering in Electrical and Computer Engineering, August 2021, Graduate School, Bangkok University

Extended Reality Technology for Maintenance of Complex Machine in Manufacturing Training (78 pp.)

Advisor of Thesis: Pakorn Ubolkosold, Ph.D.

ABSTRACT

This research was the development of extended reality technology used to improve traditional maintenance training in manufacturing. Conventional practice is an instruction that uses texts, images, and videos. Moreover, during the training session, the machines in the production line had to be stopped. Therefore, the extended reality technology, which was actually augmented reality, virtual reality, and mixed reality combined enhanced the trainee's experience through virtual environment training by simulating the machine's maintenance procedure. Three of 21 failure cases of the machine were simulated for the case study.

The system enabled learning and searching for information with the case. The system was evaluated for the satisfaction of the trainees for confirmation to be genuinely available. The system was then tested by 30 participants, where the experiment was conducted in a laboratory instead of a production line. There was less chance of these failures occurring on the production line. Therefore, a more appropriate way was to simulate the failure in the laboratory. By comparing the mean time to repair and mean time between failure of the current machine, it could be concluded that the maintenance time could be reduced.

Keywords: Extended reality, machine maintenance, manufacturing training

Approved: [redacted]

Asst. Prof. Dr. Pakorn Ubolkosold

ACKNOWLEDGMENTS

First of all, I would like to express my sincere gratitude to my thesis supervisor, Dr. Akkharaphong Eksiri, Director of the Robotics Laboratory, School of Engineering, Bangkok University, Assoc. Prof. Dr. Pakorn Ubolkosold from the School of Engineering, Bangkok University, and Dr. Chakkaphong Suthaputchakun, Director of the Electrical and Computer Engineering Program, School of Engineering, Bangkok University for providing me with professional guidance, constant encouragement from the beginning of the work, advice, and support in many ways during the study period.

In addition, an expression of appreciation is provided to Dr. Wisarn Patchoo, Dean of the School of Engineering, Bangkok University, Dr. Poompat Saegudomlert, Faculty Member of Electrical and Computer Engineering, School of Engineering, Bangkok University, and Assoc. Prof. Dr. Chowarit Mitsantisuk, Department of Electrical Engineering, CMIT Robotics Laboratory at Kasetsart University for providing me with a definite direction and professional guidance during the study period.

I am also grateful to Dr. Romuald Jolivot, Faculty Member of Electrical and Computer Engineering, School of Engineering, Bangkok University for providing me with the way of writing a journal paper, presentation design, and other valuable suggestions.

Furthermore, thanks is offered to Dr. Sampan Silapanad, Vice President of Western Digital (Thailand) Company Limited for providing good opportunities for the scholarship of the project's development, as well as Mr. Chaiya Thongrattana, Director of the AME (Thailand) Department, Western Digital (Thailand) Company Limited for the project's scope.

Moreover, I am greatly indebted to Mr. Panuwat Rodchom, Manager of the AME (Thailand) Department, Western Digital (Thailand) Company Limited, Ms. Pitanan Detsawana, Staff Engineer of Supplier Quality Engineering, Western Digital (Thailand) Company Limited, and Mr. Weerapat Somtua, Engineer of the AME (Thailand) Department, Western Digital (Thailand) Company Limited for teaching all the necessary skills; such as, data analysis, communication, humanity, responsibility, courage, project's scope, and other related issues.

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LIST OF ABBREVIATIONS

HDD	Hard Disk Drive
XR	Extended Reality
VR	Virtual Reality
AR	Augmented Reality
MR	Mixed Reality
HMD	Head-mounted Display
VR-TMT	Virtual Reality for Training in Maintenance Tasks
CAD	Computer-aided Design
SUS	System Usability Scale
MTTR	Mean Time to Repair
MTBF	Mean Time between Failure
S.D.	Standard Deviation
DoF	Degree of Freedom
CI	Confidence Interval
2D	Two-dimensional
3D	Three-dimensional
FPS	First-person Shooter
C#	C Sharp
UX	User Experience
UI	User Interface
OpenCV	Open-source Computer Vision
SQL	Structured Query Language
QR Cod	Quick Response Code
SDK	Software Development Kit
PC	Personal Computer
UWP	Universal Windows Platform

IOS	iPhone Operating System
WebGL	Web Graphics Library
WD	Western Digital
E-book	Electronic Book
OPL	One-point Lessons

CHAPTER 1

1. INTRODUCTION

1.1 Rationale

Hard disk drive (HDD) manufacturers have started implementing extended reality (XR) technology to improve the manufacturing process and transform into being a Smart Factory. XR technology combines the physical and digital world to present a new simulated world using all forms of software and hardware, which is also known as immersive technology (Fangfang Zhou, et al., 2018). Virtual instruction is currently an example of XR technology that has been widely applied to the gaming and entertainment industry. In the manufacturing industry, reality technologies are also used to avoid risk. For example, virtual reality (VR) is used to assemble and disassemble a gearbox simulation for maintenance training in virtual environments (Manoch Numfu, et al., 2020). Augmented reality (AR) is used to make assembly guidelines and maintenance of machines (Bernd Schwald, et al., 2003). Mixed reality (MR) is used to simulate aircraft maintenance training, in which users can be immersed using a see-through head-mounted display (HMD) (Mar Gonzalez-Franco, et al., 2017). The maintenance of the machine in the automated production line is complicated; therefore, XR technology is used in the application of manufacturing training.

1.2 Problem Statement

In general, engineers maintain machines according to the maintenance schedule in the production line by strictly following the instructions in the manual. Moreover, some failures are not indicated in the manual; consequently, engineers must find a solution by themselves, as an unexpected failure could lead to increased maintenance time. Thus, engineers must be trained to enhance their maintenance capabilities. However, traditional training employs text, images, and videos in the training session. Moreover, the machines in the production line need to be stopped for using in the training session; therefore, the downtime is increased.

1.3 Proposed Solution

This research presented the development of XR technology in manufacturing to avoid various failures with the machines. As such, XR technology could enhance the engineers' maintenance skills. Furthermore, the system could be used as often as needed, as the training could be performed outside the production line without stopping the machines from operating to evaluate the training effectiveness of the system. The engineers were asked to perform a survey when they had completed the training. In the next stage, the target group of 30 participants performed the maintenance of the machines, and their maintenance duration was compared with the current period.

1.4 Objective of the Study

The overall objective of the research was to increase the effectiveness of training using XR technology to enhance learning for workers in manufacturing training.

The specific objectives were:

- To reduce the maintenance time of the machines.
- To compare the suitable types of XR technology for training.
- To evaluate the satisfaction of the users using the system.

1.5 Limitations of the Study

The limitations of the study were as follows:

- The experimentation was conducted in a laboratory instead of a production line.

- Only three failure cases of the machines were studied.
- There are just ten participants of each group in the experimentation.
- The software of the machine was always updated to the new version.
- These three failure cases of the machines were not enough to the MTBF calculation.
- Groups 2 and 3 had no histories of the maintenance time recorded in the current situation.

1.6 Organization of the Report

The report has been divided into five chapters.

Chapter I Introduction: This chapter deals with the rationale, objectives, and limitations of the study.

Chapter II Methodology: The methodology adopted for the study is described in this chapter. The types of reality technologies are also given briefly in this chapter.

Chapter III Literature Review: This chapter is dedicated to illustrating the relevant literature and the recent work related to the study.

Chapter IV Results and Discussion: The analysis of the test results, tables, and figures are presented in this chapter.

Chapter V Conclusion and Recommendations: The conclusion of the study and recommendations are given in this chapter.

CHAPTER 2

2. LITERATURE REVIEW

This section presents the research study to help find a suitable way that comprises the following forms of technology.

2.1 Extended Reality Technology

Extended reality (XR) technology can be classified into virtual reality (VR), which is a simulation of a virtual object from a real object by interacting in a virtual environment; augmented reality (AR) that is a simulation of a 3D virtual object to overlay a real object; mixed reality (MR), which is a combination of augmented and virtual reality by interacting hand-free (Fangfang Zhou, et al., 2018).

2.2 Virtual Reality

Virtual reality (VR) has been used to improve maintenance training in the manufacturing industry. Some industries have operated 24 hours a day without stopping their machines. Therefore, the virtual system could help users avoid provoking breakdowns and accidents to maintain the actual machines. This paper described VR as used to train to assemble and disassemble a gearbox by using a head-mounted display (HMD) called the "Virtual Reality for Training in Maintenance Tasks" (VR-TMT) system (Manoch Numfu, et al., 2020). The sample of the experiment consisted of 27 industrial engineering students who undertook a survey to illustrate the user experience's appropriate awareness level on the VR platform. However, the virtual system indicated the limited space of the device sensor of 250 mm for using the device in a workspace. The authors' work presented the difference from this paper by using Microsoft HoloLens in maintenance training, which was not limited to the space, and users could train independently.

Additionally, VR was used to simulate a manufacturing process in an elaborate production line by familiarizing users with virtual environments. For example, a virtual electronic assembly equipment factory was created using VR to familiarize the participants with the manufacturing process (Yongmin Zhong and Bijan Shirinzadeh, 2008). Another paper presented the use of VR to simulate the manufacturing process of flat-rolled steel products by describing the movement of hot gases escaping from the reheating furnace door (Chenn Zhou, et al., 2016).

VR was also used for maintenance training in electric power plants (Bartlomiej Arendarski, Wilhelm Termath and Paul Mecking, 2008). The transformer of the electric power system simulated the operating procedures to the virtual scenario. The virtual scenario simulation allowed users to understand the complex system of the machines by interacting with computer-simulated environments. The interaction level of the system could be classified into four modes: a) The virtual scenario could be explored without the users doing any tasks in the discovery mode. b) The users could learn the work procedures in the presentation mode. c) The guided mode offered assistance for users by doing tasks step-by-step. d) The free mode was complicated, as users had to complete the tasks without any assistance. The results illustrated that the 3D visualization reduced the problems and difficulty disassembling the transformer without any faults and damage to the actual machine. However, the VR device was still limited to the space for usability. Therefore, the authors' work presented the difference between the Microsoft HoloLens device from this paper using VR goggles. Therefore, this inferred that Microsoft HoloLens could be used anywhere in a wireless format.

2.3 Augmented Reality

Augmented reality (AR) assists the user with complex assembly and maintenance tasks in an industrial environment because the machines are complex. This paper described that user could obtain all the information directly superimposed into the natural working environment using a see-through HMD by computer-generated images called augmentations (Bernd Schwald, et al., 2003). The HMD was developed to simulate the virtual object superimposed into the actual object by calibrating an optical see-through HMD, which used algorithms to calculate the parameters of the X, Y, and Z axes position for the 3D projection. Even though the system was still under development, the results of this research illustrated the display in the form of 3D augmentation that was superimposed smoothly. The disadvantage of an electromagnetic tracking system was the rapidity to responding to a metals environment, which was a disturbance of the working system. Another disadvantage of the system was using a cable connected to a sensor to a processing unit of a tracking system, which was not wireless. Therefore, the workspace and user movement were limited. However, the authors' work differed from this paper by using the Microsoft HoloLens device, which had a wireless device and could superimpose the object by using an image tracking system. The number of AR applications adapted to use in the manufacturing community illustrated 12.5% of the training and learning, 7.33% of the product design, 6.03% of safety, 5.17% of remote assistance, and 5.60% of telerobotics and robotics (Eleonora Bottani and Giuseppe Vignali, 2019). AR was used to simulate computer-generated virtual objects overlapped with natural objects in the practical manufacturing environment. For example, AR glasses could help workers control a sequence and equipment assembling methods by reading step-by-step instructions and assembling according to the instructions (Volker Paelke, 2014). AR was implemented to simulate missing objects in the production line by a system planner before actual implementation of the object (Wilhelm Dangelmaier, et al., 2005).

2.4 Mixed Reality

Mixed reality (MR) technology was developed to train new workers by implementing the HMD attached to a see-through camera for aircraft door maintenance in complex manufacturing training. This system allowed users to use collaborative interactions (Mar Gonzalez-Franco, et al., 2017). This paper described both MR training and traditional face-to-face training by evaluating the knowledge retention and interpretation test with an eight-question questionnaire. The results illustrated that the knowledge obtained from both types of training was not significantly different. Moreover, the users who had effectiveness in the MR training were as proficient as those in the traditional training. However, the MR training had limited workspace and motion capture system in the laboratory. Therefore, the authors' work was different from this paper, as it used the Microsoft HoloLens to allow users to train anywhere.

Furthermore, MR was developed for applying in many manufacturing communities, including product design, training, maintenance, assembly, and so on (Peng Wang, et al., 2020). For example, MR could assist users in planning the workshop's layout by simulating the virtual equipment in the natural environment (Jonghwan Lee, Soonhung Han and Jeongsam Yang, 2011). Thus, the structure information and monitoring data of the production equipment were integrated into the MR system to assist the maintenance tasks (Danúbia BuenoEspíndola, et al., 2013).

CHAPTER 3

3. METHODOLOGY

This project developed the application with extended reality (XR) technology in manufacturing training. A failure scenario occurred in the machines and was simulated by XR technology for the trainees' learning enhancement. Due to the traditional training, this made trainees misunderstand some information.

3.1 Extended Reality Technology

XR technology is a combination of the real world and virtual world, and is communicated through computer-aided design (CAD) or a three-dimensional model. XR technology is classified into three types: 1. Virtual reality (VR), 2. augmented reality (AR), and 3. mixed reality (MR).

(a) VR is a real-world environment simulated to a virtual environment by perception through the five senses of sight, taste, smell, hearing, and touch. VR is used to avoid training in a dangerous environment.

(b) AR is a 3D object simulation to a real-world environment. The real-world is combined simultaneously with the virtual object; such as, image, video, and sound. All the information is inserted into the application on devices, including computers, smartphones, tablets, or wearable devices. For example, AR is used to engage the reader in reading news for the media industry; as such, the reader could be immersive with a 3D image and animation.

(c) MR combines the real and virtual worlds to present new environments. The prominent points of AR and VR are used to develop MR, in which the AR is a simulation of 3D virtual objects that is mocked up with natural objects, whereas VR is a simulation of a 3D virtual environment from the natural environment. MR is similar to AR, as it provides a digital world to be superimposed in the real world. The lens of MR is see-through, and smart glasses make seeing a virtual object in a three dimension and real-time; therefore, users can instantly interact with what they see.

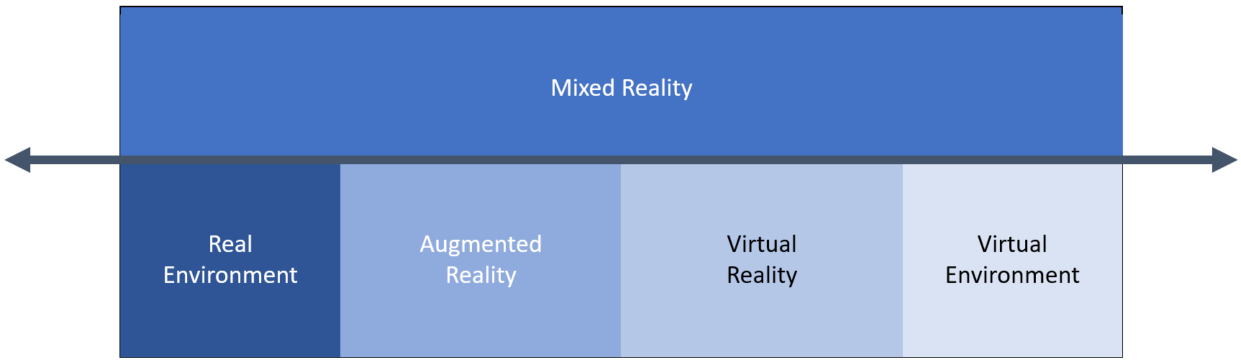

Figure 3.1: Extended reality (XR) technology.

All three types of XR technology have different prominence. For example, VR brings people into a virtual environment; AR simulates a 3D virtual object to overlay a natural object that users cannot interact; MR combines both AR and VR to present a new environment that users can interact.

3.2 The Device Properties of Extended Reality Technology

Each type of XR technology uses different devices for supporting the application. Figure 3.2 shows three kinds of equipment and the users experience in various environments. For example, AR uses a smartphone or tablet for displaying the 3D virtual object in the application, VR uses VR headsets or an Oculus Rift to display the 3D environment, and MR uses MR headsets or Microsoft HoloLens to display the 3D holographic.

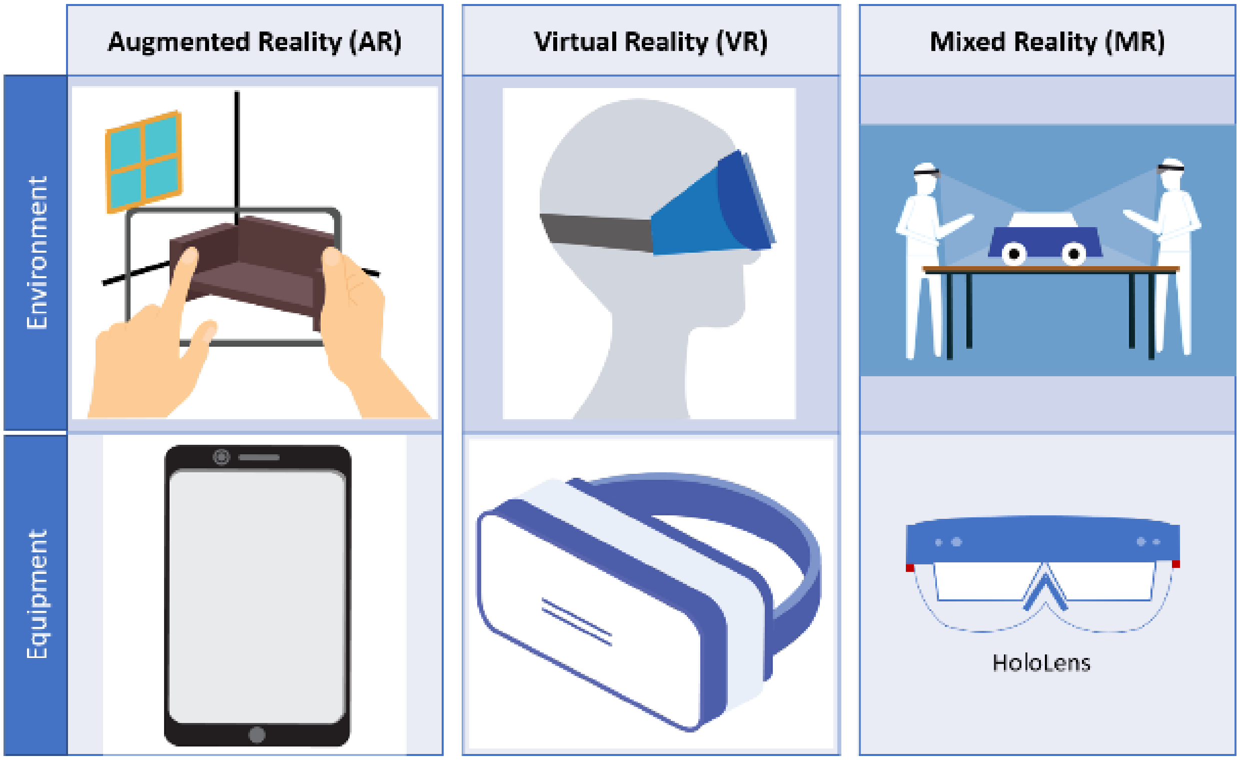

Figure 3.2 The device properties of extended reality (XR) technology.

3.3 The Advantages and Disadvantages of Extended Reality Technology

Each type of XR technology has both advantages and disadvantages. First of all, AR and VR's disadvantage is the limitation of interaction in the maintenance training; furthermore, AR uses a device to display the 3D visualization on a 2D touchscreen by scanning any QR code or images. Therefore, users cannot fully interact with virtual objects. For VR, an HMD must be used to simulate virtual environments. However, the VR has a limited space of 250 mm for user detection. Consequently, the advantages of AR and VR were developed by using MR technology for Microsoft HoloLens.

3.4 Virtual Training

Users can apply XR technology in virtual training. Moreover, these technologies have been helpful to the user in many roles because the technology allowed them to design a virtual system; such as, a virtual environment, simulation, interaction, and instructions. The environment and situation were the variable that a virtual teacher responded to the users [5, 6]. For on-the-job training, trainees found many problems that resulted in them not receiving complete training performance, which was because of the risks, cost, and time limitation. The training aimed to create interaction [7-13]. Furthermore, the user could train many times in the same scenario of virtual training, and trainees could obtain assistance from the virtual training to find suitable solutions [5, 9, 14].

Table 3.1 shows the problems found in these systems; such as, the number of trainees at a time, unrealistic virtual training, the difficulty of interaction, and limitation of the point of view. This project was designed to solve these problems by using each prominent aspect of the three types of XR technology comprising VR, to interact by controlling through a mouse and keyboard; AR could interact with virtual objects in a natural environment; MR could interact hand-free, which any virtual objects were designed from the actual size of the objects for more realistic training encouragement.

Table 3.1: Comparison of the training methods.

Items	Paper	Stereoscopic	Hand-on	Lecture	Simulation	Case Study	Interactive	Coaching	Group Discussion
5	Robotics in mixed-reality training simulations: augmenting STEM learning	✓		✓		✓			
6	Visual assembling guidance using augmented reality	✓							
7	An augmented reality framework for optimization of computer assisted navigation in endovascular surgery				✓				
8	Development an interactive VR training for CNC machine				✓				
9	Development of augmented reality training simulator system for neurosurgery using model-driven software engineering	✓			✓	✓			
10	Implementation of a virtual training simulator based on 360				✓				
11	A novel immersive augmented reality system for prosthesis training and assessment	✓			✓				
12	Simulation training in oil platforms	✓			✓				
13	Welding representation for training under VR environments	✓			✓				
14	Serious games and virtual simulator for automotive manufacturing education & training					✓			
This project	The Final Torque Machine Maintenance for The Training Program by Reality Technology	✓	✓	✓	✓	✓	✓	✓	✓

3.5 Survey Method

The System Usability Scale (SUS) is a standardized questionnaire for system measurement. In the survey, there were 10 questions (Table 3.2), and the respondents rated their level of agreement with each statement on a scale from 1 (“Strongly Disagree”) to 5 (“Strongly Agree”). Note that half of the statements are positively worded, and half are negatively worded [15].

Table 3.2: The questionnaire of the survey methods.

No.	Description	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
		(1)	(2)	(3)	(4)	(5)
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					

4	I think that I would need the support of a technical person to be able to use this system.					
5	I found the various functions in this system were well-integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could utilize this system.					

To calculate the SUS score, first total the score contributions from each item. Each item's score contribution would range from 0 to 4. For items 1, 3, 5, 7, and 9, the score contribution would be the scale position minus 1. The score contribution would be five minus the scale position for items 2, 4, 6, 8 and 10. The score contribution of both the odd and even items is described in Equation 3.5.1. Equation 3.5.2 illustrates the multiplication of the total of the scores by 2.5 to obtain the overall value of the SUS. The SUS scores have a range of 0 to 100 (Table 3.3).

$$SC_i \begin{cases} SP_i - 1; i = 1, 3, 5, 7, 9 \ (odd\ items) \\ 5 - SP_i; i = 2, 4, 6, 8, 10 \ (even\ items) \end{cases} \quad 3.5.1$$

$$Total\ score = \sum_{i=1}^{10} SC_i * 2.5 \quad 3.5.2$$

Table 3.3: Measurement of the product usability with the system usability scale (SUS) score.

