DATA VISUALISATION DASHBOARD FOR AUTOMATION LINES
DEVELOPMENT BY MIXED REALITY TECHNOLOGY (MR)

DATA VISUALISATION DASHBOARD FOR AUTOMATION LINES

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Data Visualisation Dashboard for Automation Lines Development by Mixed Reality Technology (MR) (41 pp.)

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ABSTRACT

This research aims to develop a data visualization dashboard for automation lines monitoring using mixed reality technology in order to decrease maintenance process time in a production line. This research follows the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The problem is defined through study of the production line is the lack of a display unit that gathers all information data and communication system between maintenance teams in a single location. The focus of this work is to develop a system that collects all the data from different systems, processes and displays them in an informative manner. The system focuses on the data of the automatic HDD assembly machine and its display using mixed reality technology and a communication system between users with video signals and sound through holographic equipment call HoloLens. The maintenance process flow chart shows the result of the maintenance process operation, this system can decrease maintenance procesing time in a production line by 48.97%.

Keywords: Mixed reality, visualization dashboard

Approved: --

Signature of Advisor

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LIST OF ACRONYMS AND ABBREVIATIONS

HDD	Hard Disk Drive
ADDIE	Analysis, Design, Development, Implementation, and Evaluation
IIoT	Industrial Internet of Things
3D	Three-Dimensional
AR	Augmented Reality
VR	Virtual Reality
MR	Mixed Reality
HMD	Head Mounted Display
CPU	Central Processing Unit
GPU	Graphics Processing Unit
HPU	Holographic Processing Unit
HPC	High Performance Computing
TV	Television
PLC	Programmable Logic Control
CAD	Computer-Aided Design
SDK	Software Development Kit
VM	Virtual Machine
GUI	Graphical User Interface
IP	Internet Protocol Addres

CHAPTER 1

INTRODUCTION

A data visualisation dashboard for automation lines using a mixed reality technology system use for process in automation lines maintenance to support engineers and technicians whom have to respond to problem cases in production area. The system allows engineers and technicians access to monitoring data and communicate with employees whom respond on the frontline. Mixed Reality technology support to visualise data and display real time video and audio to HoloLens device.

In this chapter is going to explain in the research background, problem statement, and objectives. For literature review in the topic of visualisation solution, Immersive technology solutions, and system design going to clarify in chapter 2. Chapter 3 shows the concept with methodology of the research. Result, discussion, conclusion, and suggestion is going to explain in chapter 4 and 5 in order.

The hard disk manufacturing industry in Thailand is an important manufacturing sector of Thailand economy. The value of hard disk exports for Thailand's Enterprise HDD in 2020 grew to US $4.75 billion, or 16.7% from 2019 according to (Kasikorn Research Centre, 2021).

Nowadays, the hard disk manufacturing industry has adopted automated technology in the production line and aims to develop and increase production efficiency with technology to evolve into Industry 4.0. It is an industrial revolution focused on developing future industries to create smarter manufacturing processes especially relevant for hard disk manufacturing (Keliang Zhou, Taigang Liu, and Lifeng Zhou, 2015) have indicated that the hard disk manufacturing industry has encountered problems with the process of checking the data of automatic hard disk assemblies because of the lack of monitoring technology, causing engineers and maintenance teams to need to detect the cause of problems with automatic hard disk assemblies on the production line. Such occurrence results in the access of data of the automatic hard disk assembler and requires coordination between engineers and maintenance teams, this problem affects maintenance time and cost.

One main issue highlighted by researchers is importance of reducing the maintenance time for the automatic lines. The ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), standardized and accepted process according to (Hüseyin Uzunboylu and Emine Koşucu, 2017). For studying in the automation lines found that transport in maintenance process affect the maintenance time. So, with mixed reality technology (MR), a technology that allow users to respond with environments that combine reality and virtual worlds through a dedicated display device, such as HoloLens, a device developed in the form of HMDs (Head Mounted Displays) for users do not need to use their hands to operate the device can developed to be used for data monitoring and remote collaboration together with imaginary or 3D visual display. It is helps to rise the perceptual ability and responsiveness of learners for solving problems to reduce the maintenance process for the automation lines.

1.1 Background

Industry 4.0 originated in Germany in 2011. It is a new phase of the Industrial Revolution that focuses on interconnectivity, automation, machine learning, real-time data, and IIoT. It is a change in the production industry through the use of digital technologies and the internet. The whole process intend to innovate the industry through digitization. Industry, 4.0 is predicted to improve efficiency of the production line.

A hard disk drive (HDD) is a complex device that requires complicated assembly and relies mostly on automation lines. Human intervention is limited and should be avoided to maintain production line efficiency, therefore it is important to have a system that gathers data about the conditions of the production for ease of overview, surveillance and maintenance of the production line.

An automatic HDD assembly machine is a new technology for manufacturers aiming to develop and increase assembly performance using the IIoT concept. It integrates all processes of combined HDD assembly into one automation line.

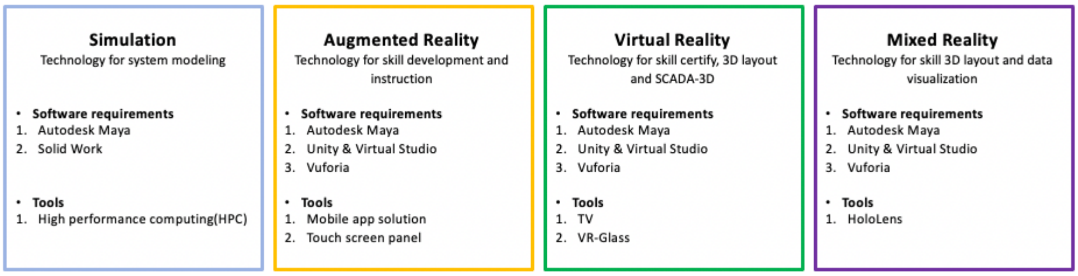
HDD production line require a specific environment. A cleanroom is an enclosed space used in the manufacture for the assembly of HDD. It keeps airborne particles, contaminants, and pollutants within strict limits to avoid the risk that can be caused to the products in order to control the cleanroom standard, employees have to clean themselves following cleanroom protocol before going inside.

Currently, all the monitoring is mostly done by employees and data is not centralized. Immersive technology can help to support development of a single system for data monitoring and communication with this technology, it can create a new reality experience with 360-degree space. It overlays digital layout with images, text, data or 3D simulation on a user's real environment. Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are categories of immersive reality technologies with different functions.

- Augmented Reality is a technology that add a digital layer over the real environment through mobile, tablet, or glasses headset.
- Virtual Reality is a technology that bring users to experience in a digital world and completely separate users from the real environment through a head mounted display (HMD).
- Mixed Reality is a new technology that is a combination between augmented reality and virtual reality. It is developed for users to interact with their environment in both experiences form real and virtual environments. It is requiring the HMD devices to overlays digital layouts on top of the real environment.

Figure 1.1 is comparing composition in each type of immersive technology for a smart factory. Simulation technology is best for system modelling, it can display a model in 3D perspective with subtle details but it has to be developed on HPC. For VR technology developing an interactive system requires a connection between TV and trigger tools. Those conditions mean simulation technology and VR are not enough to solve the problem in reducing time to use in observe the cleanroom protocol because workers also have to go to HPC or TV stations to gather the data. Although AR and MR both are the technology that overlay digital objects on top of the environment. However, MR can create holographic images and bring users closer to real experiences. And it is extending enabling users to view the content over 360 degrees.

Figure 1.1: Comparison of each type of immersive technology for smart factory



HoloLens is a mixed reality device that resulted from the collaboration between the NASA and Microsoft. They rendered holograms or 3D images and can be operated directly on the glasses using the CPU, GPU, and installed HPU within itself.

The concept of developing a data visualization dashboard through the integration of MR and HoloLens aims to offer the 3D visualization of data gathered from the automatic HDD assembly machine with virtual world, and real world together.

1.2 Problem Statement

Automatic HDD assembly machines are essential technologies that HDD manufacturers rely on. Therefore, the efficiency of the automation line can affect the quality and quantity of products and constant monitoring is required.

The efficiency of the automation line can be analyzed by using the quantity of machine time, cycle time, and pass-fail status.

Currently, manufactures do not have a technology to gather and visualize the automation lines data parameters. It is time consuming for engineers and technicians to check the parameters of the production line individually.

1.3 Objectives

The aim is to save worker's time for the maintenance process of the automation lines data parameters by gathering the data of a production line, providing live monitoring, and real time communication capabilities.

- To reduce time of transport for support automation line maintenance
- To reduce distance of transport for support automation line maintenance
- To increase Value Analysis of automation line maintenance process

CHAPTER 2

LITERATURE REVIEW

Saving workers data processing and analyzing time in maintenance process are the goal of the research. This section outlines that state of the art for production line data gathering and processing as well as MR data display.

- Visualisation solution

Data visualisation solution is designed to solve problem from standard visualisation techniques that are not sufficient for the analysis of complex multidimensional data. With instant technology, (Mark Shovman, 2011) have a lot of visualisation tools and techniques that can answer this point. An objectives of visualisation tool design are visualisation quality, human perception, and cognition. They have measured comprehension to abstract. Inside of technological advancements in visualisation techniques, each type has a different kind of use. In the case of interactivity, it helps to improve performance by enabling the user's learning. The main novelty is the formulation of the three-primary pragmatics of visualisation: the detection of outliers, clusters, and trends. It supports analysing the research's solutions methods to apply data visualisation in the system. (Lewis Richard Gill, 2013) about using real-time 3D graphics for site-based landscape design. They point to the 3D model can increase engagement and cognitive response when using it with interactive technology. However, it also takes a lot of time to process complex modeling. This study concluded that settle parametric data into 3D models can aid understanding of performance. This study is causing the researcher to have an idea to efficiently data dashboard using data visualisation technic with 3D models.

- Immersive technology solutions

VR in terms of supporting industry aims to enhance visualization of information. This technology can be developed to help reducing risk, cost, and time. It can aid multiple users in carrying out engineering activities in a networked virtual environment. (Jin Li et al, 2011) proposed applying Web-based VR technologies to support design and manufacturing applications in Networked Virtual Environments. In this study, they learned to adjust immersive technology into the industry. In term of this technology, it can improve great potential in numerous areas. (Eleonora Bottani and Giuseppe Vignali, 2019) analyzed and reviewed the scientific literature related to AR technology in the manufacturing industry. AR is becoming an increasingly diffuse technology because of the ease of application development and support it in many devices. These technologies are responsible for displaying information within the industrial environment. It shows AR is a highly flexible technology and has high potential in the industrial sectors. This study supports the researcher's concept to develop a data visualisation dashboard for manufacturing base on AR technology in the resolution of highly flexible platform technology. (Max Jurascheka, Lennart Bütha, Gerrit Posselta, and Christoph Herrmann, 2018) aim to apply MR in learning factories. They noticed that MR technology is creating a dimensional holographic image that can be applied in an industrial environment. Users can increase their learning skills by interacting and controlling holographic object through the devices. In manufacturing, it can be used for information visualisation, remote collaboration, human-machine-interfaces, design tools, education, and training. They developed on empowering users to work with MR and utilizing the potential of MR for teaching in factories. They learned that MR technology can support users in terms of increasing their learning skills. They found that MR can support manufacturing in many directions (3D visualisation, remote assist, etc.). This study is in the same direction in developing a system with MR technology. However, the researcher focuses on reduce time in the protocol.