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 - 80.3	B	Good
68	C	Satisfactory
51 - 68	D	Poor
< 51	F	Very Unsatisfactory

3.6 Experiment Methods

The classification of the three target groups consisted of 10 expert engineers (group 1), 10 experienced engineers (group 2), and 10 novice engineers (group 3). Each group's users experimented with all three applications: VR, AR, and MR. When the users had completed the testing, they did a survey. All 30 copies of the survey were calculated for the SUS score and a port graph.

In the next stage, the target group of 30 participants performed the maintenance of the machines, and their maintenance duration was compared with the current period using the calculation of the mean time to repair (MTTR) and mean time between failure (MTBF) formula. Finally, the MTTR and MTBF were used to analyze the system operation of the machines (Figure 3.3).

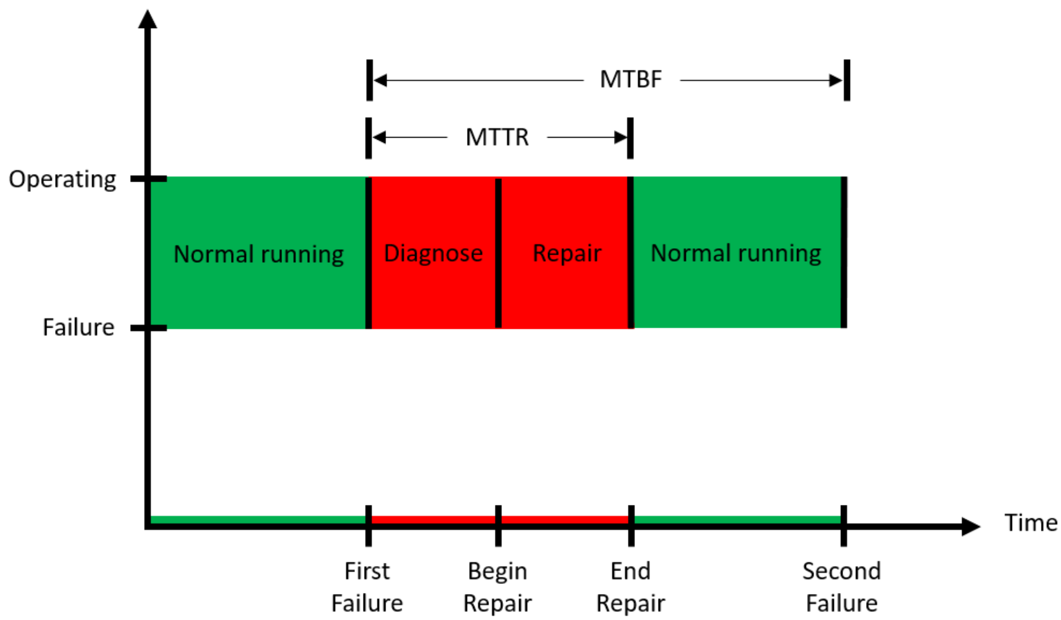

Figure 3.3: Mean time to repair (MTTR) and mean time between failure (MTBF) relationship.

3.6.1 Mean time to repair

The MTTR is the amount of time that it takes to repair the system and restore it to full functionality. The maintenance time is the amount of time when the machine stops operating to the completion of the machine being repaired and working as normal. The calculation of the formula is shown in Equation 3.6.1.

$$\text{MTTR} = \frac{\text{Total Maintenance Time}}{\text{Total Number of Repairs}} \qquad 3.6.1$$

3.6.2 Mean time between failure

The MTBF is the amount of time from the previous failure to the subsequent failure during the regular operation of the machine. The calculation of the formula is shown in Equation 3.6.2.

.

$$\text{MTBF} = \frac{\text{Total Operational Time}}{\text{Total Number of Failures}} \qquad 3.6.2$$

3.7 Statistical Methods

As described in the paragraph 3.6, the result of the MTTR calculation was used to analyze the statistics. The statistical methods were mathematical formulas of a data calculation used to analyze the raw data and describe various facts in the study. The statistical information covered almost all academic fields of various activities, including planning, management, evaluation, etc. The statistical data was classified into two types: a) Qualitative data illustrates attributes or properties; such as, gender, nationality, religion, etc. b) Quantitative data is numerical data, which illustrated the volumes of continuous or discrete variables. A continuous variable is a variable whose value is obtained by a measurement, which can be performed with mathematical methods. A discrete variable is a variable that cannot be continuously measured, which illustrates a symbol of an identical member group classification. Moreover, the elements of the statistics consisted of two elements: a) Descriptive statistics that are statistical methods to describe the characteristics of what was being studied to understand the characteristics of the collected data. b) Inferential statistics are statistical methods that conclude the characteristics of the population from the data results of the sample group. This is based on the probability theory of the characteristics inference of the population.

The statistic is a numerical value calculated from sample group data to conclude or describe the characteristics of the sample group, including the mean of the sample group represented by the symbol, the standard deviation of the sample group represented by the symbol SD, etc. In the evaluation of this research, the various statistical formulas were used to calculate the sample group of the 30 participants that were composed of the mean, standard deviation, Z-score, T-score, confidence interval (CI), and percentage change.

a) Mean ($\overline{X}$) is a mathematical average of the sample group, which summarizes all values of the sample group and is divided by the number of the sample group. This method was used to find a median value of the sample group. The calculation of the formula is shown in Equation 3.7.1.

$$\overline{x} = \frac{(\sum x_i)}{n} \qquad 3.7.1$$

Where: $\overline{x}$ is the sample mean, Σ is the total, which means "add up", x_i is all of the x-values, and n is the number of the sample group.

b) Standard deviation (S.D.) measures the dispersion of the statistical values, which is used to describe the dispersion of the data. The formula calculation was classified into two methods, where the first method was to find the S.D. in the case where the data had no frequency distribution. The calculation of the formula is shown in Equation 3.7.2.

$$\text{S.D.} = \sqrt{\frac{(x-\overline{x})^2}{n-1}} \qquad 3.7.2$$

The second method was to find the S.D. in the case where $\overline{x}$ was a decimal number. The calculation of the formula is shown in Equation 3.7.3.

$$\text{S.D.} = \sqrt{\frac{n\sum x^2-(\sum x)^2}{n(n-1)}} \qquad 3.7.3$$

Where: SD is the standard deviation, X is the data of the sample group, $\overline{x}$ is the sample mean, and n is the number of all the data.

c) Degree of freedom (DoF) was the amount of logically independent values that were used to estimate the statistical parameters. However, the number of parameters that required estimation depending on the amount of data was determined for the analysis and testing the hypothesis. The DoF was often a positive number and an integer. The DoF consisted of the amount of data and parameters. The calculation of the formula is shown in Equation 3.7.4.

$$df = N - 1 \tag{3.7.4}$$

Where: df is the degree of freedom, and N is the sample size.

d) T-value was a type of statistical testing used to evaluate the sample data. T-value is the rate statisticians call test statistics. The sample data were used to compare the null hypothesis to calculate the test statistics. The calculation of the formula is shown in Equation 3.7.5.

$$T = \frac{(\bar{x} - u_0)}{(\frac{s}{\sqrt{\mu}})} \tag{3.7.5}$$

Where: $\overline{x}$ is the sample mean, μ_0 is the hypothesized population mean, s is the sample standard deviation, and n is the sample size.

e) Margin of error (E) was the sample size consistent with the level of the accepted sampling error, which was related to the confidence interval statistics. The sample data were used to compare the null hypothesis to calculate the test statistics. The calculation of the formula is shown in Equation 3.7.6.

$$E = T_{\frac{\alpha}{2}} \text{ x } \frac{S}{\sqrt{n}} \tag{3.7.6}$$

Where: E is the margin of error, T is the T-value, S is the standard deviation of the sample data, α is the probability a confidence interval would not include the population parameter, and n is the sample size.

f) Confidence interval (CI) was the range of the estimated value that consisted of a minimum value and a maximum value that were calculated, which covered a parameter value with the established probability. The calculation of the formula is shown in Equation 3.7.6.

$$\text{CI} = \overline{x} \pm T_{\frac{\alpha}{2}} \text{ x } \frac{S}{\sqrt{n}} \qquad 3.7.7$$

Where: CI is the confidence interval, $\overline{x}$ is the sample mean, T is the T-value, S is the standard deviation of the sample, α is the probability a confidence interval would not include the population parameter, and n is the sample size.

g) Percentage change is a number or ratio represented as a fraction of 100. Percentage change is used for calculation in various fields; such as, finance, tax and inflation rate, sales, physics, and other fields of mathematics. The calculation of the formula is shown in Equation 3.7.7.

$$\text{Percentage change} = \frac{New\ value - Original\ value}{Original\ value} \text{ x } 100\% \qquad 3.7.8$$

The percentage change is a positive value, which is an increase. On the other hand, the percentage change can be a negative value, which would be a percentage decrease.

3.8 Implementation

This section describes a reality-based interaction system in which virtual and natural environments are integrated into new learning environments instead of learning on the production line. The difficulty of the current learning is to stop the machines from operating, so to teach the trainees;

consequently, the machines could not produce the workpiece. Therefore, the new system aimed to protect any vulnerability during the training in the production line by training outside in virtual environments. The virtual system was simulated from all the information in the production line by gathering and learning how it operated. The collected information spent some extended time in learning because of the complexity of the machines' operations. Furthermore, 2D drawing and 3D visualization were used to describe the complex machine for facilitating the trainees' learning. Therefore, the utilization of 2D and 3D information was a prerequisite for designing the system (Figure 3.4).

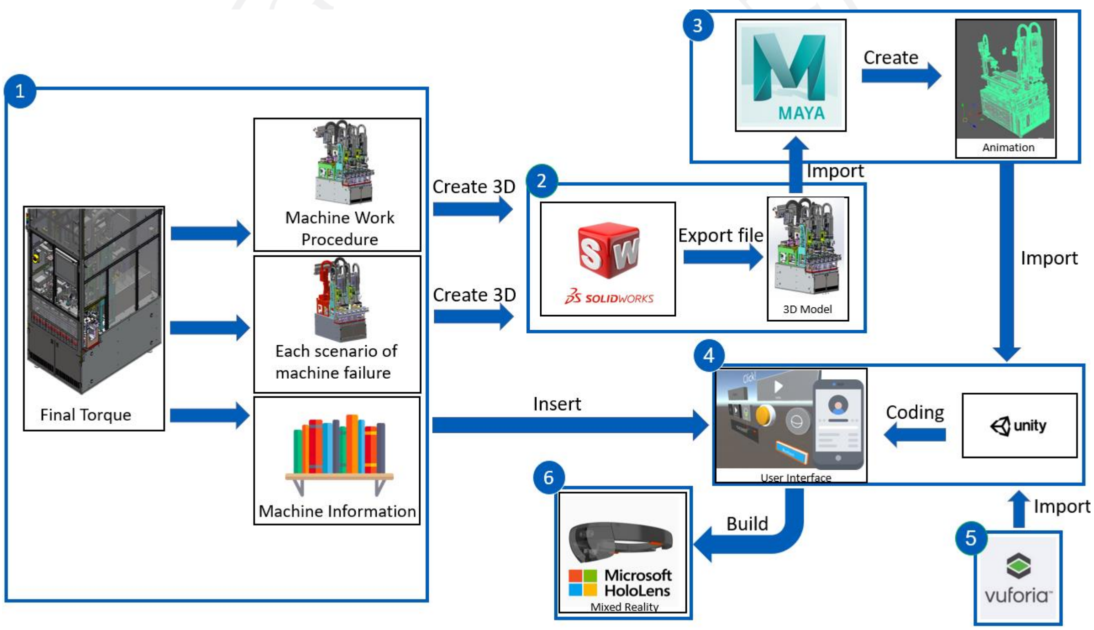

Figure 3.4: The procedures of creating an application.

There were six steps in the development of the application as follows:

(a) The first step was to gather all the information.

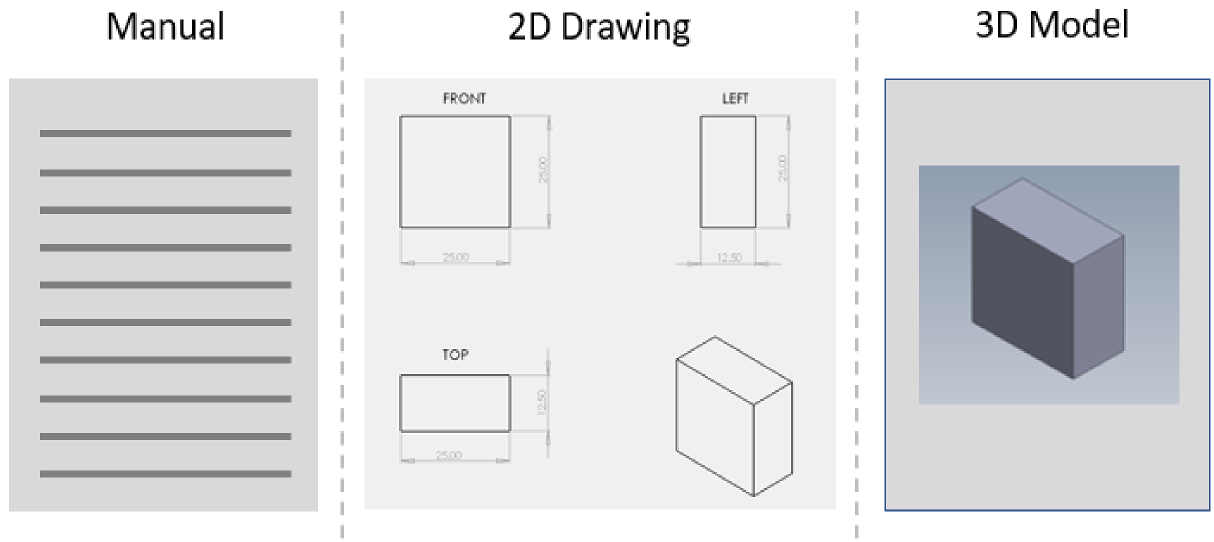

Figure 3.5: Gather the information, including the manual, 2D drawing, and 3D model.

The information was gathered into an application; such as, a manual, 2D drawing, and 3D CAD (Figure 3.5). All three items has different location files. Consequently, time was wasted searching for any file. However, all files were gathered in the same location file for the convenience of searching. All three items mentioned above were used to design the machines in the production, which was called mechanical design. The machines design had two parts: 1. Software development and 2. mechanical design. The mechanical design was started by designing the 3D CAD in SolidWorks. The next step was to set each axis's dimensions in a 2D drawing for creating the real object of implementation in the production. Another necessary step was to describe how the machine operator set up and conducted the maintenance described in the manual. Software development was used to control the machines operations through input/output devices in the controller cabinet. The software was operated on the individual machine's touchscreen monitor, which could adjust the values in this interface, and the software detail was simulated in Adobe

Illustrator for the reality of the training. Some buttons were used according to the maintenance procedure. Therefore, some details were not necessary for the interaction (Figure 3.6).

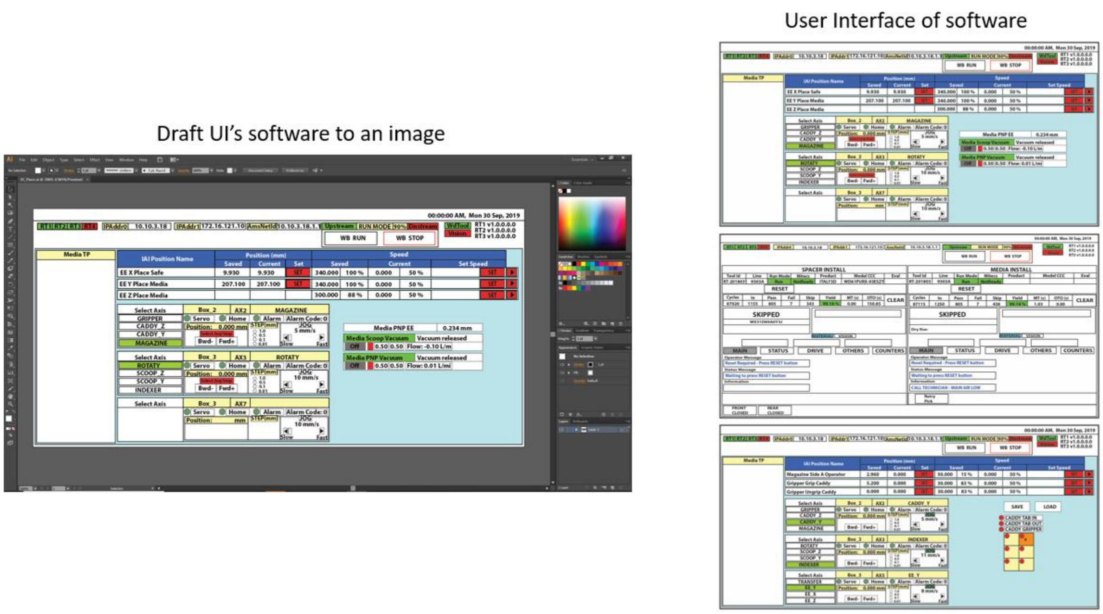

Figure 3.6: Study of the overall machine in the production line.

(b) The second step was to edit a 3D CAD and downsize.

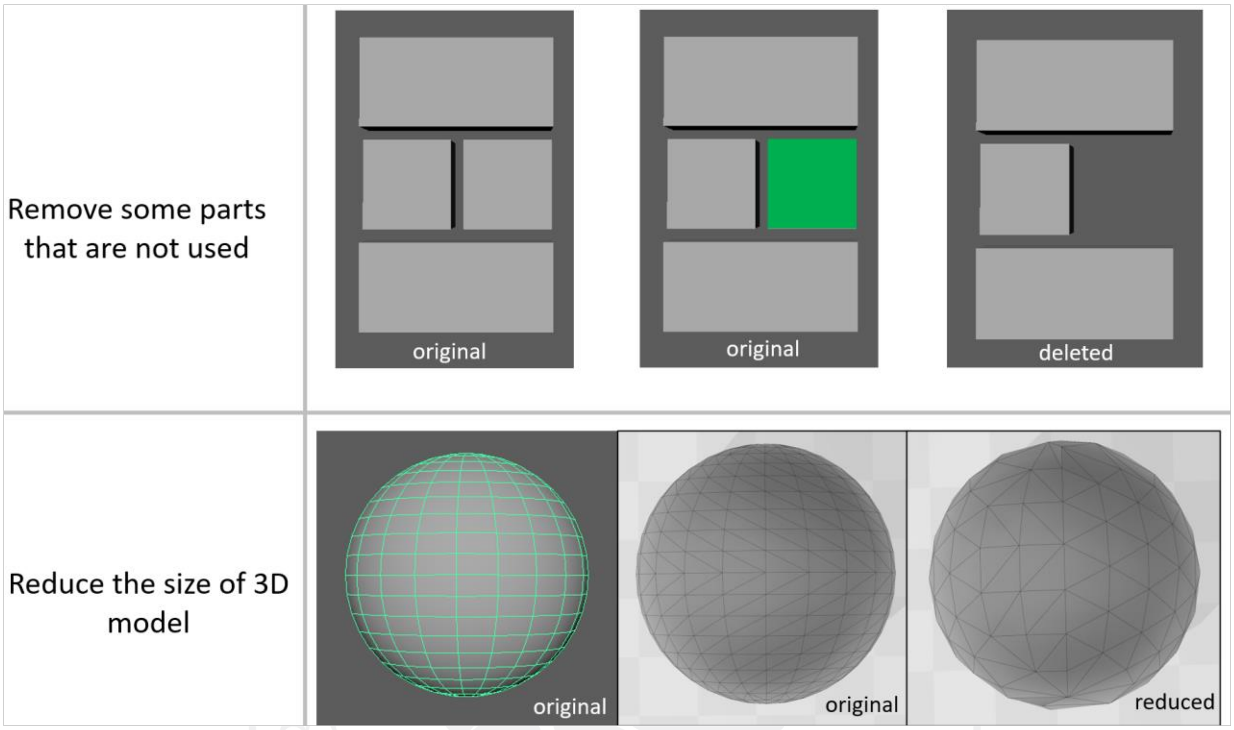

Figure 3.7: Deleting components of the 3D model that were not used for downsizing the file.

The 3D CAD was designed by a mechanical designer (Figure 3.7). The components of the mechanical part were used to assemble the machines. Some mechanical parts were designed for movement, whereas other parts were motionless. As mentioned in paragraph one of this section, the 3D animation was created by learning how the machines operated in the production line. The central problem of the 3D CAD design was the over large size. Thereby, the 3D CAD was downsized by reducing the surface area's size for faster processing.

Moreover, the reduction of the surface area of the 3D size was done to animate the 3D smoothly. However, this resulted in another problem, in which some 3D CAD files had disappeared or were damaged. Nevertheless, the 3D CAD could design a new one by using a 2D drawing. The 2D drawing described the mechanical design details, including to set the dimensions of each axis, width, length, height, and angle degree (Figure 3.8).

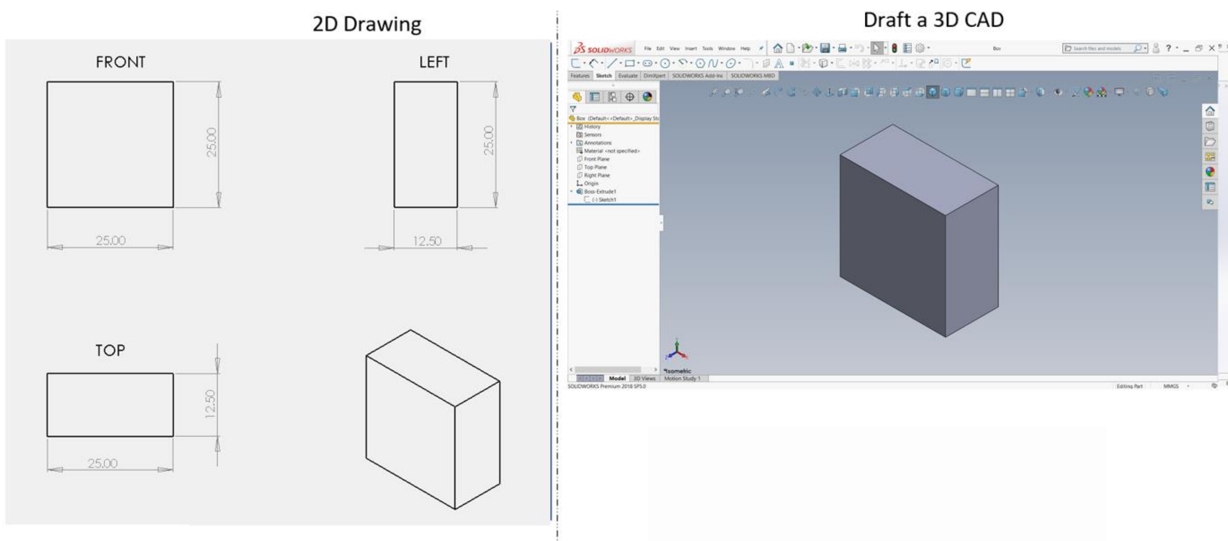

Figure 3.8: 3D CAD designing on SolidWorks.

(c) The third step was to animate the 3D CAD.