- System design

The concept of IoT is connecting anything and anyone at any time and online. (Yang Lu, 2019) is interested in the user perspective in IoT. This research performs empirical studies on 615 internet users in the United States following a theoretically constructed tested framework serving users concerning IoT. Step one is exploring the antecedents and outcomes of Internet use from the psychological perspective. Then study conceptualised and experimented with the user intent of the IoT adoption. The result of this research is psychological factors and the characteristics of innovation affect user acceptance of IoT with positive outcome. The focusing result is the outcomes of the users' acceptance of the IoT, it points that all of technologies should not be considered separately. This study confirms the solution to integrate systems using IoT in terms of user perspective. (Garon et al., 2016) show implementation of small object detection on the HoloLens device to reduce limitations through calibrating a depth sensor connected to a computer that communicates with the HoloLens in real-time. This study specifying that Microsoft HoloLens is an AR headset that released cutting-edge AR device has attention with its advanced capabilities. It is a transformation from a 2D screen to a 3D hologram interface. This study has supported in terms of implementation using HoloLens to display data visualisation. This research is going to build a data visualisation dashboard using three-dimensional to increase engagement and cognitive response. It is developed using MR technology with HoloLens device to create an interesting system helping users to improve their learning skill efficiency helps user increase their efficient learning skill. This system is designed with the Internet of Things concept to connect all devices.

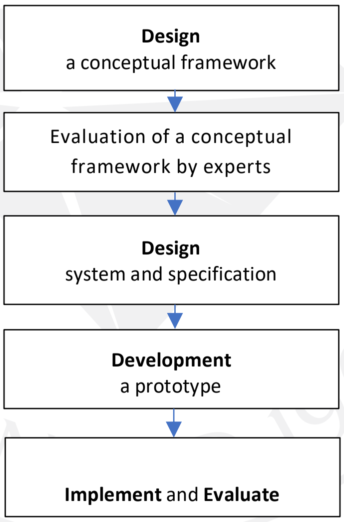
In all the previously mentioned methods, it can be observed that developing the system for decreased maintenance processing time in manufacturing should apply visualisation techniques to support working with immersive technology and IoT. Recently AR technology had developed visualisation systems to maintain in industrial but with MR technology, it evolves visualisation systems with an increase in interacting and controlling.

CHAPTER 3

METHODOLOGY

This research is designed to supporting worker gathering data of the production line. It aims to reduce the time used by workers that needs to go into cleanroom, requiring them to follow strict and time-consuming protocol to observe data from the production line be delivering these data directly on a headset outside of the cleanroom.

Figure 3.1: Research procedure diagram

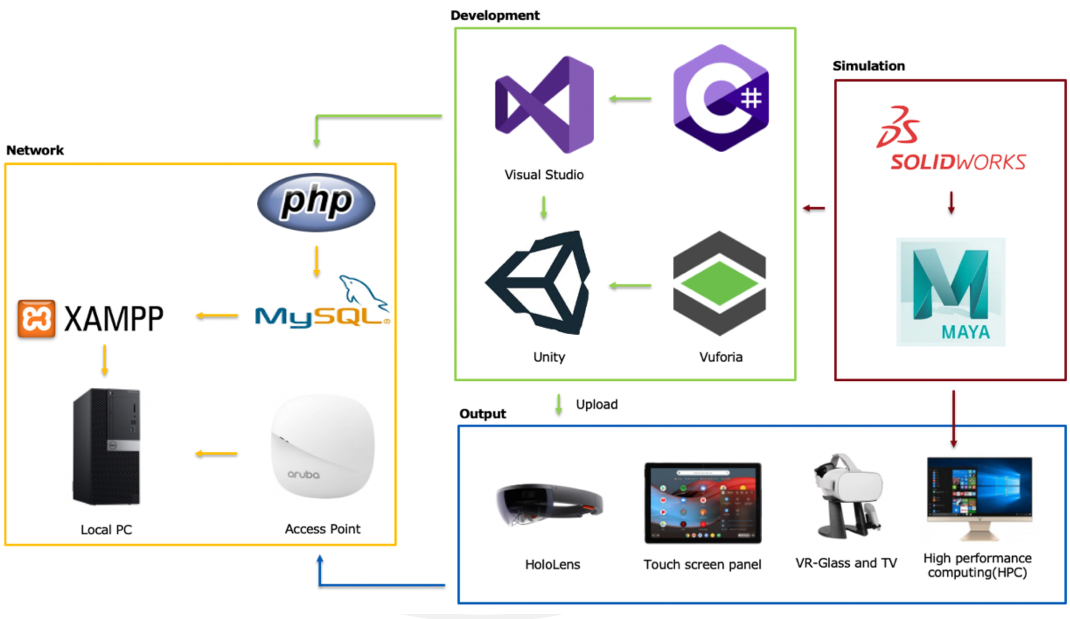


One problem is linked to the protocol that technicians have to follow to access the cleanroom. This problem can be solved with technology that allows users to access the production line data from anywhere. A prototype is then developed using the drafted framework succeeding to implement before being final evaluated.

The system overview in figure 3.2 shows the different elements used for developing an immersive technology. It is divided into four sections: simulation, development, network, and output.

The simulation section goal is to create a simulated object in 3D perspective or a solid modeling using computer-aided. This section is the first step of the whole project.

Figure 3.2: System overview of developing an immersive technology



The development section is the most significant part to develop immersive technology. This section combines all elements. It encompasses the coding as well as the integration of the plug-ins of all the equipment.

The network section supports the whole system as it is accessible online through WIFI to gather system data and allow their access by the workers from anywhere.

The last section relates to the display and its interaction by the user.

From the system overview in figure 3.2, shows the used software for the project development.

- Autodesk Maya program is a software to create 3D computer animation, modeling, and simulation objects. It is used to build simulation machines or adjust CAD from the SolidWorks program.
- Unity program is a flexible development platform to develop cross-platform application. It supports various solutions and technology. It is used for programming and integrating the whole system.
- Vuforia engine is an SDK providing advanced computer vision solutions to the application. It allows objective recognition and interaction with spaces in the real world. It is used with unity program to build an environment.

The outcome of this work targets to be measured using a numerical value for objective assessment following the condition below to agree with an expected result or not.

- Define a group of experts

  Requirement to be considered in the expert group for the project assessment:

  - At least 5 years' experience which technology
  - Master's degree or higher in field of technology
- Interpretation of the Likert Scale Questionnaire

  The questionnaire collects information from respondents with using the Likert Scale theory to find the mean of the total score ($\overline{x}$), the results of the satisfaction or opinion of the respondents according to the Likert Rating Scales concept are as follows:

- The average of 4.50 to 5.0 means that there is the highest level of satisfaction of the prototype or the highest level of opinion.
- The average of 3.50 to 4.49 means that there is a high level of satisfaction of the prototype or a high level of opinion.
- The average of 2.50 to 3.49 means that there is moderate satisfaction of the prototype or a moderate opinion.
- The average of 1.50 to 2.49 means that there is a small level of satisfaction of the prototype or a low level of opinion.
- The average of 1.00 to 1.49 means that there is the least level of satisfaction of the prototype or the least level of opinion.

• Maintenance process flow

A flow process chart is a typical representation of the series of activities within a process. It is used to observing with record and analyze physical actions to determine, identify, and eliminate waste.

A flow process chart can describe in three categories base on the type of activities.

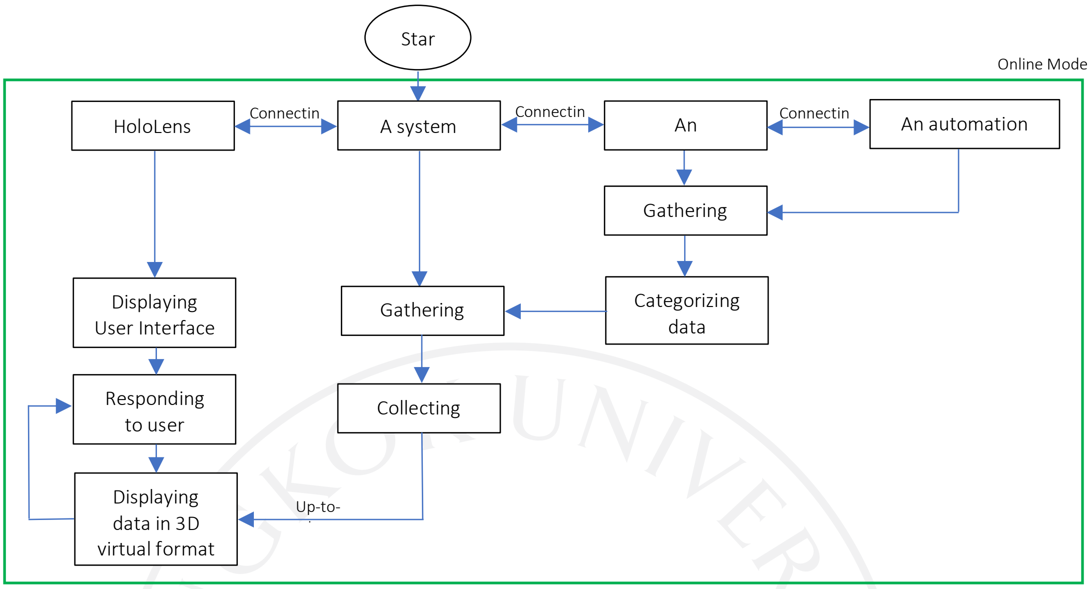
- A man-type chart presents the actions of a people
- A material-type chart explains what happens to a product
- An equipment-type chart illustrates the activities from the viewpoint of the equipment involved

It can describe an explanation symbolic to five sections

- Operation: Produce, add, change, or process something
- Inspection: Monitoring items to guarantee quality or quantity
- Storage: The storing until a later time
- Transport: The transfer of people, materials, or other
- Delay: The temporary waiting for something

Figure 3.3 shows the operation of the data visualisation dashboard system. First, data about the efficiency of an automation line are gathered using a Logstash opensource data collection engine, then they are categorized according to an Elasticsearch opensource search and analytics engine. The data are continuously being collected on the server to have an up-to-date status of the machine. In the next stage, a User Interface is designed to present the data in a practical manner and shows the current state of the data in a 3D virtual format in HoloLens using mixed reality technology. With MR technology, the system can support engineers and technicians to access automation lines data parameters from anywhere. They do not have to go to the production line to check the data anymore hence saving time.

Figure 3.3: Diagram of a data visualisation dashboard operation system



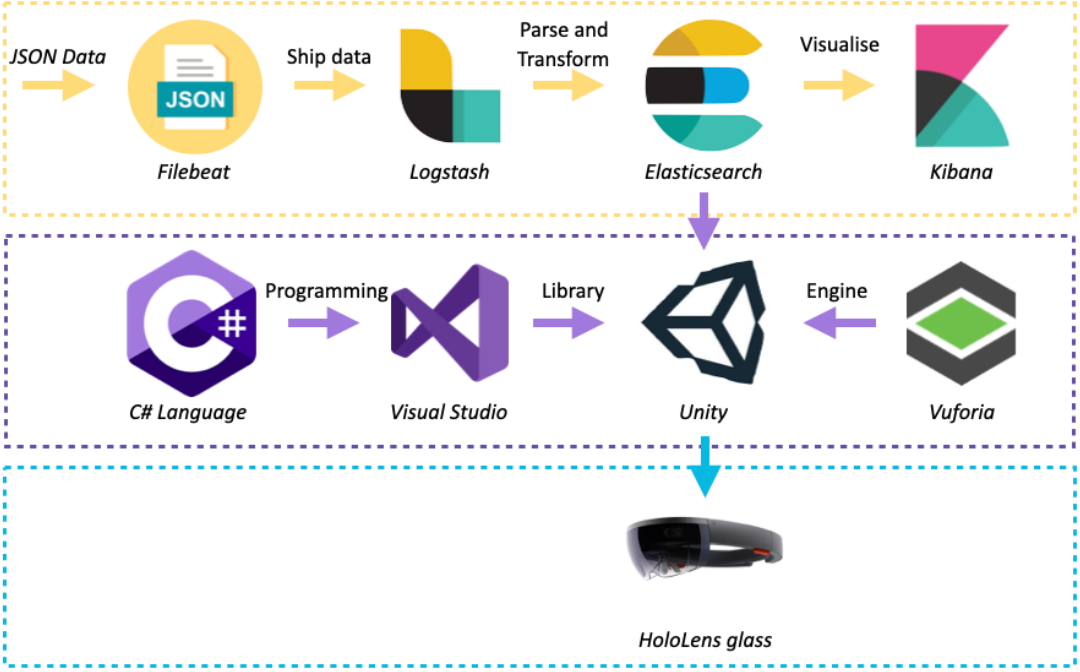
A data visualisation dashboard for automation lines development by the mixed reality technology is presented and is divided into two phases as shown in figure 3.4.