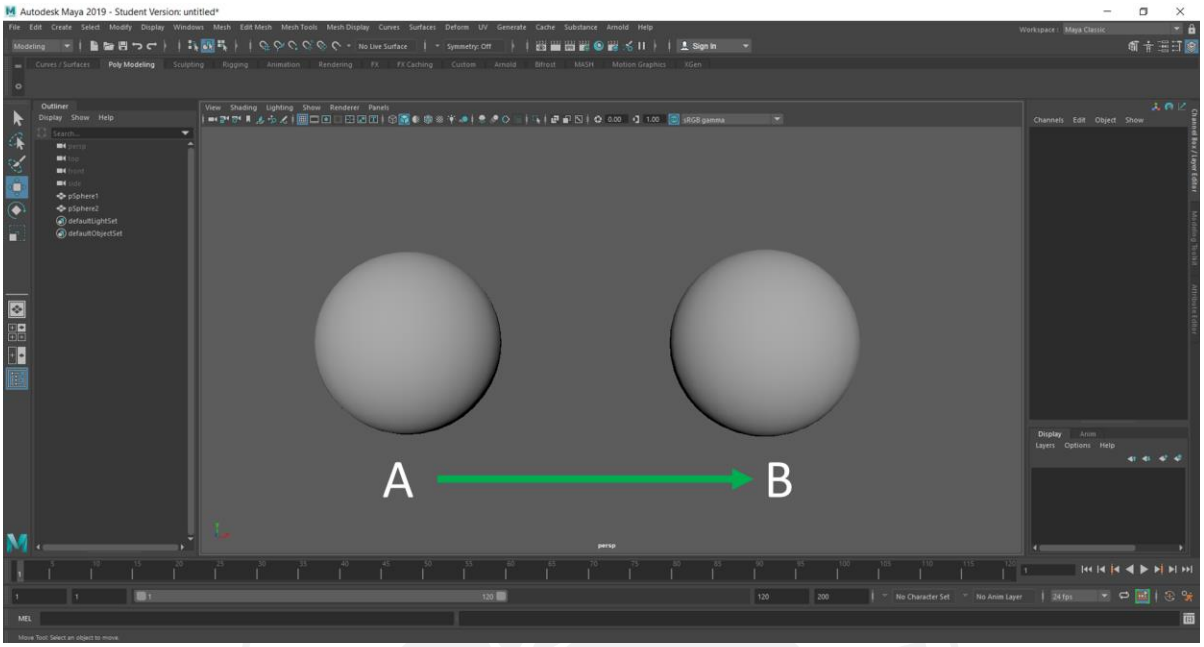

Figure 3.9: Animating a 3D CAD.

The 3D CAD was used to create animation by moving objects in a three-dimensional space (Figure 3.9). Nonetheless, the 3D CAD was exported from SolidWorks to Autodesk Maya, which found the color of the 3D CAD had disappeared and all the files were ungrouped. As mentioned, the difficulty of creating animation was increased accordingly by adding color and classifying the 3D CAD group. The creation of the animation was started by moving objects independently according to the X-axis, Y-axis, and Z-axis. Then, the position of the objects was established to create animation in the keyframe. Each keyframe was a computer-generated image, in which the rapid movement of an image depended on the frame per second (FPS), which was called animation.

(d) The fourth step was to create the script for controlling by using C# language.

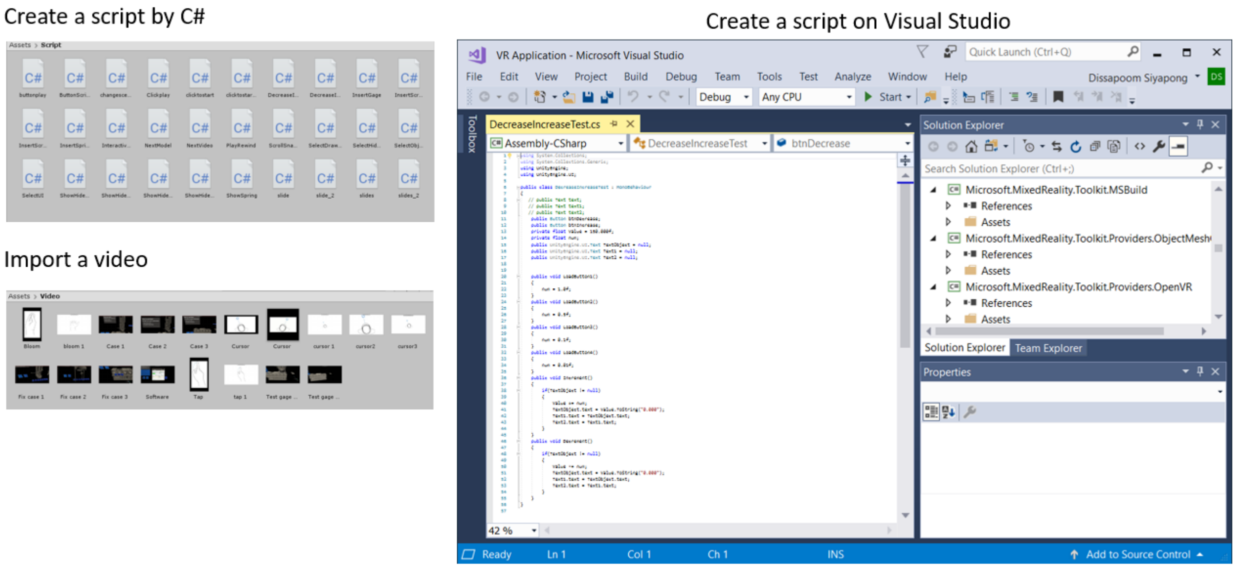

Figure 3.10: The script for controlling by using C# language**.**

The C sharp (C#) of the programming language is used widely to develop the game engine in Unity 3D by using Visual Studio. Figure 3.10 shows that the Unity 3D tools allow developers to design the system independently by using system control scripts to develop the 3D application. In addition, the variety of the Unity 3D consisted of creating animation, a UX/UI design, multimedia, and others controlled by the C# scripts. These scripts would be attached to the objects for controlling the behavior of the objects. Therefore, scripting would be a necessary component in the development of applications. Moreover, Unity 3D's ability could assist developers in connecting other systems by using assets/plugins to be integrated; such as, OpenCV, database, MySQL, and others.

(e) The fifth step was to add a QR code to generate a position of marking for detection and showing a 3D CAD.

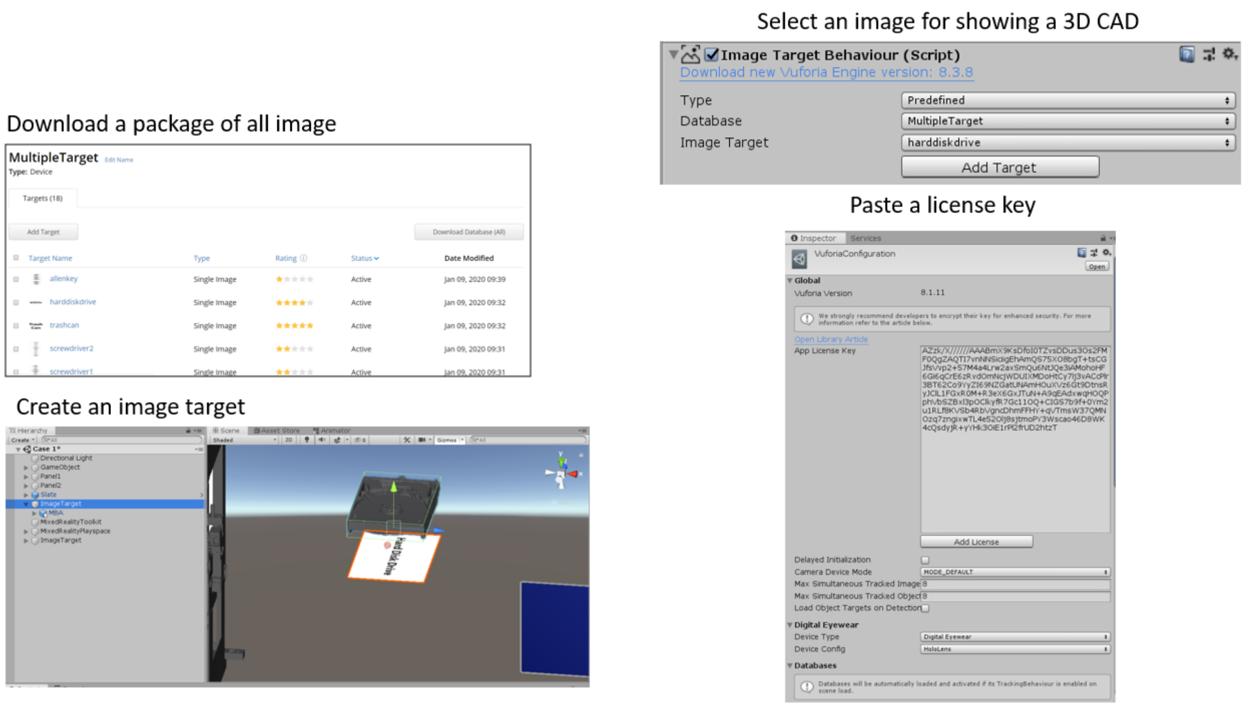

Figure 3.11: Adding a QR code or an image to unity 3D for displaying a 3D CAD.

As mentioned in the previous paragraph, Unity 3D offers tools for supporting development. A software development kit (SDK) is an essential tool that could help developers access complex systems. Therefore, the Vuforia SDK was implemented by tracking the QR code marker into the AR applications (Figure 3.11). The QR code was generated by importing it into the Vuforia portal browser. However, the computer vision would detect the marker depending on the image was marked as a point in a grayscale tone.

(f) The sixth was to build an application on a PC.

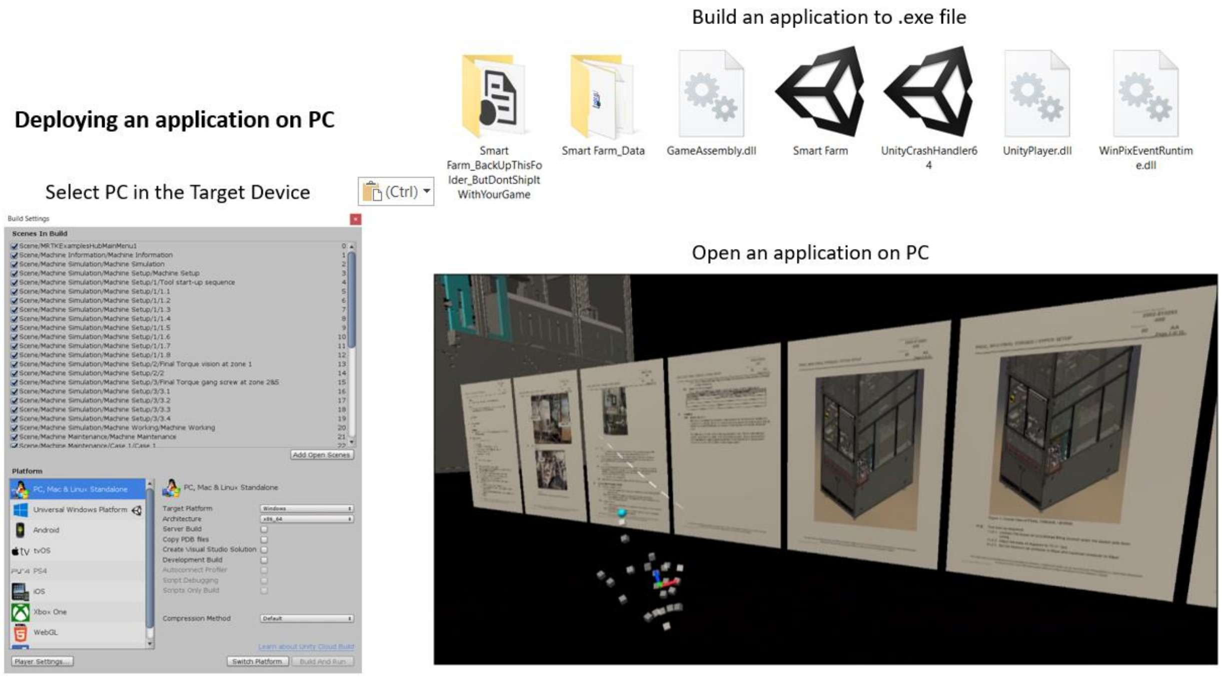

Figure 3.12: Building an application on a PC.

Unity 3D supports various platforms for building the application, including the Universal Windows Platform (UWP), Android Mobile, IOS Mobile, Xbox, WebGL, PC, etc. Figure 3.12 shows the built setting started by using the scenes in the built panel, in which the built setting would depend on the selected platform.

3.9 Process Flow of the Application

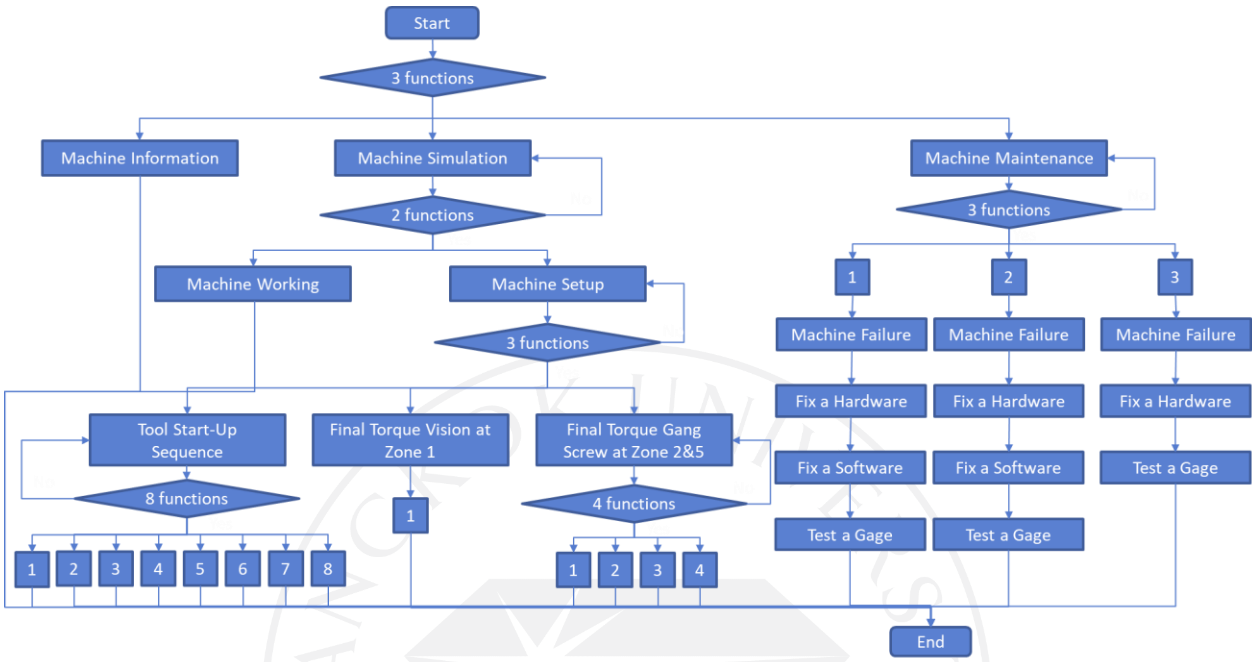

Figure 3.13: Process flow of the application.

Figure 3.13 indicates how the application operates, in which it is designed to suit an industry by creating three functionalities: information, simulation, and maintenance. The information is gathered to retrieve the machine's information; such as, manual, 2D drawings, and 3D CAD. The manual describes how the machine would be set up and maintained, which would be a traditional form of instructions. These documents would be used to design the new instructions in a three-dimensional simulation by creating the function of machine simulation. Machine simulation is essential for learning enhancement by using 3D visualization and animation, which would classify the machine's set up and operation. The function of machine maintenance would also be designed to allow users to train with an interactive virtual machine in a virtual environment. Finally, the maintenance training would allow users to learn how to maintain hardware and software for realistic training with a real machine in the production line.

3.10 The 3D Application

This section illustrates an overview of the 3D application, as mentioned in the previous paragraph and shown by Figure 3.13. The complex machine is simulated in the virtual environment of the 3D application by creating a practical instruction manual for training. The classic instruction manual would be adapted to the 3D application by allowing users to interact with virtual objects to enhance their learning skills. There are three functionalities of the 3D application (Figure 3.14) or refer to the true image as shown in the WD thesis: (a) Machine information, (b) machine simulation, and (c) machine maintenance.

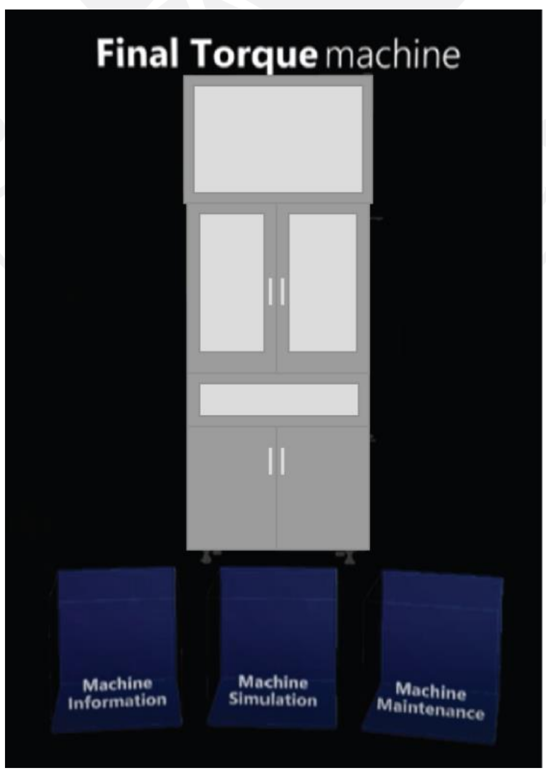

Figure 3.14: The main menu in the application for the first page.

(a) Machine information is an instruction manual of the machine gathered in the exact location for convenience. This information includes a manual, 3D CAD, and 2D drawing. In addition, the application would allow users to control the independent systems using a mouse and keyboard on a PC, which is called a first-person shooter (FPS) (Figure 3.15).

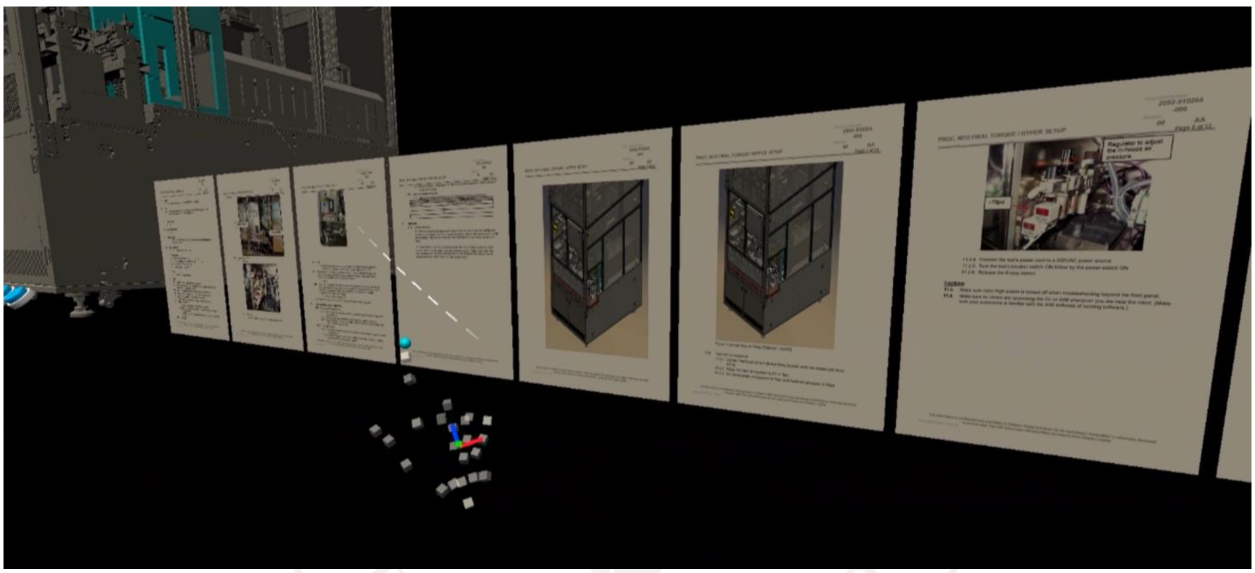

Figure 3.15: The manual in the application for machine information.

The integration of 3D CAD and 2D drawing would be the time reduction of searching for files simultaneously. Electronic book (E-book) documents are created by computer-generated images used to design the 2D drawing documents. The 2D drawing documents would indicate the details related to the mechanical design; such as, the name and number of the parts (Figure 3.16) or refer to the true image as shown in the WD thesis. Additionally, the virtual machine was designed by using 3D CAD (Figure 3.17) or refer to the true image as shown in WD thesis. The 3D CAD is an overview of the complex machine in the production line. In the proposed system, some components of the machine could be displayed by clicking on a button. Each button would be used to display each component of the machine and the description.

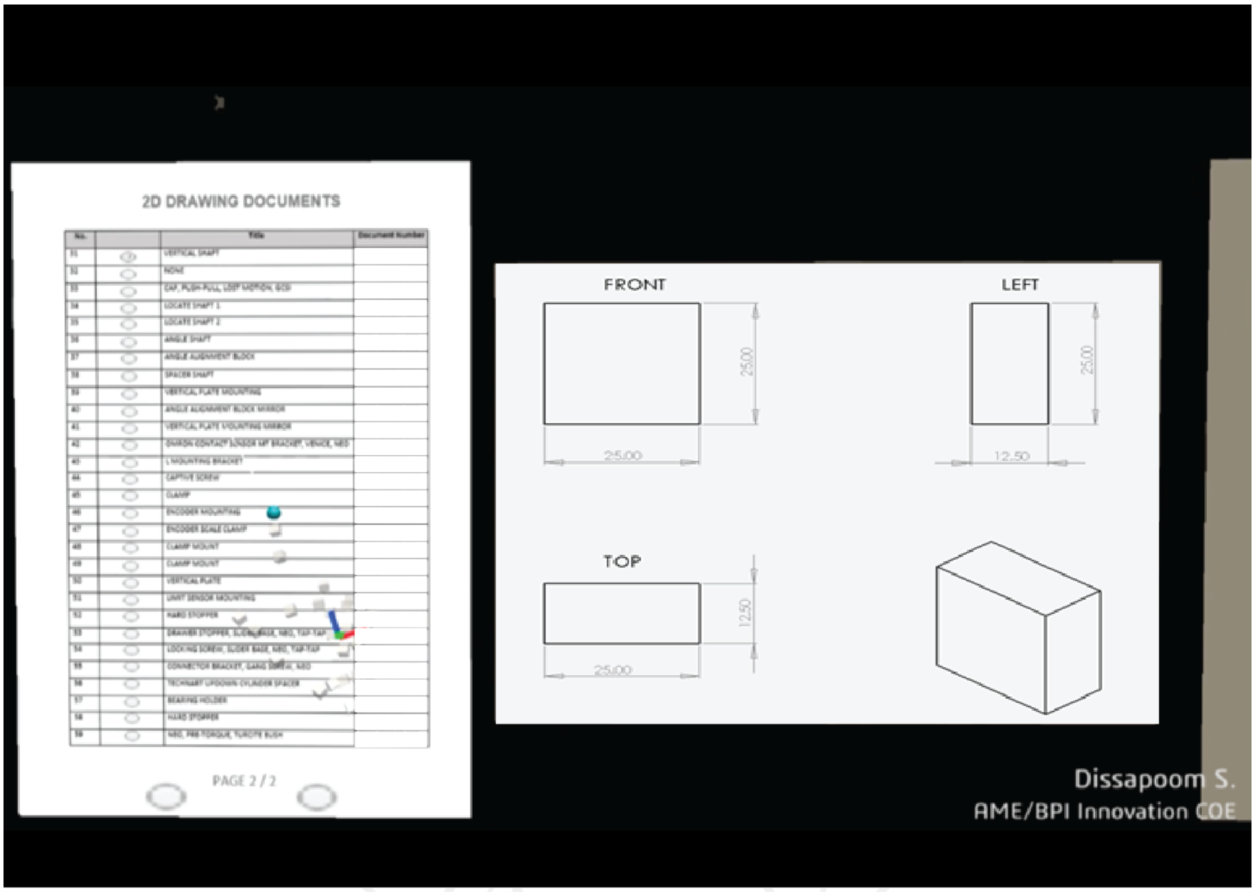

Figure 3.16: The 2D drawing and the 3D CAD in the application for machine information.

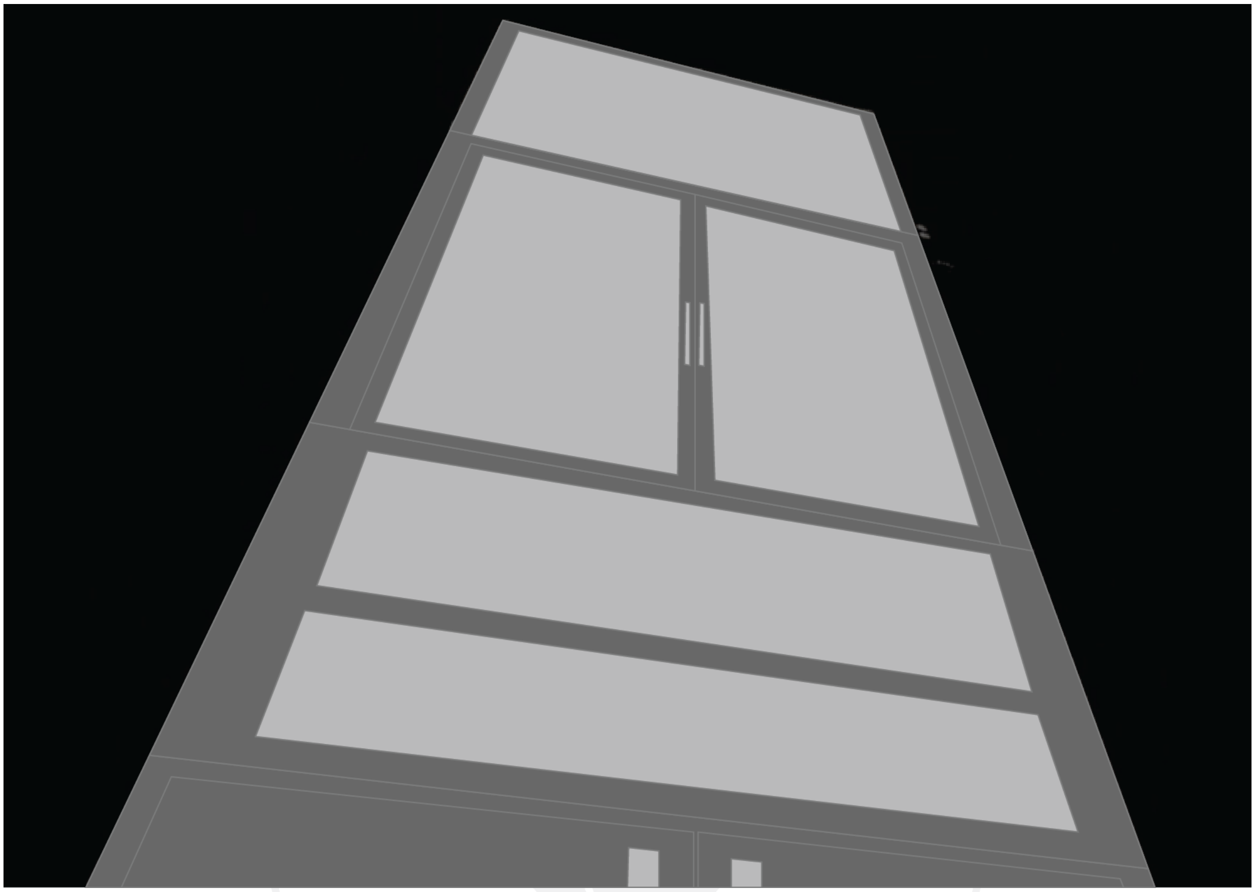

Figure 3.17: The 3D CAD of the full machine in the application for machine information.

(b) Machine simulation is a replication from the machine's instruction manual by using 3D animation. The 3D animation describes how the machine is set up and operated. The machine’s set up is one of the functions of machine simulation consisting of the users learning how to set up the machine by using rotation and scaling the object. Moreover, 3D animation would be used to describe more by clicking on a button (Figure 3.18).

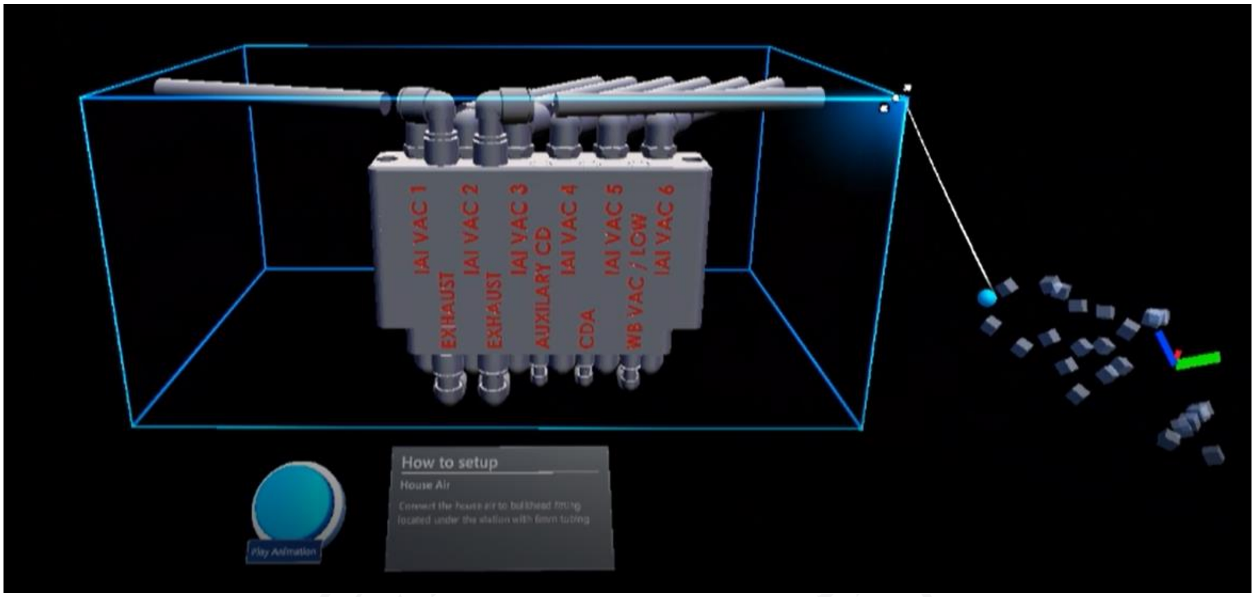

Figure 3.18: The simulation in the application for the machine set up of the machine simulation.

Another function of the machine simulation was the machine’s working, which described the operation through a virtual 3D simulation (Figure 3.19) or see the true image as shown in the WD thesis. The 3D simulation would allow users to be immersive in the virtual machine similar to the actual machine in the production line, which could resolve the limitations of any problems encountered in the production line; such as, space, vision, and time limit.

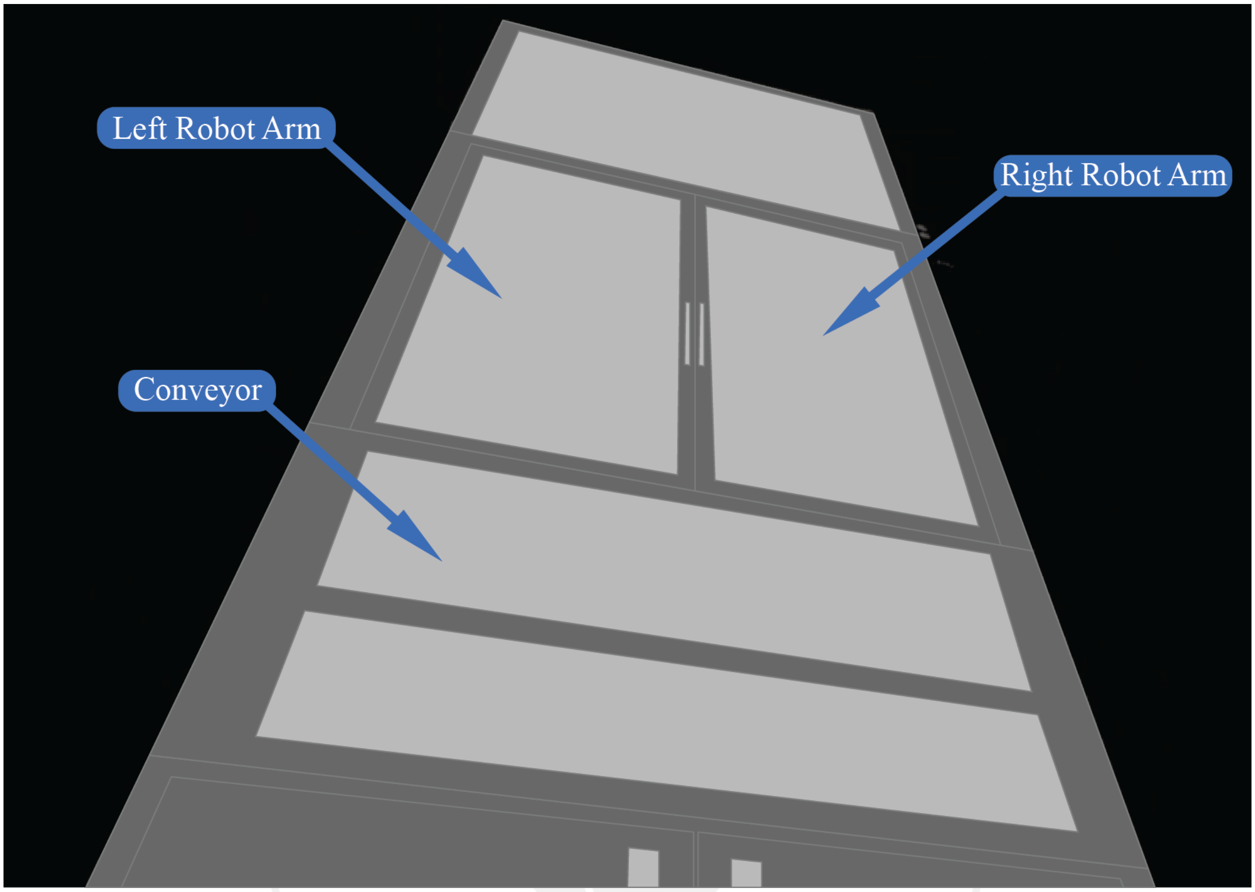

Figure 3.19: The machine operation in the application for the machine’s working.

(c) Machine maintenance is a scenario of both the failure cases and maintenance of the machine. The maintenance of the machine is an essential element in the production line. Consequently, the maintenance time of the machine would probably impact the production process. However, the improvement of maintenance training could help trainees comprehend more by training many times in virtual environments. There were three failure cases used for the case study, which each case was classified into four parts of training: (1) Machine failure, (2) hardware maintenance, (3) software maintenance, and (4) testing. In addition, the knowledge of multimedia increased a more practical understanding for the trainees; such as, text, video, 3D animation, and 3D simulation.

(1) Machine failure describes how failure occurs in the machine (Figure 3.20) or see the true image as shown in the WD thesis. Effective maintenance is an acknowledgement of where the failure was and how it occurred. The system could help users learn through interaction by clicking on the 3D HDD to insert in the conveyor for the instructions of the 3D animation. The next part would be guided by clicking on the Fix button.

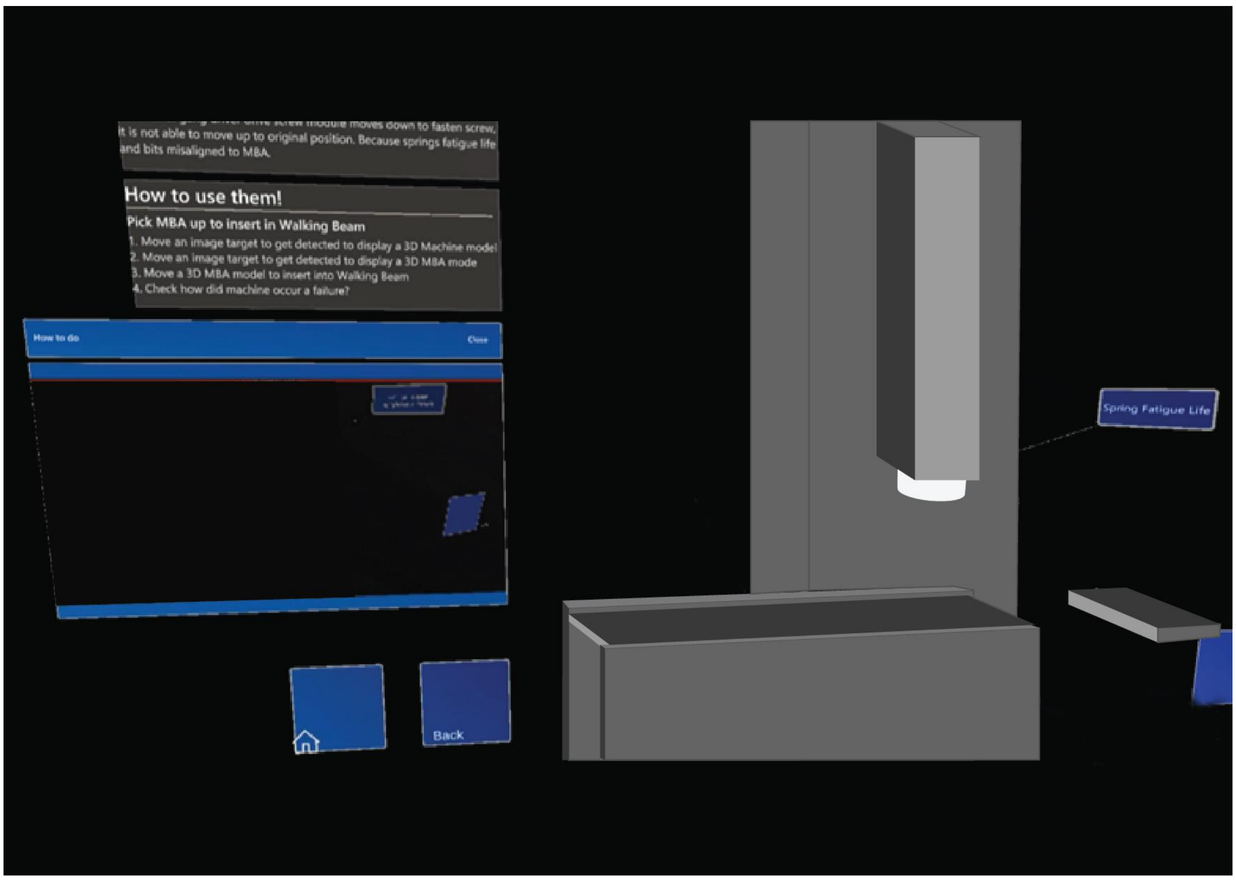

Figure 3.20: The first case of machine failure in the application for machine maintenance.

(2) Hardware maintenance consists of the maintenance of the mechanical parts in the machine (Figure 3.21) or see the true image as shown in the WD thesis. The mechanical component is involved, elemental, and small-scale. The proposed system would use special effects for learning enhancement. The special effects would be a technique of the 3D motion by using fade-in and

fade-out behavior to simulate changing a mechanical part. The system guided users to click on the Separate button for the separation of the mechanical parts, which these parts were removed using the trash can. Therefore, the system guided users to click on buttons 1 to 6, thus displaying the new parts for combining with the mechanical parts. The next part was guided by clicking on the Fix button.

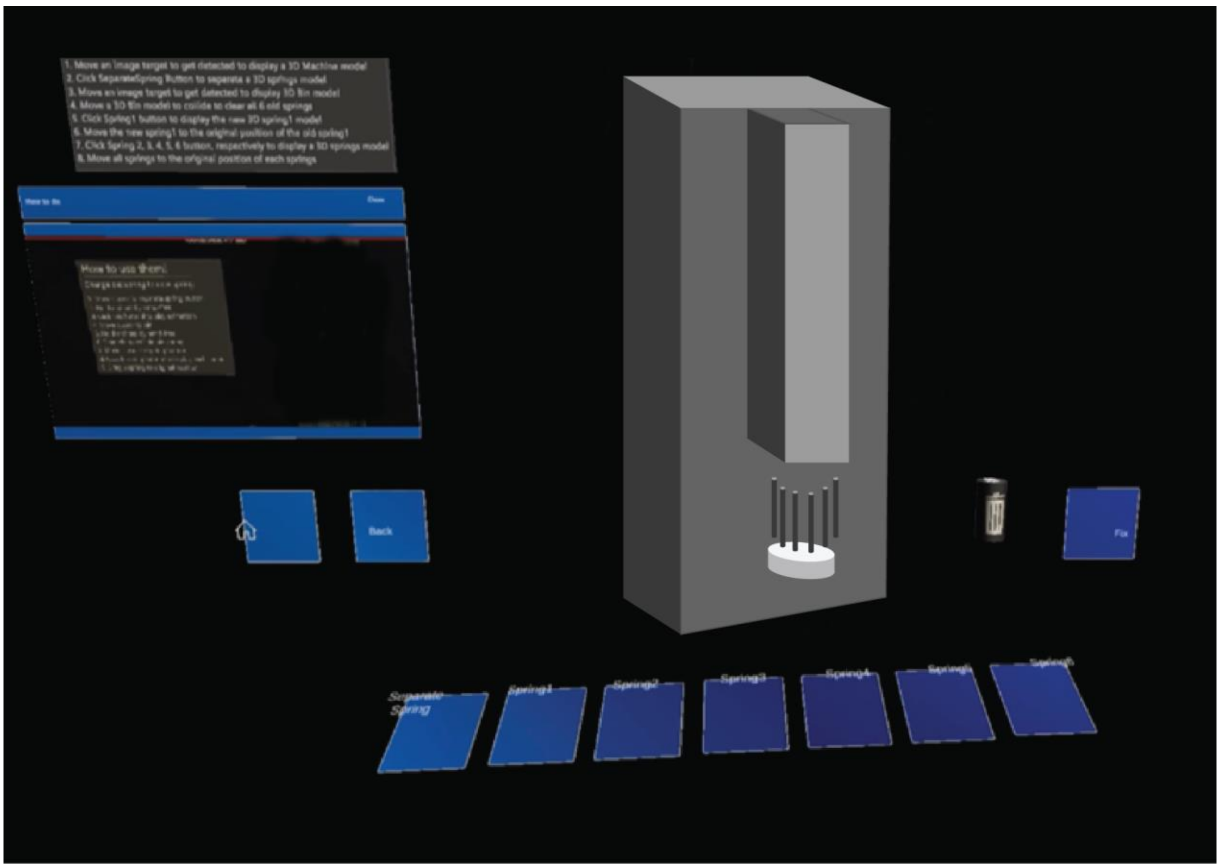

Figure 3.21: The first case of solving hardware in the application for machine maintenance.

(3) Software maintenance consists of values adjustment in an interface (Figure 3.22) or see the true image as shown in the WD thesis. The software was used to control the machine. Nevertheless, software maintenance would be another essential element. The system could assist users to interact with the software interface of the monitor's machine, in which the interface would be simulated to

the same software of the machine in the production line. Therefore, users would be trained similar to the actual machine. The next part was guided by clicking on the Fix button.

Figure 3.22: The first case of solving software in the application for machine maintenance.

(4) Testing is a recheck of the maintenance (Figure 3.23) or see the true image as shown in the WD thesis. The recheck is implemented by using the 3D HDD to insert in the conveyor for the instructions of the 3D animation, which efficient maintenance would be confirmed by testing.

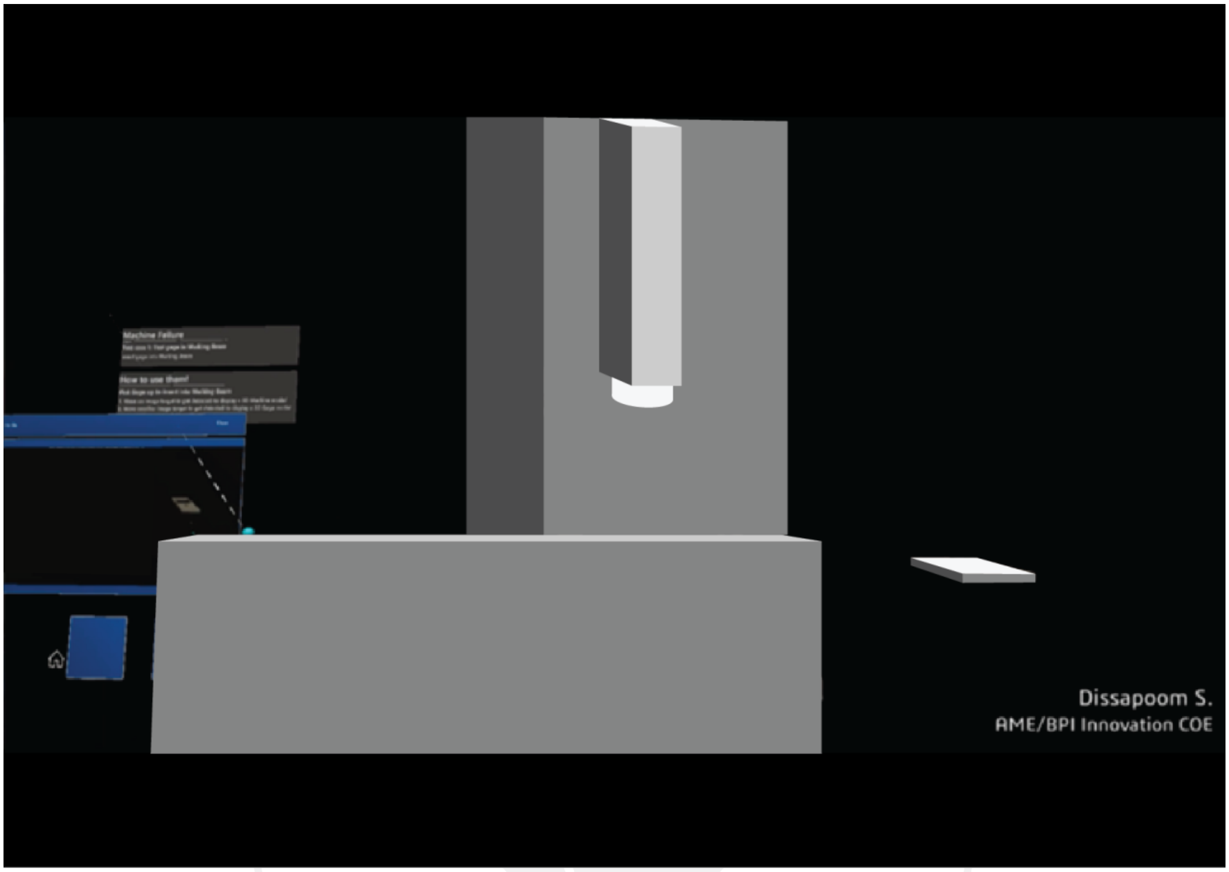

Figure 3.23: The first case of testing in the application for machine maintenance.

3.11 Comparison of Extended Reality Technology for the Application

The application was generated for two systems (Figure 3.24) comprising the 2D desktop and the 3D full immersive technology with Microsoft HoloLens. However, both systems were different. The 2D desktop was used to display 3D visualization on a 2D screen monitor by users interacting with a mouse and keyboard. On the other hand, the 3D fully immersive technology with Microsoft HoloLens was used to display the 3D holographic by users interacting hand-free to control the system. AR was used to assist users in fully interacting with virtual objects by scanning a QR code or images with a camera to display the 3D objects. Moreover, users could use the VR version without camera scanning.