Phase 1 focuses on gathering the data using Logstash and Elasticsearch opensource gather in json files. Categorized and collected data are included in this phase.

Phase 2 aims to develop visual report of the automation line data parameters using unity a cross-platform engine developed with Vuforia immersive technology engine.

Then the solution is uploaded into the HoloLens. The system must allow the interaction between the user and virtual the data visualisation dashboard on HoloLens.

Figure 3.4: Preliminary system overview of a data visualisation dashboard



Questionnaire in table 3.1 is for measurement of the effectiveness of the MR dashboard for reducing time for the cleanroom protocol. Questionnaire is designed to create a rating scale targets to determine the suitability of the development prototype to support users gathering data from the production line.

The questionnaire following issues:

- The suitability of the user interface
- The suitability of the system
- The suitability of the objective
- Suitability for practical use

Table 3.1: Measurement questionnaires

Topic	Suitability level				
	5	4	3	2	1
1. The suitability of the User Interface					
- The suitability of composition					
- The suitability of display					
- The suitability of functions					
2. The suitability of the system					
- Ability in connecting information					
- Accuracy in following orders					
- Accuracy of information					
3. The suitability of the objective					
- The suitability of assisting in data analysis					
- The suitability of save worker's time					
- The suitability of increases efficiency in the production line					
4. Suitability for practical use					

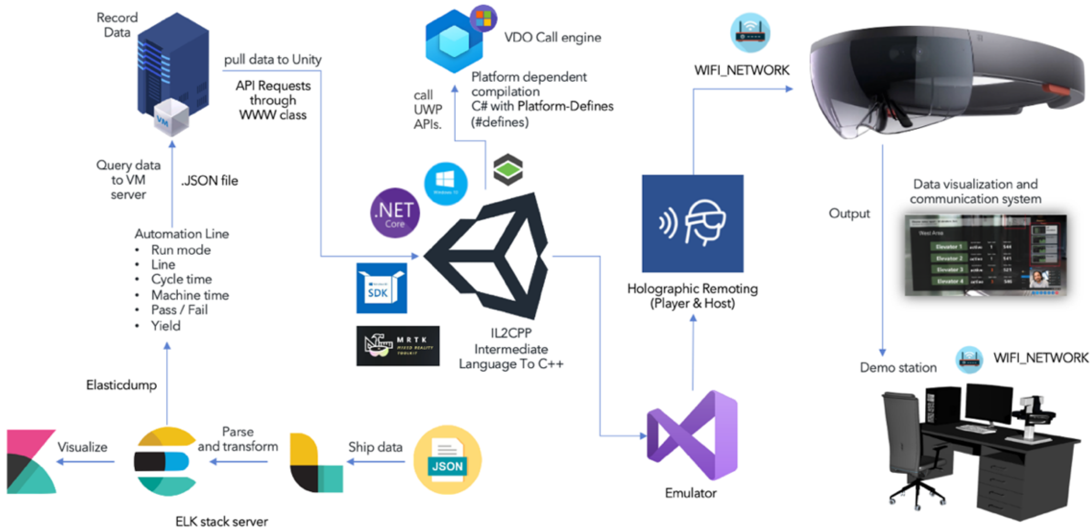
The researcher has a protocol for conducting research according to the ADDIE model with the following:

1. Data Collection, studies the process and analyzes problems that arise in the hard disk manufacturing industry by using the process chart tool. Maintenance process flow has been found that the maintenance procedures currently, engineers and maintenance teams have to manually determine the

cause of automatic hard disk assembly machine problem in production line without technology supporting. As a result, the maintenance process have to take time to access the data and coordination between engineers and maintenance team.

2. Studying and analyzing the relevant theories makes it possible to set objectives and guidelines for solving the problem of maintenance time of automatic hard disk assembly machine in production line by using mixed reality technology as a tool to solve problems, displaying information in a visual form with a focus on perception and user response which Mixed reality technology can be supported visualization.
3. Design of research conceptual framework as shown in Figure 3.3, the automatic hard disk assembly will be transmitted the machine's working data to be collected, sorted, and saved on an open-source computing system. Visualization of automation line information display system cooperate with the mixed reality technology will be retrieved the data to save on the host computer in real-time. When the user wears HoloLens and activates the system. The system will retrieve the current data on the host computer to display on HoloLens glasses in 3D and respond to user reactions by relies on the connection between devices through the internet network.
4. System design and develop a prototype as shown in Figure 3.9, referring to the research conceptual framework.

Figure 3.9: Overview of the Data Visualisation Dashboard for Automation Lines Development by Mixed Reality Technology