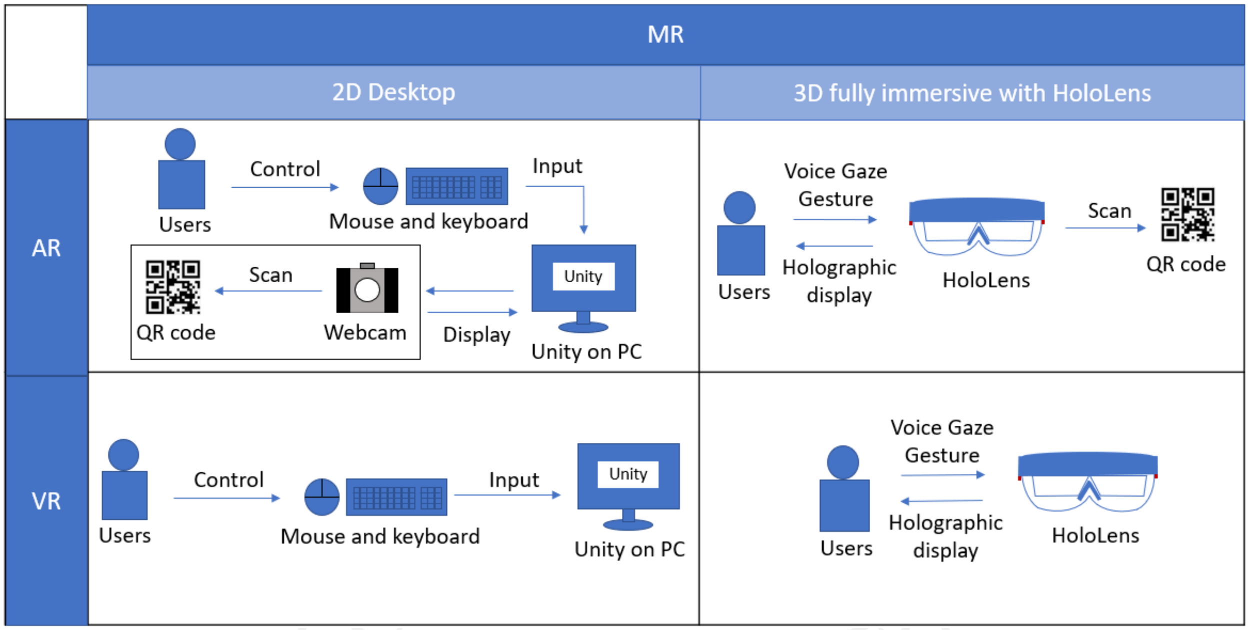

Figure 3.24: Process flow of the systems.

The proposed system offered a difference in learning, in which the excellent performance of the technology was extracted by creating three types of XR technology, including AR that allowed a user to enable a camera function of the system (Figure 3.25) or see the true image as shown in the WD thesis, which was tracked by an image marker to display the 3D virtual object. The 3D virtual object was an overlay of the real object to increase the trainee's understanding. VR allowed a user to interact with the virtual machine in the virtual environment (Figure 3.26) or see the true image as shown in the WD thesis. Thus, the system provided users with a novel experience in which the virtual environment was similar to a natural environment. Finally, MR allowed a user to be immersive in the 3D holographic visualization through Microsoft HoloLens (Figure 3.27), which was called HMD. The system offered hand-free interaction to control the virtual object.

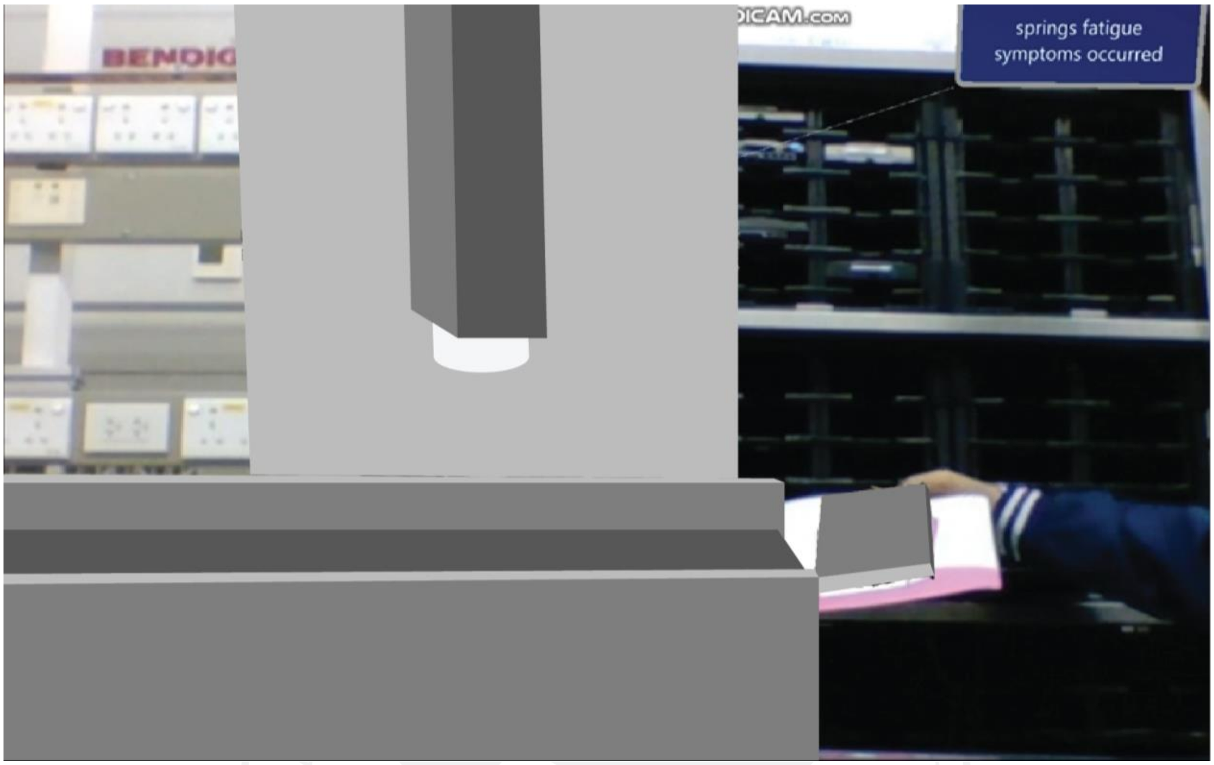

Figure 3.25: AR application.

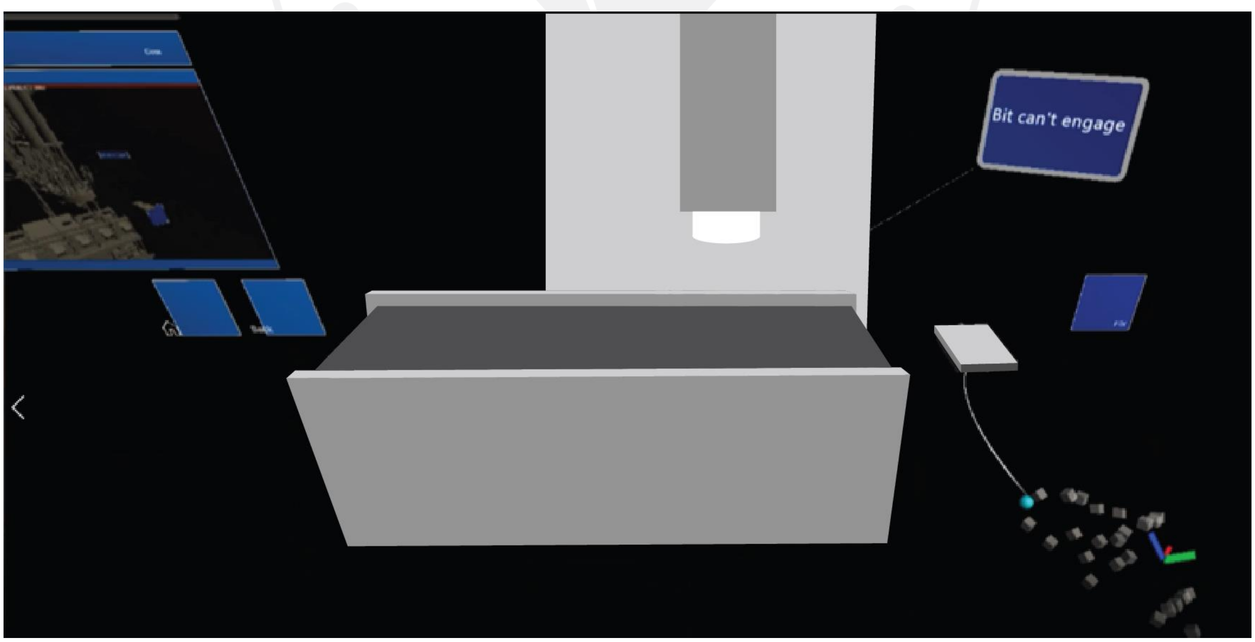

Figure 3.26: VR application.

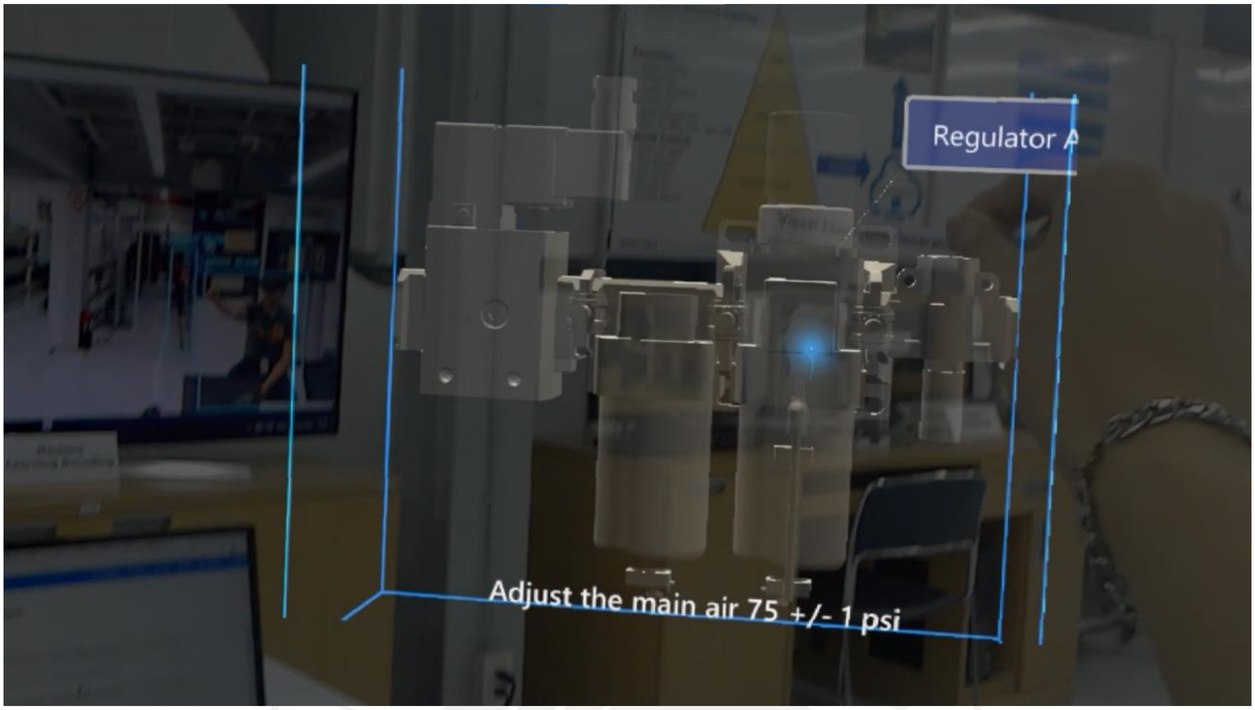

Figure 3.27: MR application.

3.12 Comparison of the Current Operation and New Operation by a Process Chart

The mechanical design was designed by the designer team (Figure 3.28). The mechanical design consisted of a 2D drawing, 3D CAD, and an instruction manual. First, 3D CAD was used to design the machine. Next, the completion of the 3D CAD design was used to set each axis's dimensions (X-axis, Y-axis, and Z-axis) in the 2D drawing. Finally, these mechanical parts were used for the machines' assembly in the production line.

Additionally, the implementation of the machines was described in the instruction manual. The central problem of the mechanical design was that some files had disappeared or been damaged. The designer also utilized a long time searching and loading any files. This was because the 3D CAD files were too large.

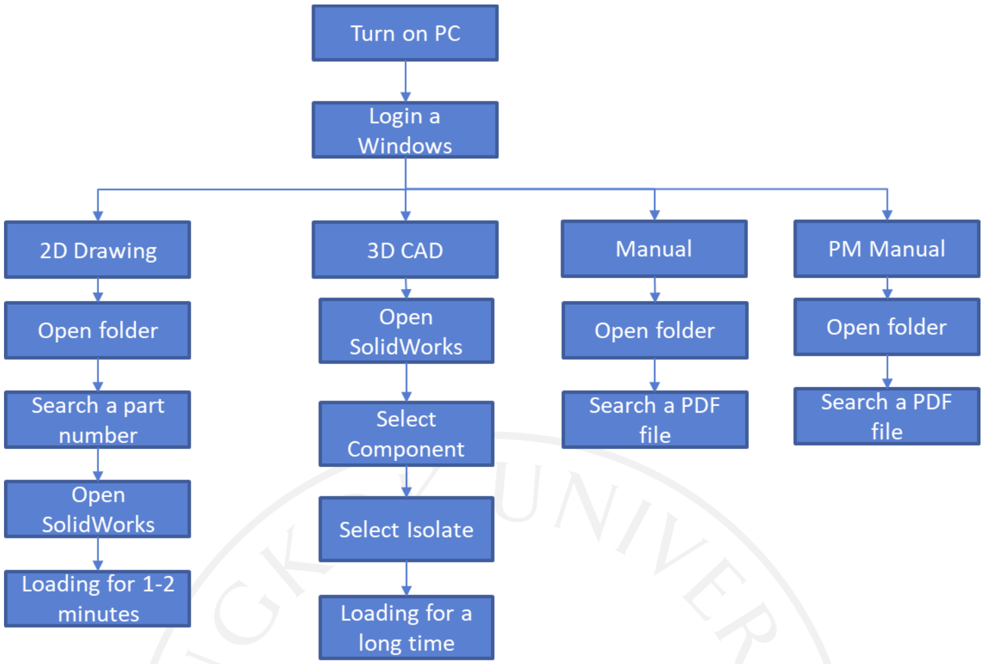

Figure 3.28: Searching all the information (current).

Another chart indicated the training in the production line (Figure 3.29). These protection processes were used to protect the machine from contaminated dust, which impacted the production process. There was also a team to check for dust on the workers' bodies in front of the production line before the worker went to the production line. All accessories were prepared in front of the clean room. Steps 2 to 8 above are the process of the body covering: 1. Step 2 is wearing the clean room bouffant caps, 2. step 3 is wearing plastic gloves, 3. step 4 is wearing the mask, 4. step 5 is wearing the clean room coverall, 5. step 6 is wearing the clean room boots, 6. step 7 is changing plastic gloves to latex gloves, and the last step is scanning by the machine scanner.

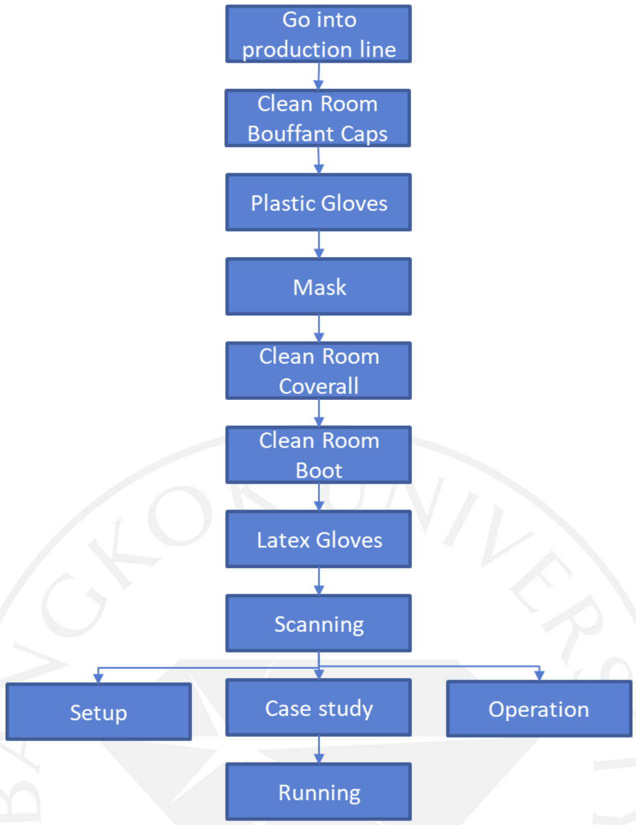

Figure 3.29: Training with on-the-job training (current).

These problems were solved by creating a new operation (Figure 3.30). Then, as mentioned in the process chart, those files were gathered into the 3D application, and the 3D CAD was downsized. Nevertheless, all files were at the exact location and had faster processing. Additionally, the 3D application could help users enhance their maintenance and learning skills by interacting with a virtual machine in a virtual environment, in which users were trained unlimited times and also without any time limit.

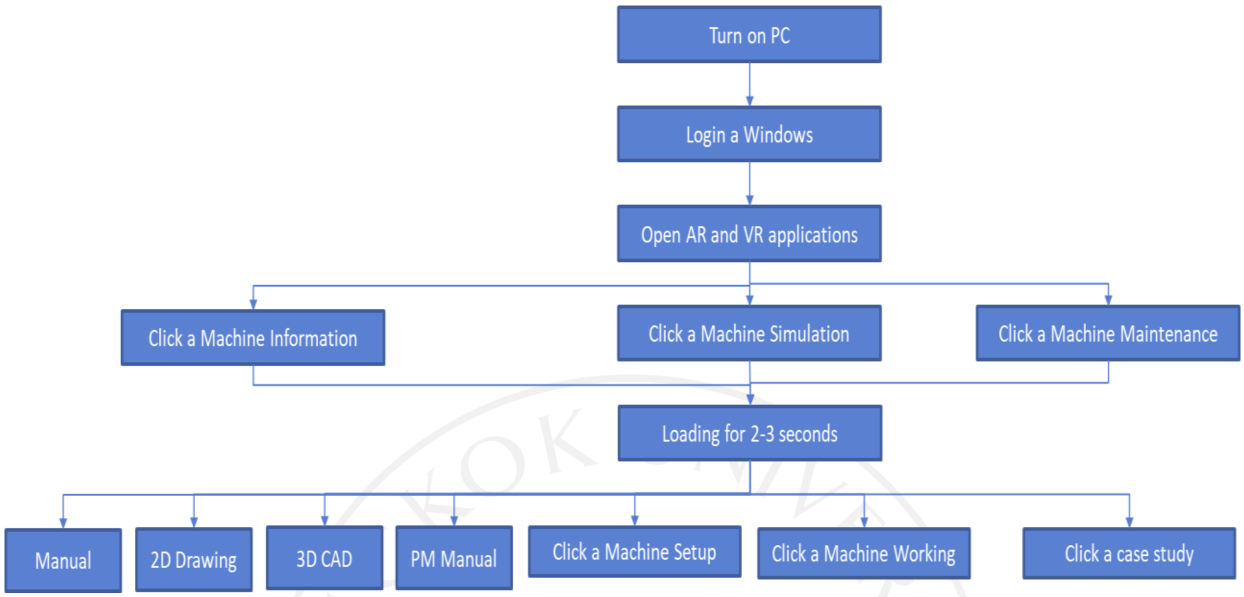

Figure 3.30: Searching all the information and training off-the-job training (new).

CHAPTER 4

4. RESULTS AND DISCUSSION

A summary of the evaluation results is shown in Table 4.1. The 30 participants were asked to test the application system and undertake 10 questionnaires of the SUS survey. This survey consisted of 10 questions that were classified into two parts comprising both positive and negative questions. In the part of the positive questions, the first results showed that 33.33% of the participants strongly thought they would like to use this system frequently. Then, 30% of the participants thought that the system was easy to use, and 20% of the participants found the various functions in this system were well-integrated. The following results showed that 33.33% of the participants would imagine that most people would learn to use this system quickly. Moreover, 16.67% of the participants felt very confident using the system.

On the other hand, the part of the negative questions illustrated the first results showed that 6.67% of the participants strongly found the system unnecessarily complicated; in addition, 23.33% of the participants thought they would need a technical person's support to use this system. Furthermore, 13.33% of the participants thought there was too much inconsistency in this system, and 3.33% of the participants found the system very cumbersome to use. Likewise, 36.67% of the participants needed to learn many things before they could utilize this system.

Table 4.1: Survey result (SD: strongly disagree, D: disagree, N: neutral, A: agree, and SA: strongly agree).

Questions	SD	D	N	A	SA
I think that I would like to use this system frequently.		3	9	8	10
I found the system unnecessarily complex.	2	9	11	6	2
I thought the system was easy to use.	1	3	7	10	9
I think that I would need the support of a technical person to be able to use this system.	3	6	4	10	7
I found the various functions in this system were well-integrated.		5	4	15	6
I thought there was too much inconsistency in this system.		9	9	8	4
I would imagine that most people would learn to use this system very quickly.	2		3	15	10
I found the system very cumbersome to use.	5	7	13	4	1
I felt very confident using the system.		5	6	14	5
I needed to learn a lot of things before I could utilize this system.	1	3	8	7	11

In the calculation of the SUS score (Table 4.2), 30 participants tested the application and undertook the SUS survey. They were classified into three groups: (a) The 10 participants of group 1 comprised expert engineers or machine owners, (b) 10 participants of group 2 were experienced engineers or other machine owners, (c) the 10 participants of group 3 were composed of novice engineers. The green highlight was a user group that had a score of 68 for an acceptable user or able to apply the application to the training program. The SUS formula calculated the score of the 30 participants. There were only 10 participants out of the three groups with 68 points or more: Seven participants of Group 1, two participants of Group 2, and one participant of Group 3. Figure 4.1 indicates the graphs of the SUS calculation that showed many participants having less than 68 points. A score of 68 points illustrated these participants' acceptance of using the application. However, a lower score of 68 illustrated the unacceptance of using the application by these participants. The majority of the participants with 68 points or more were those in Group 1, as they had more machine knowledge than the participants of Groups 2 and 3.

Table 4.2: The calculation of the 10 questionnaires.

	People	Point
Group 1	1	77.5
	2	52.5
	3	67.5
	4	60
	5	77.5
	6	80
	7	72.5
	8	75
	9	87.5
	10	87.5
Group 2	11	27.5
	12	62.5
	13	72.5
	14	50
	15	85
	16	52.5
	17	57.5
	18	55
	19	57.5
	20	57.5
Group 3	21	52.5
	22	47.5
	23	50
	24	75
	25	52.5
	26	35
	27	47.5
	28	32.5
	29	35
	30	15

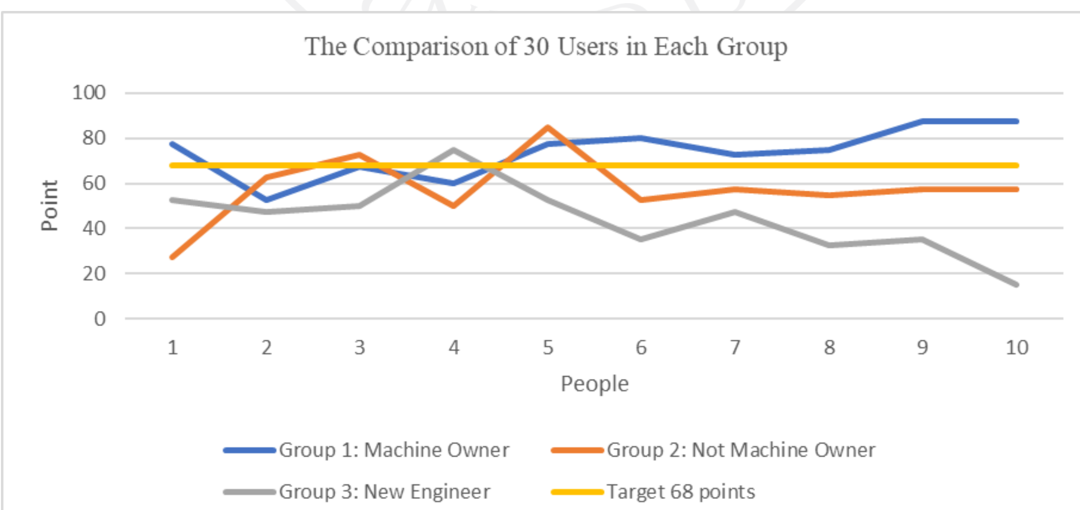

Figure 4.1: The survey calculation of the 10 questionnaires.

Moreover, there were participants with less than 68 points, as these participants did not have any knowledge about XR technology. Therefore, these participants avoided using new technology and utilized older methods. However, the participants needed to learn about XR technology first to know the new technology and the learning enhancement effectively.

In addition, users could understand more details about the training programs through the AR and VR applications, which were compared differently:

1. The VR application was placed in a fixed position, so it would be convenient to use by interacting through a first-person view with a keyboard and mouse on a PC.

2. The AR application enabled a camera to increase the user's understanding by interacting with virtual objects and three-dimensional CAD.

3. The MR application was not applied to the training program because it was too expensive for many people and needed many support devices.

In the next stage, the 10 engineering experts, who were the participants, performed the maintenance of the machine and their maintenance duration was compared with the current period of one month. On the other hand, the experienced engineer and novice engineer did not have any histories of the maintenance time of the machine in the current period of one month. Both of the engineer groups of 20 participants performed the maintenance of the machine to record the maintenance time before training with the VR application to compare between before and after training with the VR application (Table 4.3 or Figure 4.2).

Table 4.3: The current MTTR is recorded in each group.

Case	Group 1	Group 2	Group 3
A	7	7.45	8.23
B	83	85.12	87.54
C	29	30.37	31.08

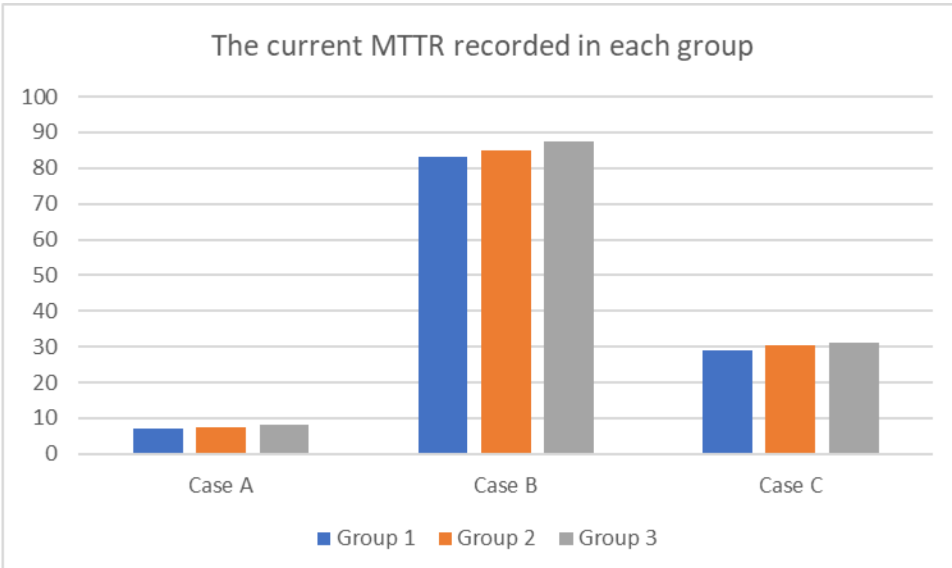

Figure 4.2: The current MTTR recorded in each group

There were three failure cases of the machine selected from 21 failure cases for the case study (Table 4.4). That machine had 22.7 hours of runtime, which it was not operating 24 hours. As a result, the production line always had to be cleaned and stopped working. Case A indicated the failure occurred with two counts using maintenance time of seven minutes for one time, and the machine stopped operating for 238.28 hours. Case B indicated the failure occurred with one count using maintenance time of 83 minutes for one time, and the machine stopped operating for 475.93 hours. Case C indicated the failure occurred with one count using maintenance time of 29 minutes for one time, and the machine stopped operating for 476.83 hours.

Nevertheless, these failures were because of uncertain reasons that occurred in the machine in the production line. Therefore, the authors' work presented these failures to be cases simulated from an equivalent machine in the laboratory for experimentation.

Table 4.4: The current maintenance time.

Case	Count of Category	Sum of Down Duration	MTBF (hour)	MTTR (min)	MTTR (hour)
A	2	14	238.28	7	0.12
B	1	83	475.93	83	1.38
C	1	29	476.83	29	0.48

Table 4.5: The experimental configuration

Experimental Configuration	
Sample size	30 participants
Engineer group	3 groups
Failure cases	3 cases
Failure cases simulations time	5 minutes / 1 cases
Total simulations time	15 minutes
Experimentation time (Case A)	9 minutes
Experimentation time (Case B)	86 minutes
Experimentation time (Case C)	32 minutes
Total experimentation time (3 cases)	127 minutes
Total simulations and experimentation time	142 minutes
Total experimentation (30 participants)	4,260 minutes or 71 hours

Table 4.5 shows the experimental configuration described the experimentation in the laboratory. There are three engineer groups of 30 participants performed the maintenance of the machine and counted the maintenance time in each case. Firstly, three failure cases has been simulated for 5 minutes in each case, which the total simulations time was 15 minutes. On the other hand, the

maintenance time was used more than the simulations time. The maximum maintenance time of three failure cases included case A was 9 minutes, case B was 86 minutes, and case C was 32 minutes, which the total maximum maintenance time of three failure cases were 127 minutes and plus with the total simulations time was 142 minutes for only one participants. Therefore, the total maintenance time of three failure cases were 4,260 minutes or 71 hours for 30 participants. The experimentation has been estimated for 9 days, which the fact was three engineer groups were quite busy and their time unmatched. The experimentation has been finished for 3 months.

Table 4.6 shows that the results of case A of group 1 illustrated that the mean of the 10 participants was 6.49 minutes, the results of case A of group 2 illustrated that the mean of the 10 participants was 6.852 minutes, and the results of case A of group 3 illustrated that the mean of the 10 participants was 7.335 minutes. The results of case B of group 1 illustrated that the mean of the 10 participants was 75.39 minutes, the results of case B of group 2 illustrated that the mean of the 10 participants was 83.45 minutes, and the results of case B of group 3 illustrated that the mean of the 10 participants was 83.694 minutes. Finally, the results of case C of group 1 illustrated that the mean of the 10 participants was 27.57 minutes, the results of case C of group 2 illustrated that the mean of the 10 participants was 28.941 minutes, and the results of case C of group 3 illustrated that the mean of the 10 participants was 29.389 minutes (Figure 4.3).

Table 4.6: The maintenance time of the 30 participants is recorded in each case.

Group 1: Expert Engineer				Group 2: Experience Engineer				Group 3: Novice Engineer			
Participants	Case A (min)	Case B (min)	Case C (min)	Participants	Case A (min)	Case B (min)	Case C (min)	Participants	Case A (min)	Case B (min)	Case C (min)
1	6.54	76.57	27.53	1	6.58	81.54	28.50	1	7.54	83.57	29.53
2	6.49	72.46	28.38	2	7.05	84.41	29.34	2	7.49	84.46	29.38
3	6.56	74.51	28.15	3	7.11	83.50	29.56	3	6.55	84.51	28.35
4	6.51	76.34	27.49	4	6.59	81.58	28.41	4	8.01	83.34	29.49
5	6.47	75.28	27.55	5	7.02	83.23	30.08	5	7.47	84.28	29.55
6	6.44	78.14	26.59	6	7.09	84.19	29.36	6	7.44	85.14	30.09
7	6.52	74.43	28.03	7	6.57	82.44	27.51	7	6.58	80.43	28.53
8	6.43	72.23	27.21	8	6.47	82.35	28.12	8	7.43	83.23	29.21
9	6.41	77.44	26.56	9	7.01	84.39	29.23	9	7.31	84.44	29.56
10	6.53	76.54	28.20	10	7.03	83.45	29.30	10	7.53	83.54	30.20
Mean	6.49	75.39	27.57	Mean	6.852	83.108	28.941	Mean	7.335	83.694	29.389

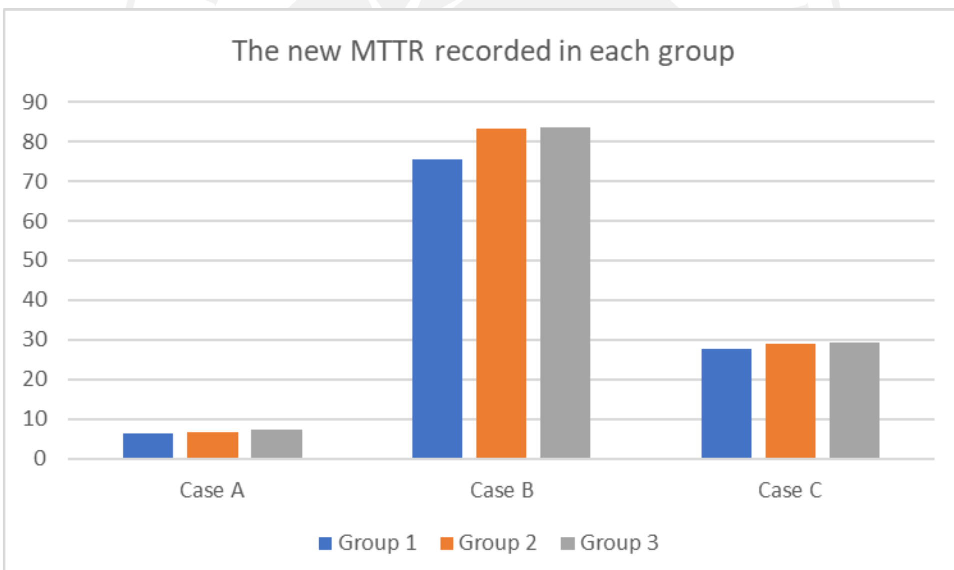

Figure 4.3: The new MTTR recorded in each group

The majority of all three groups took less maintenance time than the current time. Therefore, the majority of the mean maintenance time was reduced from the current time. Hence, the authors hypothesized that the MTTR of the machine was reduced according to the maintenance time of the 30 participants. Moreover, the MTBF decreased as well. Nevertheless, the recorded maintenance time of the 30 participants was the raw data. Consequently, the raw data were calculated statistically to measure the distributions of the sample group by using standard deviation (SD). Table 4.7 shows that the SD of case A of group 1 was 0.05077 minutes, the SD of case A of group 2 was 0.26148 minutes, and the SD of case A of group 3 was 0.44532 minutes. The result of case B of group 1 illustrated that the SD was 1.99055 minutes, the SD of case B of group 2 was 1.08572 minutes, and the SD of case B of group 3 was 1.30285 minutes. Finally, the result of case C illustrated the SD was 0.64286 minutes, the SD of case C of group 2 was 0.77645 minutes, and the SD of case C of group 3 was 0.58536 minutes. The results of all three groups illustrated that group 1 was the minimum of the three groups. However, the sample size was too small, and it had a chance of a margin of error. In the next stage, the margin of error was used to calculate the data discrepancies using the degree of freedom (DoF) that was nine, and the T-value of 95% CI was 2.262, as the sample size was 10 participants from each group. The result of case A illustrated the margin of error of group 1 was 0.0363 minutes, group 2 was 0.1870 minutes, and group 3 was 0.3185 minutes. The result of case B illustrated the margin of error of group 1 was 1.4238 minutes, group 2 was 0.7766 minutes, and group 3 was 0.9319 minutes. Finally, the result of case C illustrated the margin of error of group 1 was 0.4598 minutes, group 2 was 0.5554 minutes, and group 3 was 0.4187 minutes. Therefore, in the next stage, the CI was used to calculate the confirmation of the true mean.

Table 4.7: The 95% confidence interval of the three groups are calculated in each case.

Case	A			B			C		
Group	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Mean	6.49	6.852	7.335	75.39	83.108	83.694	27.57	28.941	29.389
S.D.	0.05077	0.26148	0.44532	1.99055	1.08572	1.30285	0.64286	0.77645	0.58536
DoF	9	9	9	9	9	9	9	9	9
T-Value for 95% CI	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262
Margin of Error	0.0363	0.1870	0.3185	1.4238	0.7766	0.9319	0.4598	0.5554	0.4187
Sample size	10	10	10	10	10	10	10	10	10
Upper Value	6.5263	7.039	7.6535	76.8138	83.8846	84.6259	28.0298	29.4964	29.8077
Lower Value	6.4537	6.665	7.0165	73.9662	82.3314	82.7621	27.1102	28.3856	28.9703

The 95% CI calculated to indicate the true mean in the range between an upper value and a lower value. Case A of group 1 indicated the sample mean of 6.49 minutes was between a lower value of 6.4537 minutes and an upper value of 6.5263 minutes, which was 6.49±0.0363. Case A of group 2 indicated the sample mean of 6.852 minutes was between a lower value of 6.665 minutes and an upper value of 7.039 minutes, which was 6.852±0.1870. Case A of group 3 indicated that the sample mean of 7.335 minutes was between a lower value of 7.0165 minutes and an upper value of 7.6535 minutes, which was 7.335±0.3185 (Figure 4.4). Case B of group 1 indicated that the sample mean of 75.39 minutes was between a lower value of 73.9662 minutes and an upper value of 76.8138 minutes, which was 75.39±1.4238. Case B of group 2 indicated that the sample mean of 83.108 minutes was between a lower value of 82.3314 minutes and an upper value of 83.8846 minutes, which was 75.39±0.7766. Case B of group 3 indicated that the sample mean of 83.694 minutes was between a lower value of 82.7621 minutes and an upper value of 84.6259 minutes, which was 83.694±0.9319 (Figure 4.5). Case C of group 1 indicated that the sample mean of 27.57 minutes was between a lower value of 27.1102 minutes and an upper value of 28.0298 minutes, which was 27.57±0.4598. Case C of group 2 indicated that the sample mean of 28.941 minutes was between a lower value of 28.3856 minutes and an upper value of 29.4964 minutes, which was 28.941±0.5554. Case C of group 3 indicated that the sample mean of 29.389 minutes was between a lower value of 28.9703 minutes and an upper value of 29.8077 minutes, which was 29.389±0.4187 (Figure 4.6). Thus, the correct interpretation of the CI was that 95% of the confidence was the proportion of the sample of each group, which was between a lower value and upper value. The new maintenance time was verified by computing the percentage change, which had a better maintenance time improvement in the next stage.

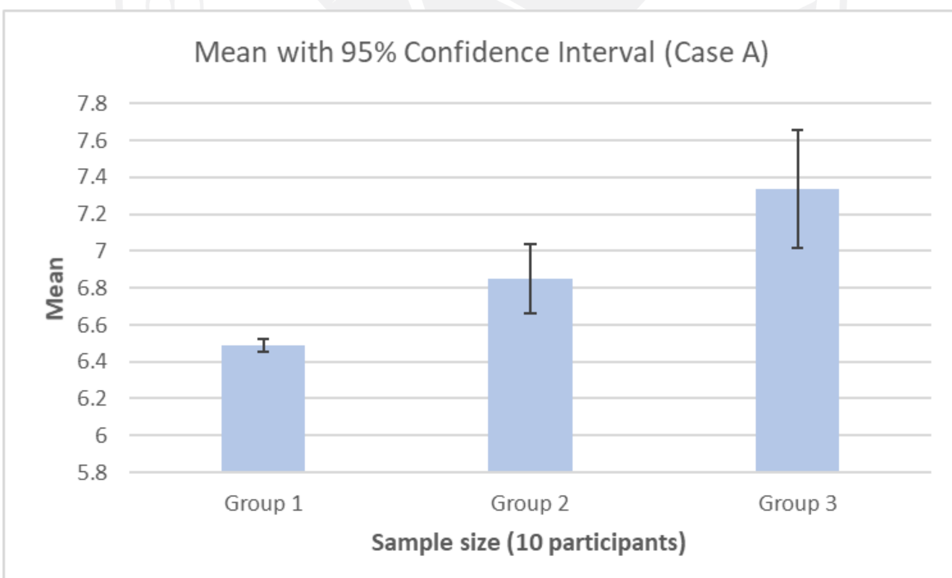

Figure 4.4: Mean with 95% Confidence Interval (Case A)

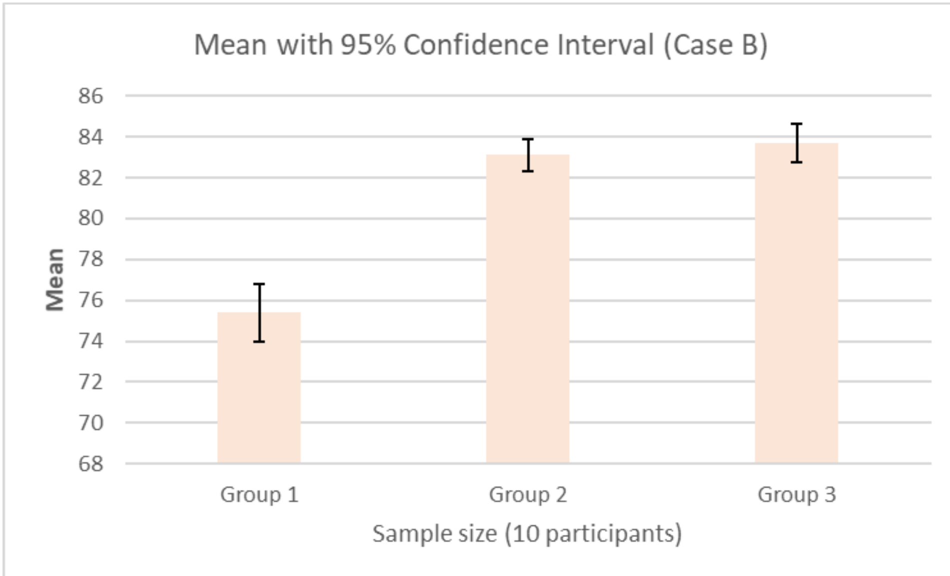

Figure 4.5: Mean with 95% Confidence Interval (Case B)

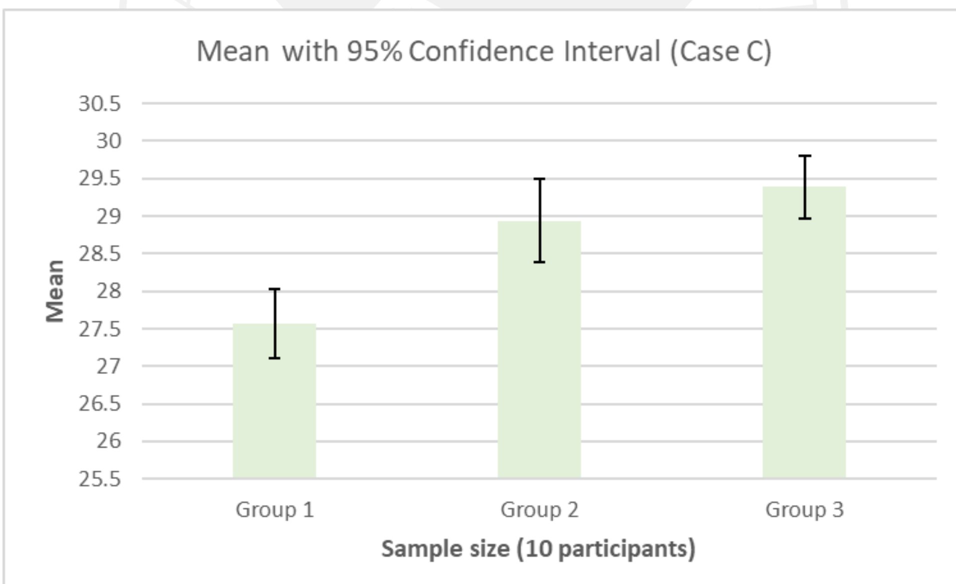

Figure 4.6: Mean with 95% Confidence Interval (Case C)

Table 4.8: The percentage change of the three groups is computed in each case.

	Group 1: Experience Engineer				Group 2: Intermediate Engineer				Group 3: Novice Engineer			
Item No.	Current MTTR (min)	New (Avg.)	%increase	%decrease	Current MTTR (min)	New (Avg.)	%increase	%decrease	Current MTTR (min)	New (Avg.)	%increase	%decrease
Case A	7	6.49	-	7.29%	7.45	6.85	-	8.05%	8.23	7.33	-	10.94%
Case B	83	75.39	-	9.17%	85.12	83.1	-	2.37%	87.54	83.694	-	4.39%
Case C	29	27.57	-	4.93%	30.37	28.941	-	4.71%	31.08	29.389	-	5.44%

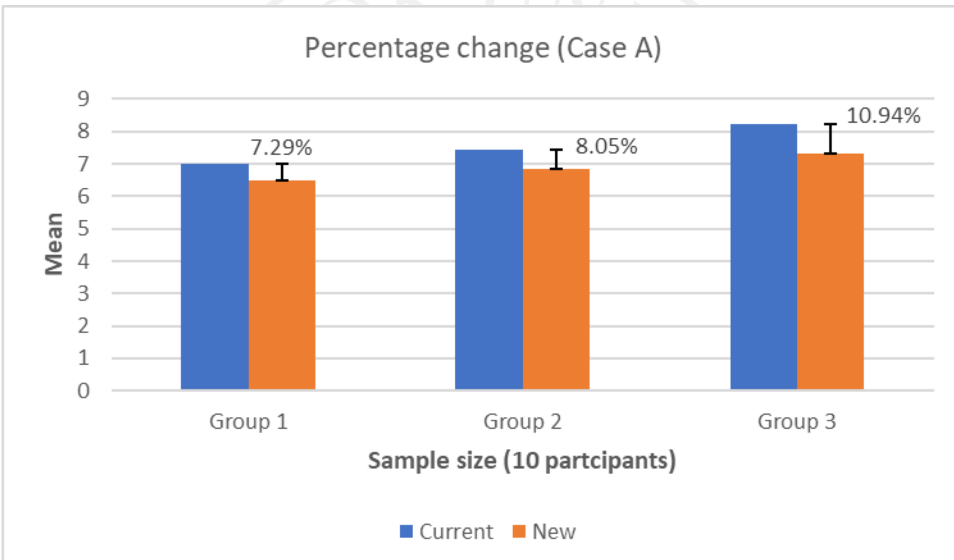

Figure 4.7: Percentage change (Case A)

Table 4.8 shows that all three groups had a percentage decrease for all cases. Therefore, the maintenance time was reduced, which showed a better improvement. Group 1 comprised expert engineers or machine owners who had more machine knowledge than the other groups (Figure 4.7). Therefore, group 1 took less maintenance time than the other groups. Group 2 consisted of experienced engineers or similar machine owners (Figure 4.8). Therefore, group 2 took less maintenance time as well.