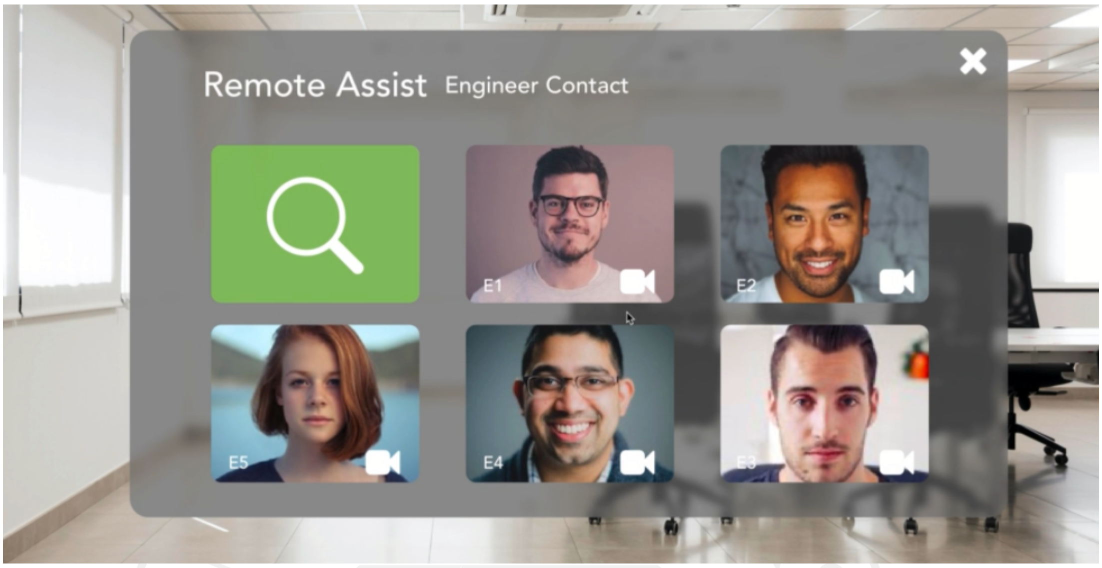
a. The system started by automatically retrieving the working results of the hard disk assembly machine, consisting of the working status (Run mode), the machine's serial number (Line ID), the production time of the workpiece within one process cycle (Cycle time). , machine cycle time (Machine time), the number of complete workpieces and incomplete (Pass / Fail) from an open-source processor or ELK stack. It is retrieved through automation code running on the host computer cooperate with the Elasticdump tool to help access data on the ELK stack and save it in JSON format on the host computer.

b. System Development with Mixed Reality Technology developed on Unity with C# and C++ languages to display on glasses HoloLens which was developed by Microsoft. The system set up with the Windows10, the software development kit, SDK and Mixed Reality Tool Kit to support cross-platform development.

c. User interface design designed according to the recommendations of the research team and develop a HoloLens device from Microsoft to support users to match the capabilities of the device for usage efficiency, the design perspective is shown by the head-mounted display and display with 2D and 3D graphics in the real environment as in Figures 3.10 and 3.11.

Figure 3.10: User Interface design of data dashboard

Figure 3.11: User Interface design of VDO call function



d. The data from the host computer is retrieved and displayed on the hologram glasses in real time through the Application Programming Interface (API).

e. Audio-visual communication and real-time remote developed from functions of Remote Assistance applications as In-Apps or calling application functions from outside applications. To run the functions of other applications without logging out for supporting users to access to functions faster.

f. Real-time operations rely on intranet connections or on-premises networks to support long-distance wireless data transmission function without leaking information.

g. System functions are compiled on Unity program and transcribed from the system to be installed for use on HoloLens devices through Visual Studio. A simulation program to test the functionality. And send it through the Holographic Remoting program that must be installed on the HoloLens device and computers that use for development to connect and send and receive information for system installation.

h. When installing the system into a holographic device for testing research prototypes by installing the work area of the automatic hard disk assembly maintenance team in the production line and the engineering team's office area.

- The output of the system
    - MR Application

      Data visualisation dashboard for automation lines MR application has 3 main parts including record data system part, TCP/IP send and receive data system, and MR application on HoloLens.

      Figures 3.12 and 3.13 show GUI (graphical user interface) of record data system. When presses start auto record button, system is going to start connecting to ELK internal server, gets query and retrieve data, and saves it in JSON format to the directory and rename to timestamp.

Figure 3.12: GUI of record data system

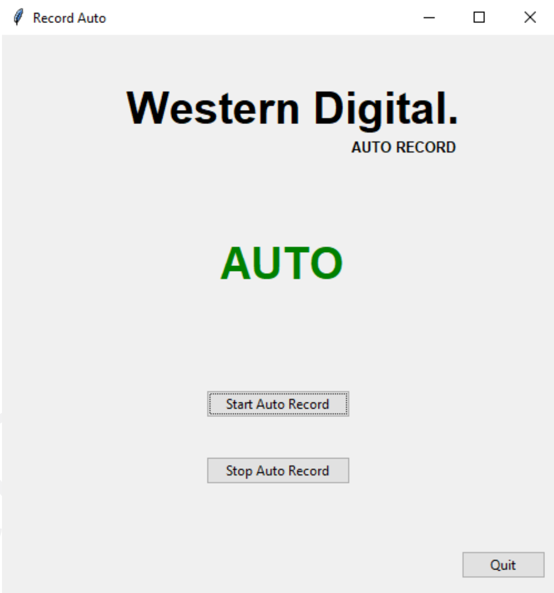


Figure 3.13: Record data system process

Figures 3.14 and 3.15 show TCP/IP send and receive data system. This system separated to 2 parts: server and client. Server system is runs through command line waiting for client request. Client system is embed in unity script to order request data list form MR application to server through by IP (Internet Protocol Address). When server system gets request list from client, the server filters the data following client list and send encode data back to client. Client receives and decodes data to use in application.