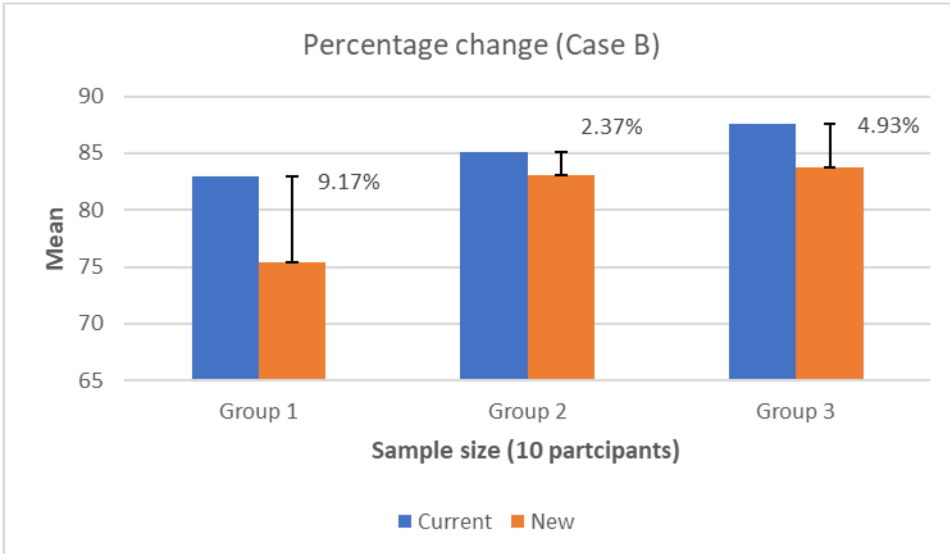

Figure 4.8: Percentage change (Case B)

On the other hand, group 3 was composed of novice engineers who had no machining knowledge at all (Figure 4.9). Therefore, group 3 took more maintenance time than the current time.

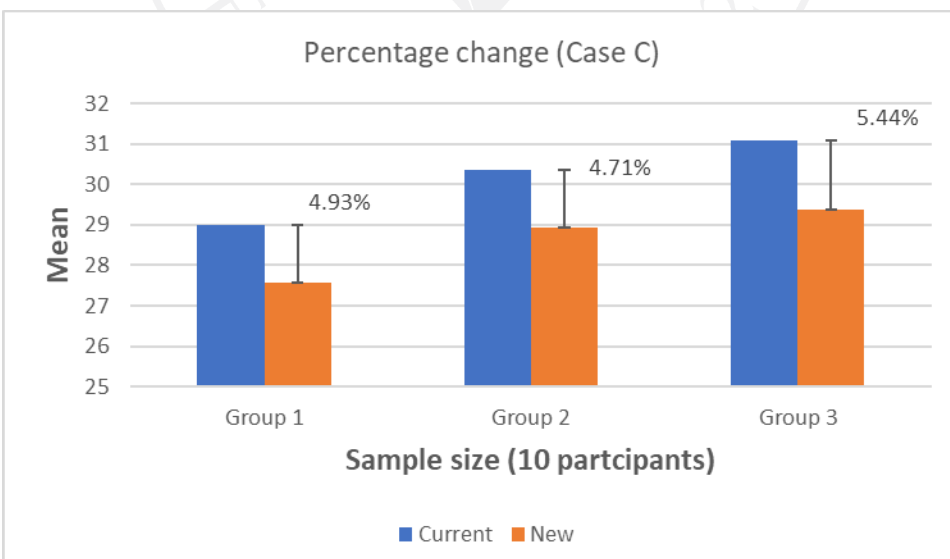

Figure 4.9: Percentage change (Case C)

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- **System**

Both systems of the application had different advantages and disadvantages. The 2D desktop systems were worth the investment of training for using several computers among a number of people at the same time. Nevertheless, this system displayed 3D visualization on a 2D screen monitor, which users could not fully interact, whereas the 3D full immersion with Microsoft HoloLens could allow users to interact with virtual objects anywhere. The authors used the VR version of Microsoft HoloLens in the experiment, which used only one piece of equipment and offered the most effective experience for the users. On the other hand, the AR version of Microsoft HoloLens utilized many QR codes for scanning. However, Microsoft HoloLens was rather expensive and was not suitable for the investment of use with many people in training.

- **Development**

The difficulty of the development of the application was an instruction media design that was consistent with the maintenance manual and transferred complete knowledge to the workers. In addition, each failure case had a difference; therefore, the maintenance procedure was also different. Hence, the next level of difficulty was a system design that was suitable for the maintenance procedure.

- **Solutions**

The instruction of XR technology was applied to the training program to teach users by one-point lessons (OPL), which users used less time than instruction with documents. As a consequence, the XR technology system was applied to industry, as it was the most effective, which depended on the people who knew machines and new technology. Moreover, the maintenance time was reduced according to the increased maintenance skills. Thus, the training of the workers would constantly improve their maintenance skills.

- **Location**

The experiment was conducted in a laboratory, with little chance of being undertaken in the production line. Therefore, these failures were simulated in the laboratory by performing with an identical machine. The operation in the production line offered a difference with the laboratory. The engineer was required to wear a cover suit and various necessities as described in Figure 3.28 before performing anything in the production line. On the other hand, the engineer was not required to wear a cover suit and any various necessities in the laboratory. As such, the mobility of the operation might affect the maintenance time either directly or indirectly.

- **Sample size**

Thirty participants were classified into three groups in the experiment, which the sample was too small and had a chance of a margin of error. The sample size was specified by 10 participants in each group. Nevertheless, group 1 took the least maintenance time in the experiment. Because of group 1 was the expert engineers and owners of machines.

- **Mean Time Between Failure**

These three failure cases of the machine were not enough to the MTBF calculation. The MTBF formula needs to calculate from all twenty-one failure cases, which was the total operational time divided by the number of failures. The run time of 22.7 hours was subtracted by the failure time a day on the machine, which was the MTBF results.

- **Mean Time to Repair**

These MTTR results were calculated from the failure cases simulations of the machine on the laboratory. There was only maintenance duration of the expert engineer recorded for the current period of one month. Moreover, the maintenance duration of both the experience and novice engineer were recorded from the failure cases simulations on the laboratory. Therefore, these failure cases simulations did not impact on the production line.

- **WD engineering team comments**

Firstly, the expert engineer has commented the HoloLens useful on their work environment. They had learned fast quite with the VR applications, which assists them more remember the process of maintenance on their own machine. In part of the experience engineer has commented likewise the expert engineer. On the other hand, they had learned slower quite than the machine owner, which the machine was not owned by them. The MTTR results illustrated that the experienced engineer's score less than the expert engineer. In the part of the novice engineer has commented the HoloLens was suited to the expert in their fields. Therefore, the HoloLens offered the maximum experience with users. Secondly, all three engineer groups have commented in the same way that using the HoloLens too long time to make eye strain symptoms and symptoms of headaches with prolonged. However, the use appropriately of the HoloLens assists them avoid these symptoms.

- **Publications**

The author had sent the research to publish in public, which was selected by three reviewers for publications. The research has been reviewed since February to August 2021. The author's research was published on Aug 25, 2021 by the Srinakharinwirot University (SWU) Engineering Journal of Vol. 16 No. 3 (2021): September - December.

5.2 Recommendations

In the future, the authors would add another 18 failure cases in the application for the comprehensiveness of all cases. Nevertheless, machine learning would be used to analyze the data set of the machine for predicting the future of any failure occurring and immediate notifications in real time. Before any failure cases could possibly occur, the users would train themselves for maintenance preparedness. As such, the failure case would have a chance of decreased occurrences in the machine.

Additionally, object recognition would be used to detect any mechanical part for finding a number of the mechanical part. Finally, a mockup of the virtual object would be made to overlay the actual object, which it would be necessary for the correct position of the virtual object.

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APPENDIX

1. The comparison of previous and current solutions for development

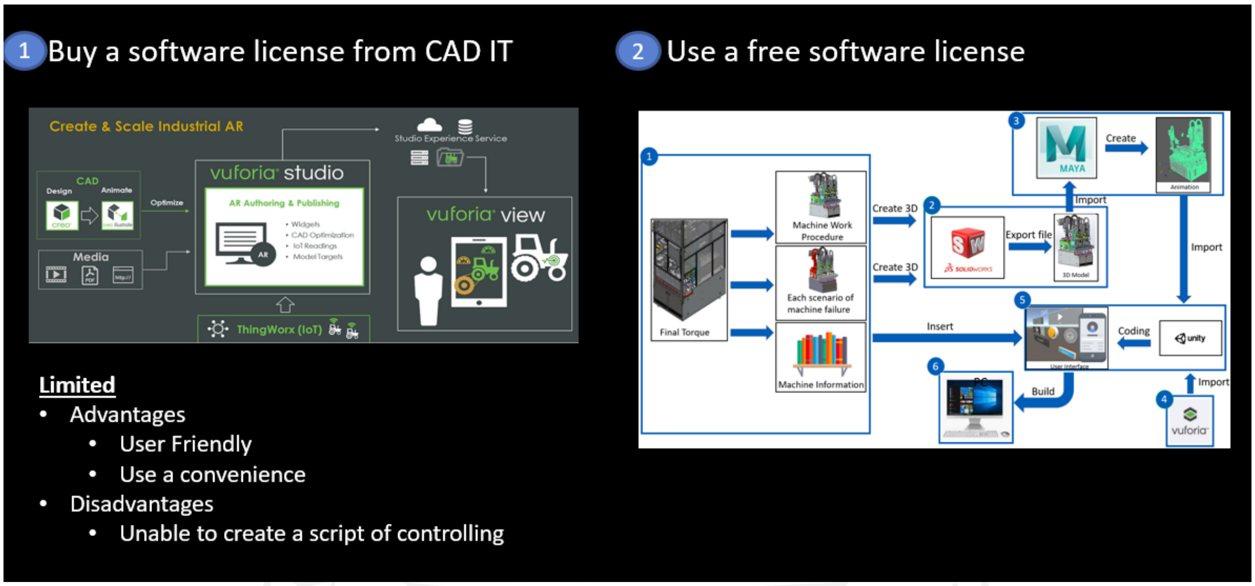

Figure 3.4A: The comparison between advantage and disadvantage of two solutions

2. The information gathering of the machine in the production line

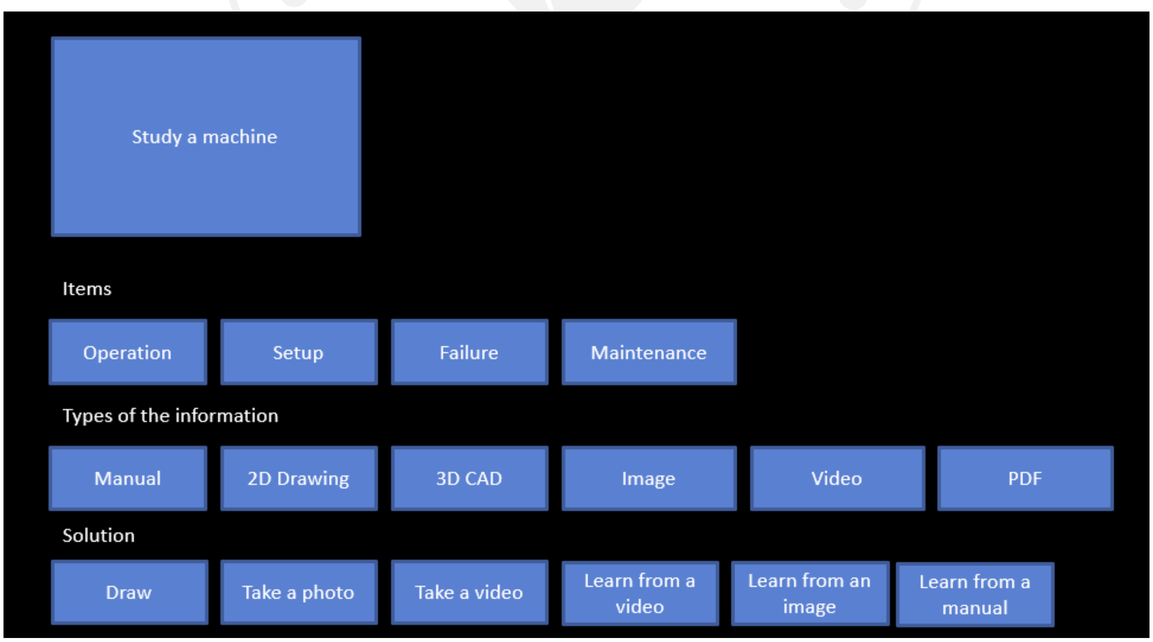

Figure 3.5A: The detail of gathering information in the machine

3. The picture sketching of the machine in the production line

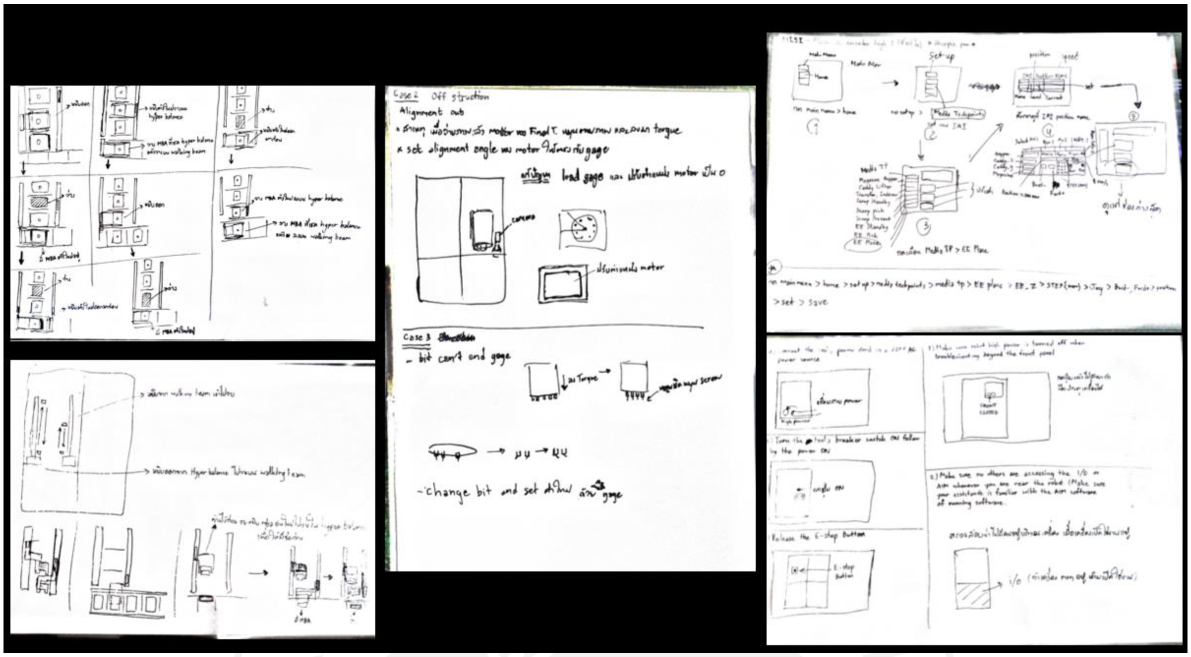

Figure 3.6A: The picture sketching of the machine

4. Cleaning the 3D CAD up and downsizing

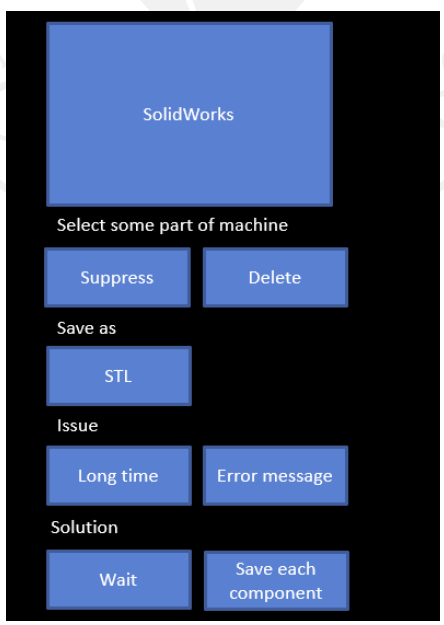

Figure 3.7A: The 3D CAD cleaning and downsizing

5. Animating the 3D CAD in Autodesk Maya

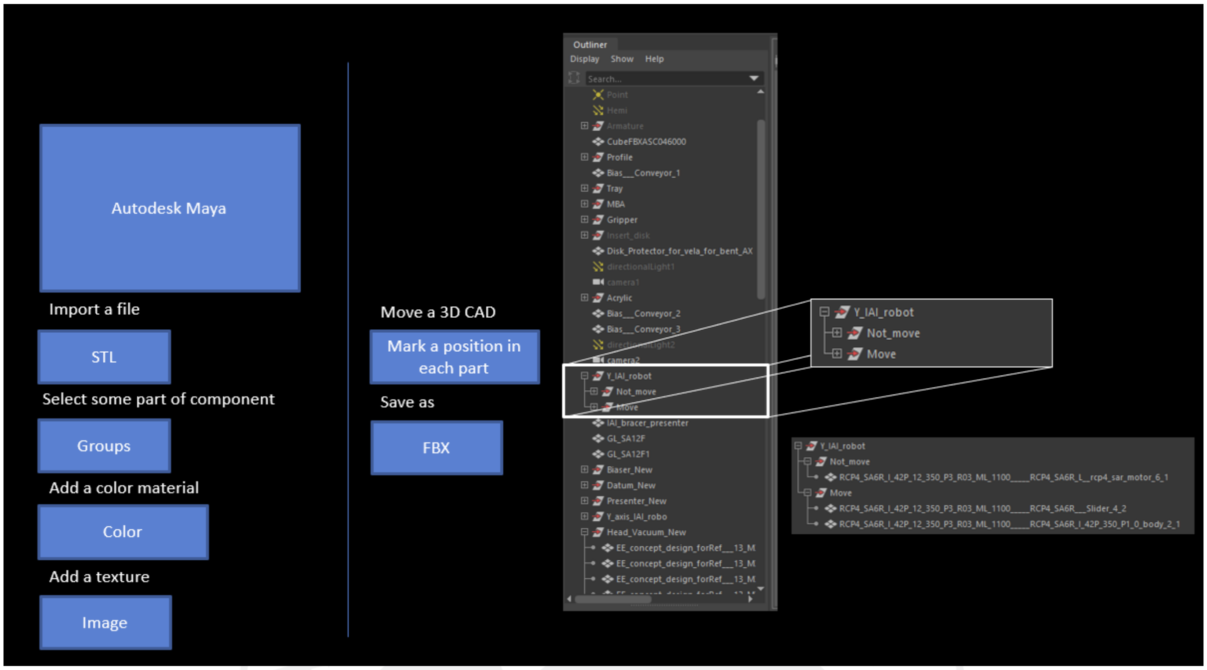

Figure 3.8A: Making the 3D CAD animation

6. The work procedure of developing the application in Unity 3D

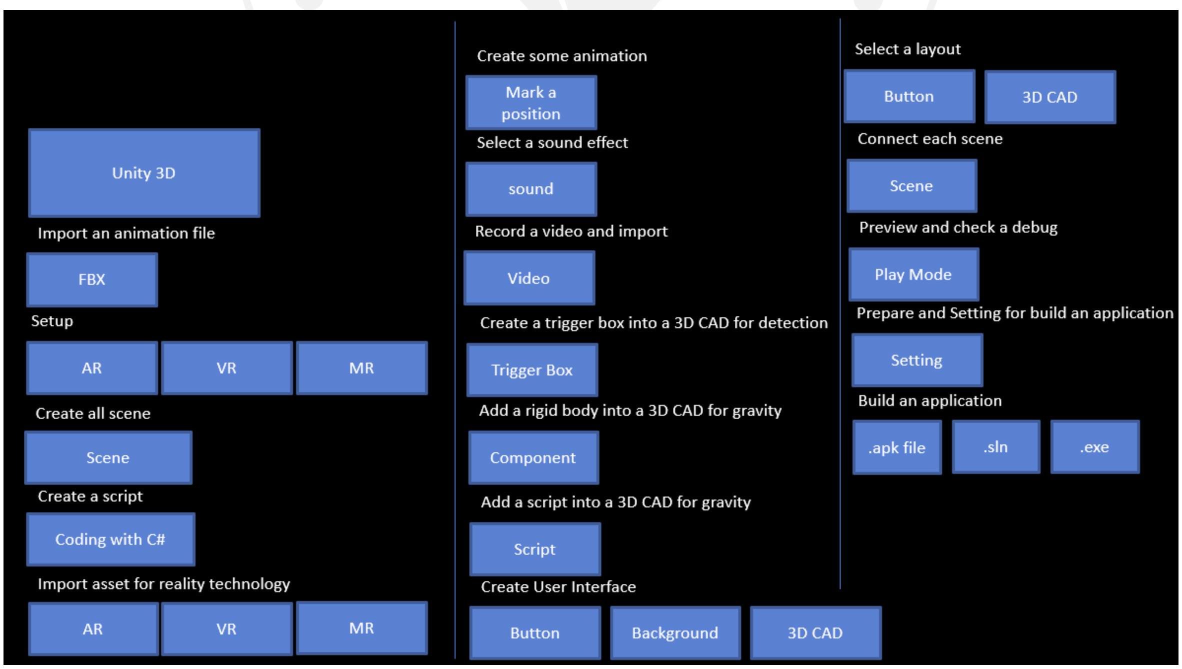

Figure 3.9A: Developing the application in Unity 3D

7. Setting the animator controller of the system animation

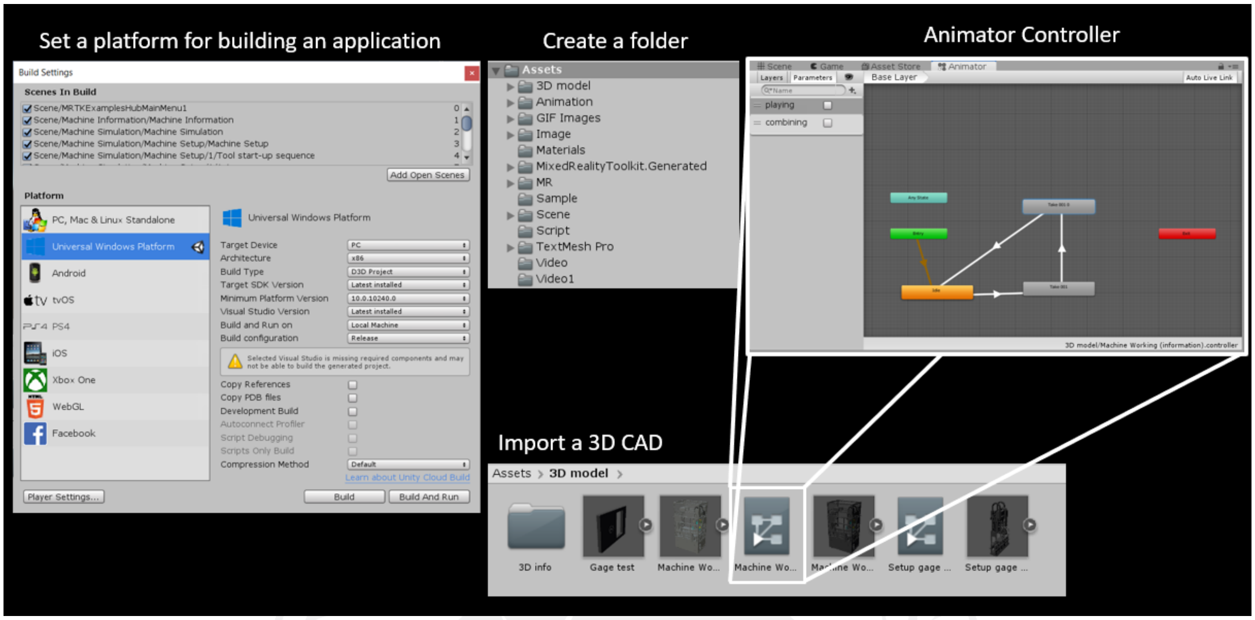

Figure 3.10A: Setting the animation loop using the animator controller

8. Creating the 3D CAD animation in Unity 3D

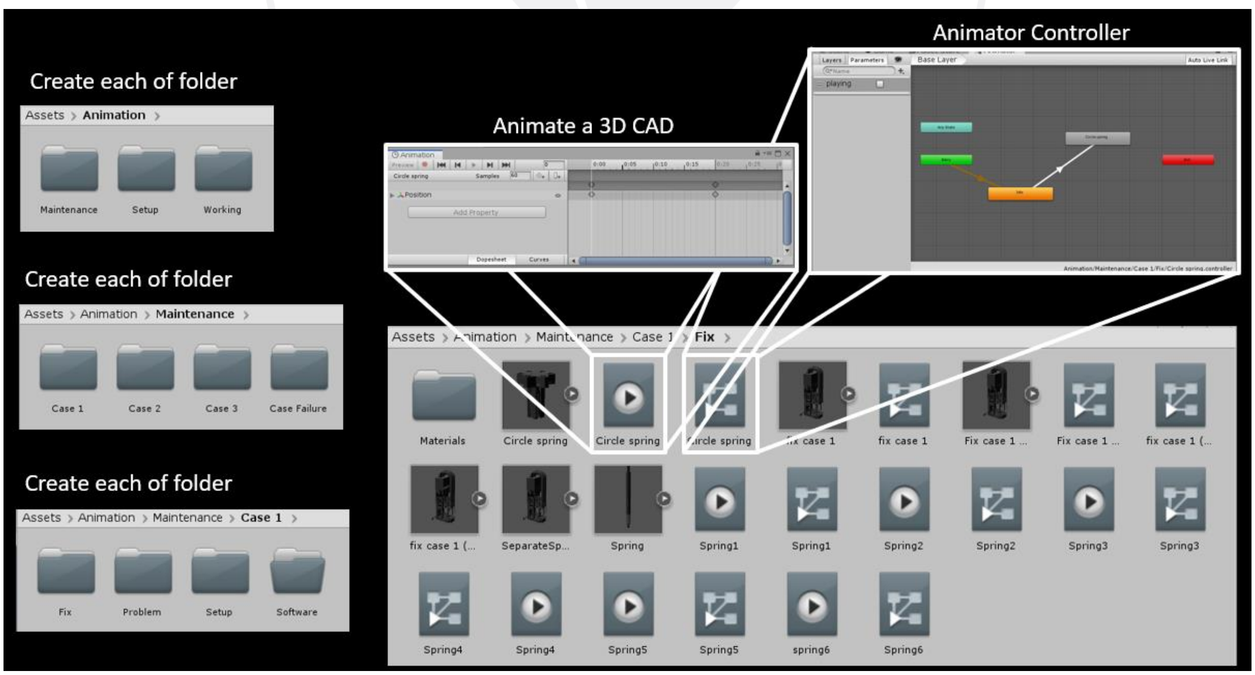

Figure 3.11A: Animating the 3D CAD in Unity 3D

10. Importing the image to generate a QR code marker for tracking the 3D CAD

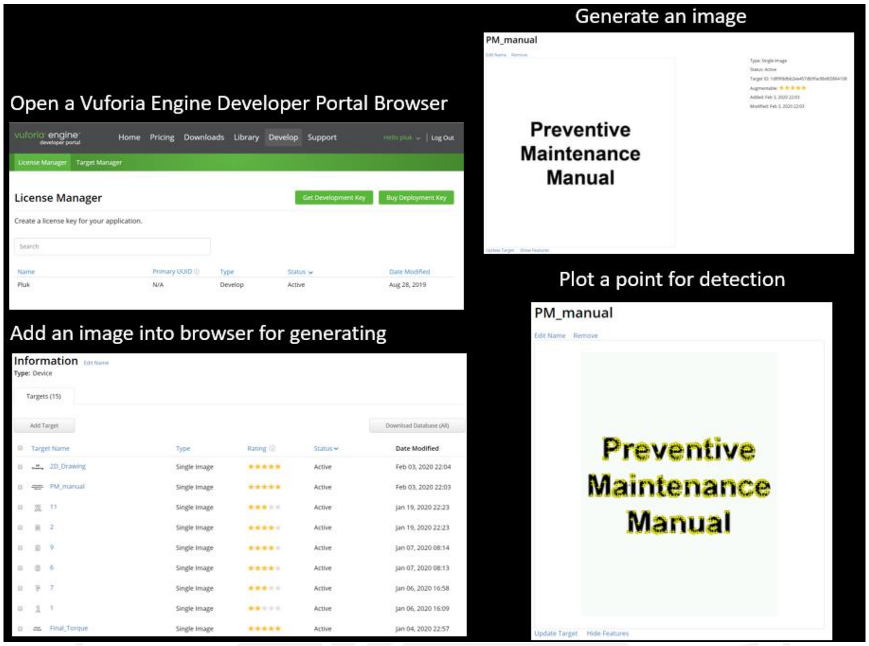

Figure 3.12A: Generating the 3D CAD tracking

11. Building the application on the HoloLens

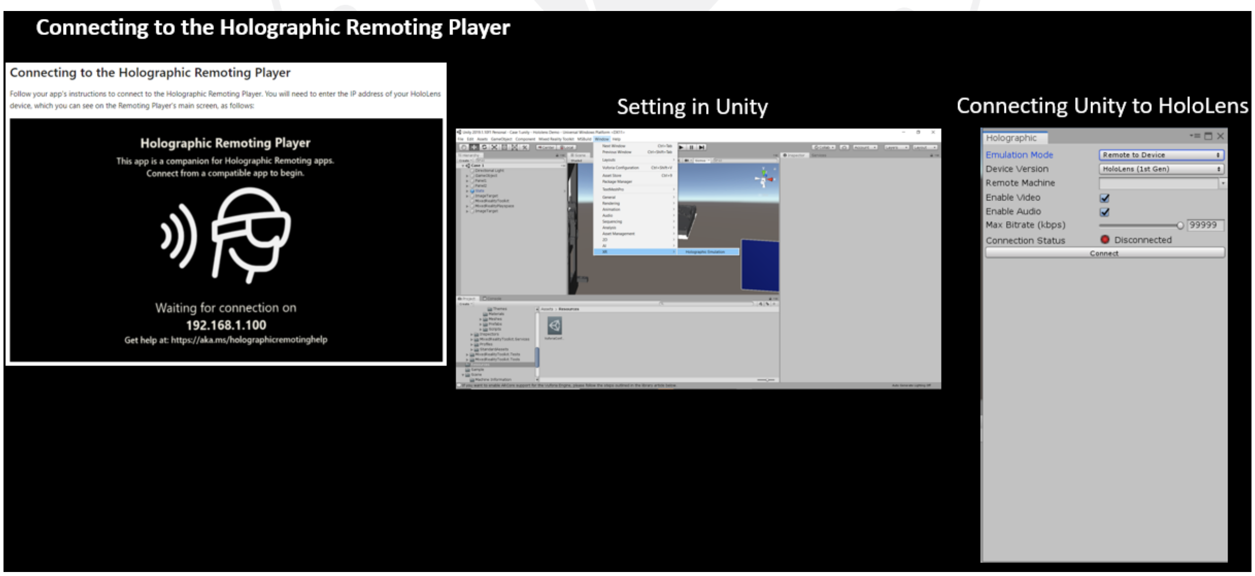

Figure 3.13A: Building the application

12. Deploying the application on the HoloLens using Wi-Fi

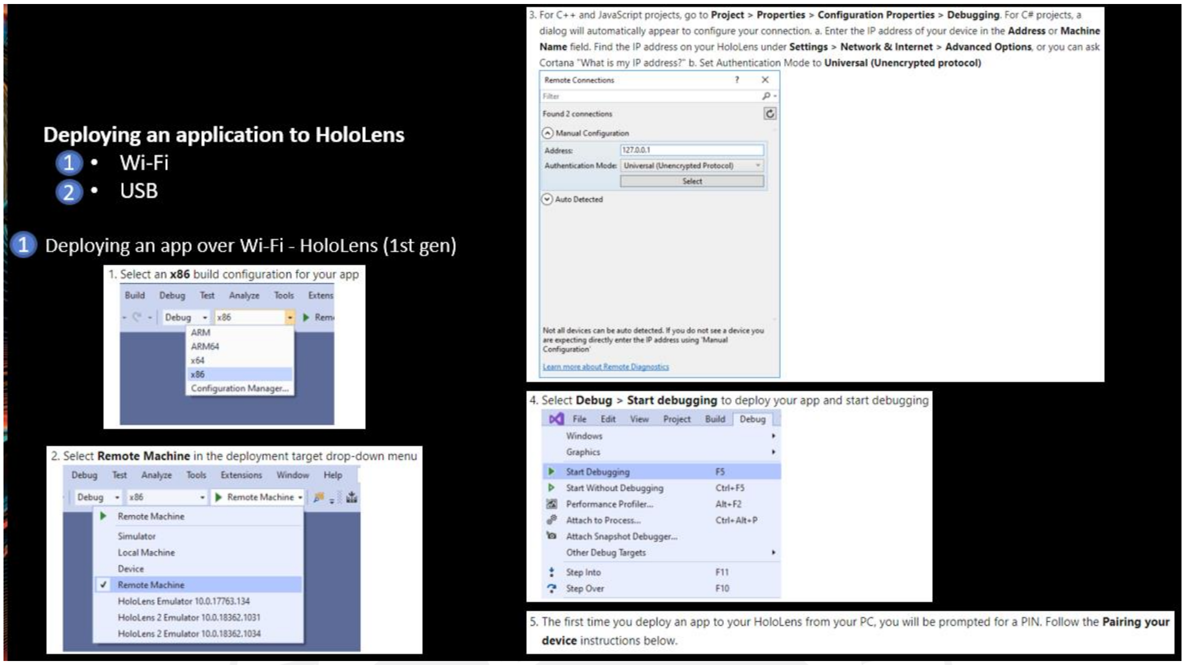

Figure 3.14A: Using Wi-Fi for deployment on the HoloLens

13. Deploying the application on the HoloLens using USB

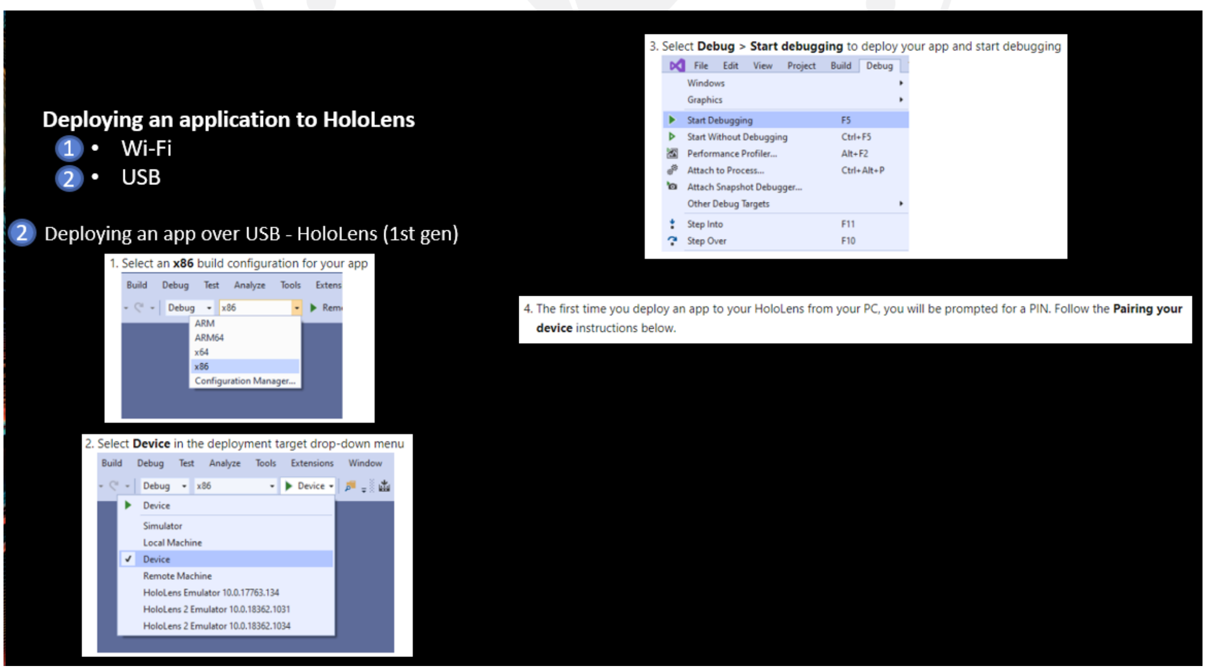

Figure 3.15A: Using USB for deployment on the HoloLens

14. Livestreaming the application on PC to the HoloLens using Microsoft HoloLens App

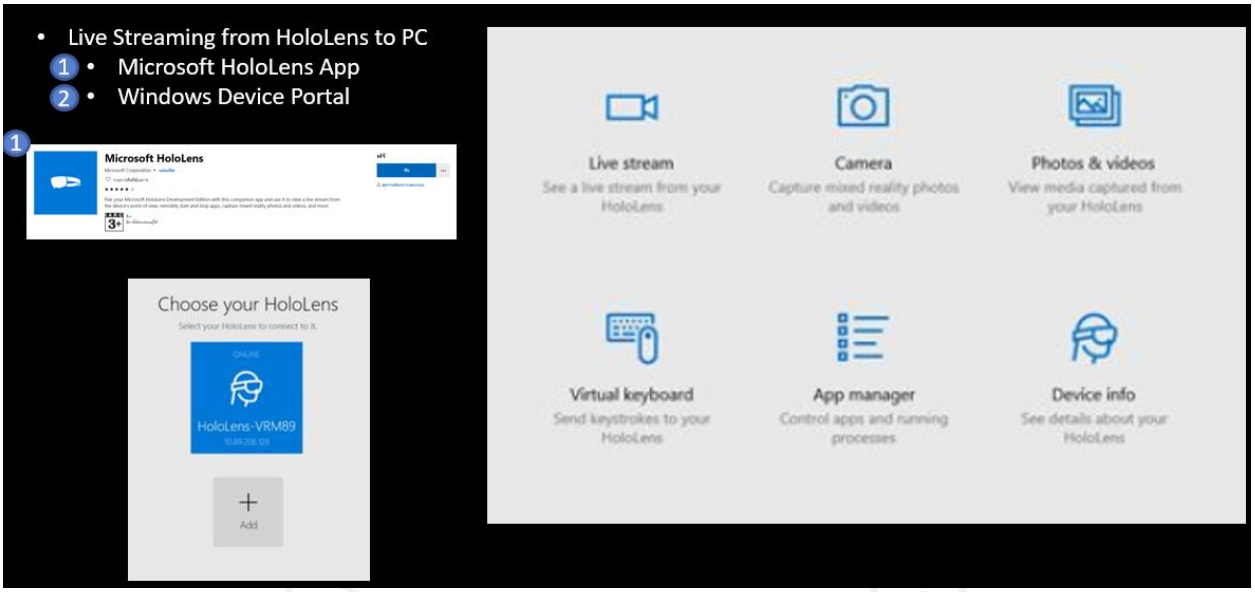

Figure 3.16A: Using Microsoft HoloLens App for Livestreaming

15. Livestreaming the application on PC to the HoloLens using Windows Device Portal

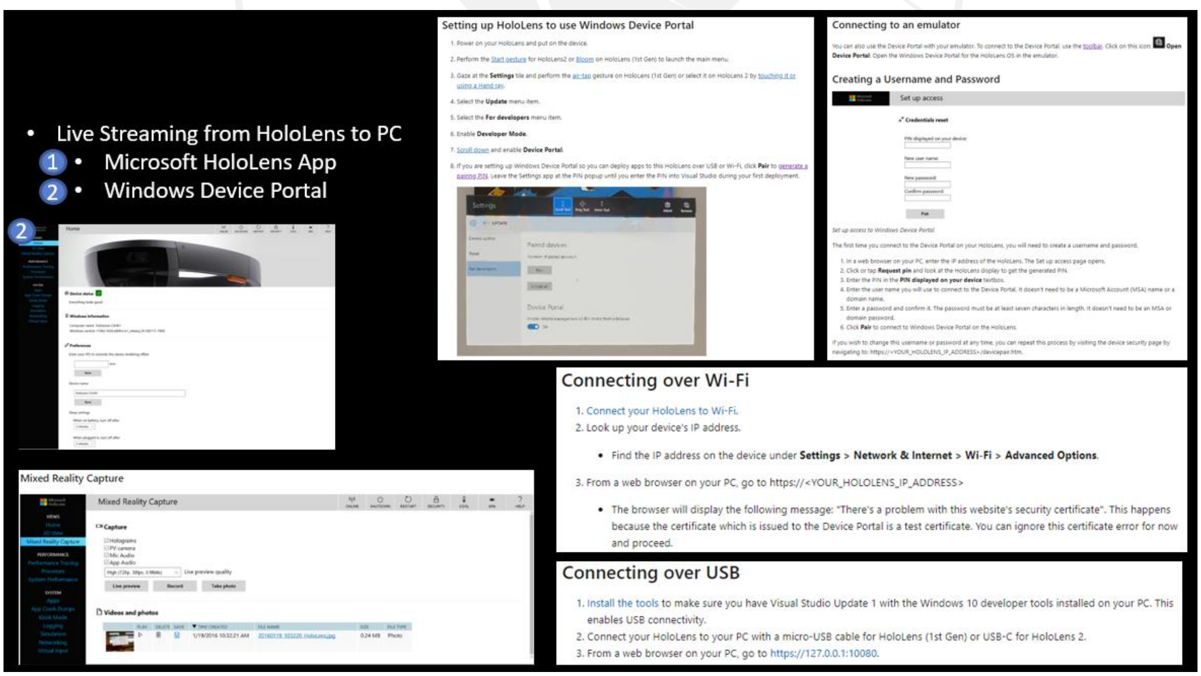

Figure 3.17A: Using Windows Device Portal for Livestreaming

16. The virtual object simulated was in the real world

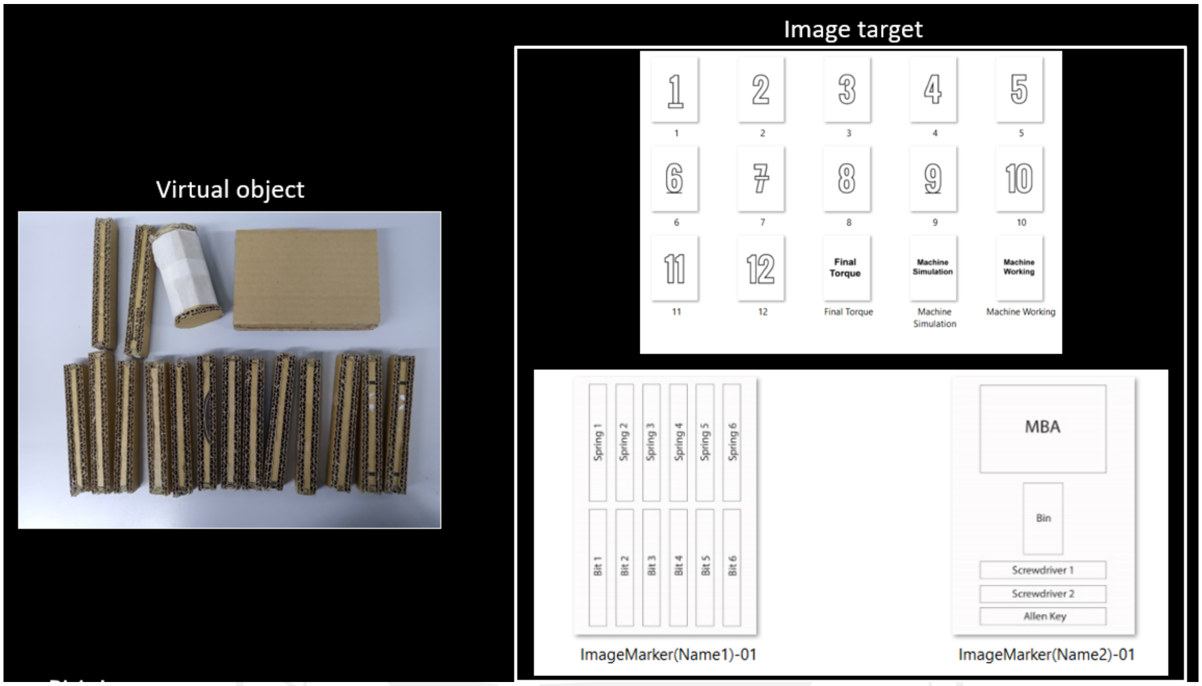

Figure 3.18A: Simulating the virtual object with the image tracking

17. The combination between the image tracking and the virtual object

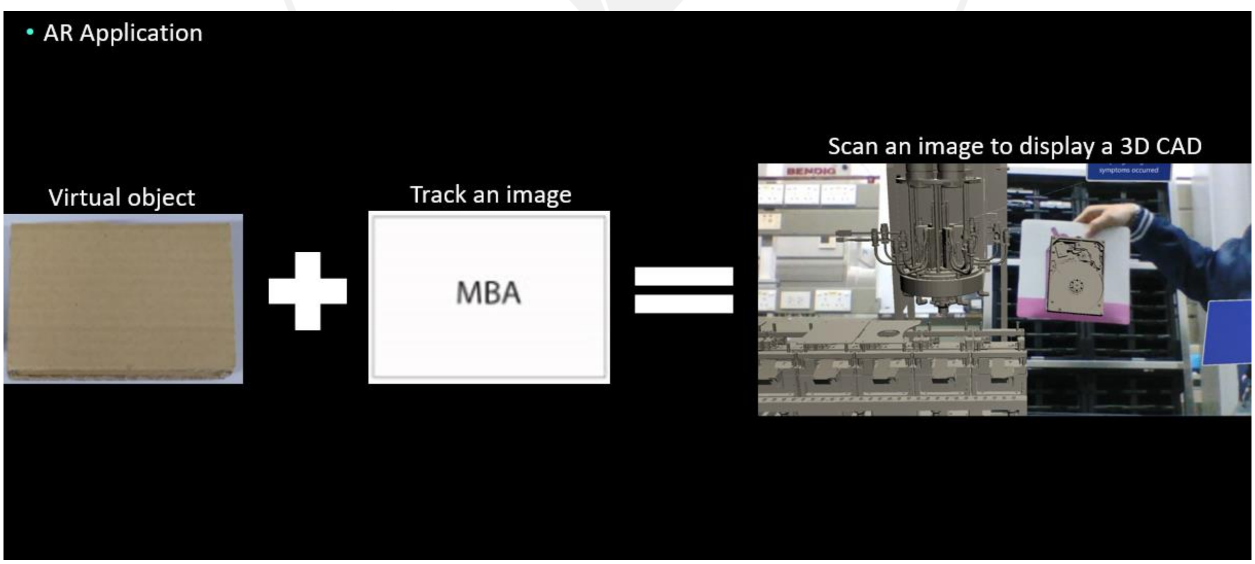

Figure 3.19A: Combining the image tracking to the virtual object

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