Figure 3.14: Server TCP system running on command line

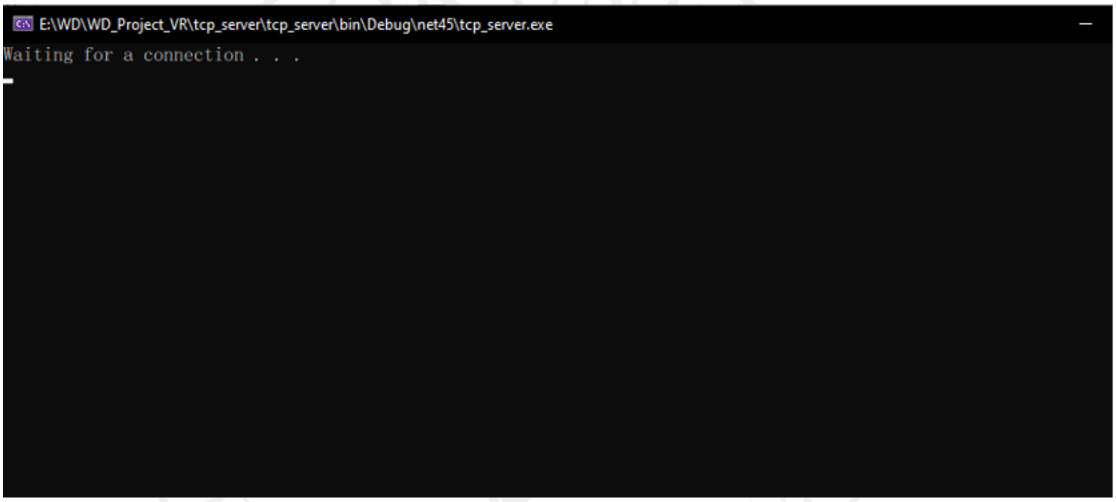
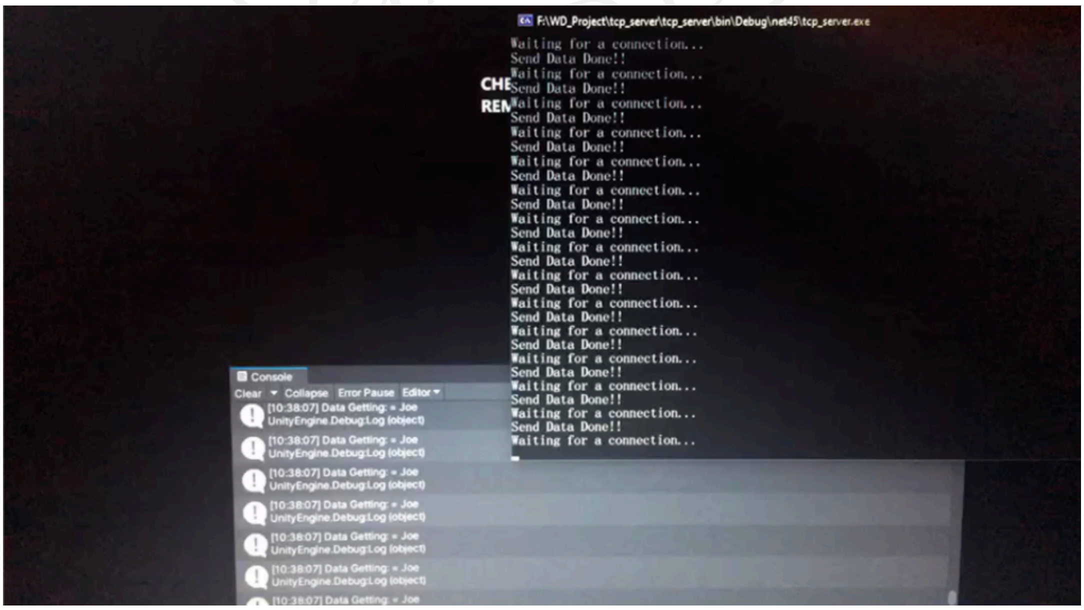


Figure 3.15: Client TCP system running on unity console



Figures 3.16 and 3.17 show GUI (Graphical User Interface) of MR application on HoloLens. Figure 3.16 is home menu of application. It has button that links to each visualisation dashboard. Feature hub is for support function including back to home menu, screen record, and VDO call function from remote assistance. Figure 3.17 is visualisation dashboard for automation line display real time data with fetch data function every 15 seconds with line ID, machine name, product name, pass/fail status, machine time, and cycle time. It also has graph display machine time and cycle time for visualisation.

Figure 3.16: User Interface Menu

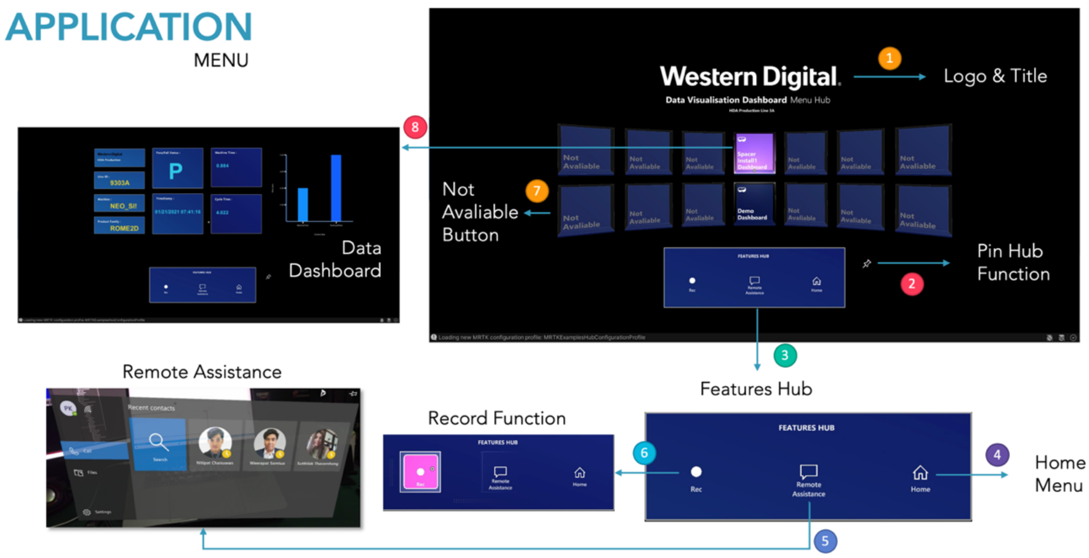
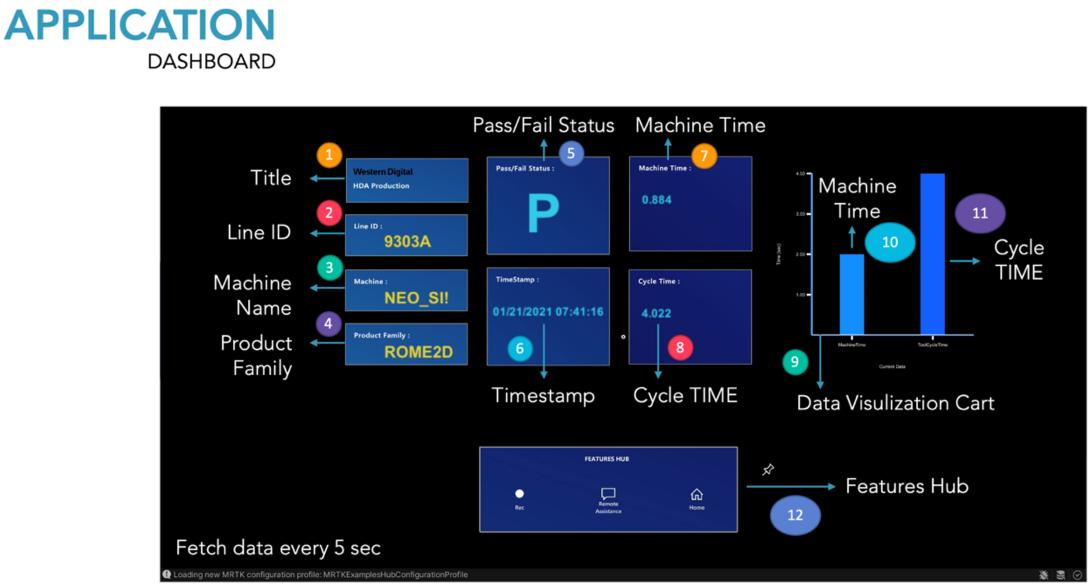


Figure 3.17: User Interface Dashboard



CHAPTER 4

RESULTS AND DISCUSSION

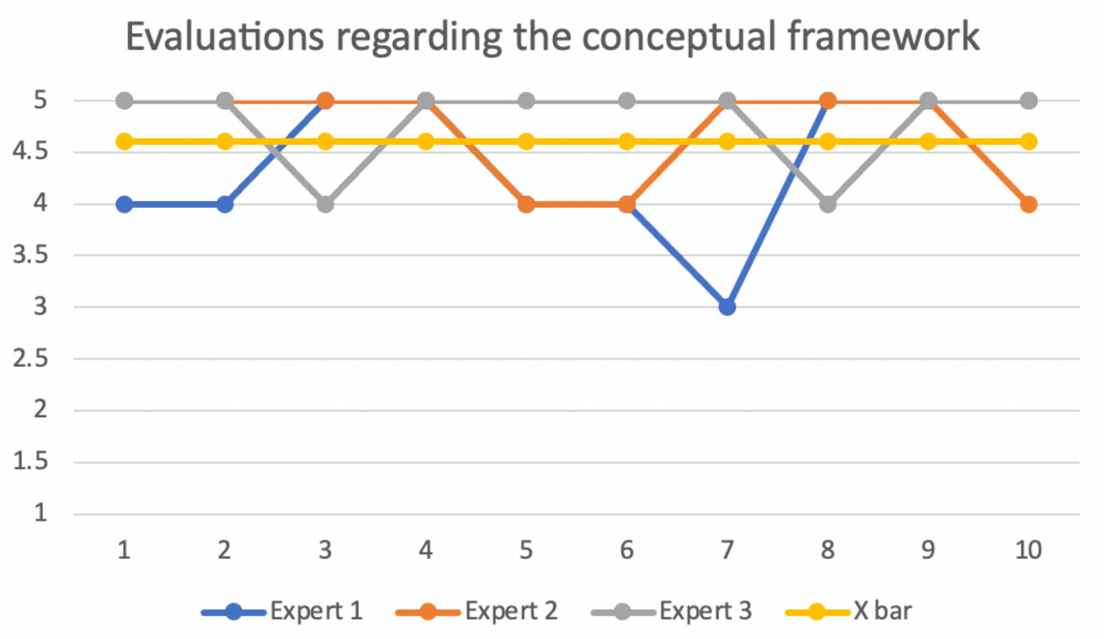
- Evaluations of the conceptual framework

Research concepts were assessed by technology experts to bring the all of results to find the mean from the assessment. (Dane Bertram, 2007) Results as shown in Table 4.1, is the results from evaluations regarding the conceptual framework. It shows the mean total score is 4.6 and compare with Likert scale as figure 4.1, the number 4.6 is between section 4.5 to 5. It is the highest level of satisfaction of the concept of this research. These are only preliminary results.

Table 4.1: Conclusion of evaluations regarding the conceptual framework

Topic	Expert 1	Expert 2	Expert 3
The suitability of the User Interface			
The suitability of composition	4	5	5
The suitability of display	4	5	5
The suitability of function	5	5	4
The suitability of the system			
Ability in connecting information	5	5	5
Accuracy in following orders	4	4	5
Accuracy of information	4	4	5
The suitability of the objective			
The suitability of assisting in data analysis	3	5	5
The suitability of save worker's time	5	5	4
The suitability of increases efficiency in the production line	5	5	5
The suitability for practical use	5	4	5
Each Total	44	47	48
Total All	139		
$\bar{X}$	4.633333333		

Figure 4.1: Result evaluation chart



- Data analysis

Analysis the system performance by using a process flow chart device which is a tool used to record the details of the production process. (Kulaya Sriyom, Pichet Chantawee, and Suwatchanee Petcharat, 2018) Using standard symbols in the recording so that the process can be seen clearly analysed the differences in the maintenance process first. And after using the system by collecting the before and after maintenance steps on the process flow chart as shown in Figures 4.2 and 4.3 and analysing the working results of the system prototype.

Figure 4.2: Process flow chart of the current maintenance process.

Process Chart

Project: Data Visualization Dashboard for Automation Lines Development by Mixed Reality Technology

Process: Fail case happen - Process and Support Team can't solve problem

State: Current

Chart type: Man

Step #	Activity description	Time (minutes)	Distance (meters)	Operation ○	Transport ⇨	Inspection □	Delay D	Storage ▽	Value Category (VA.ENVA.NVA)	Inputs, outputs, rejection points, remarks, ...
1	Maintenance team take action	5.00	-	X					VA	
2	Process team monitor fail data and analyse problem	5.00	-	X					VA	
3	Process team support maintenance team	5.00	-	X					VA	
4	Process team mailing request support from engineer team	2.00	-	X					ENVA	
5	Engineer analyse problem and priority to get solution	3.00	-	X					VA	
6	Engineer come from B3 to B4 (Jumpsuit Room)	9.57	-		X				ENVA	
7	Engineer request and waiting for jumpsuit/BT	0.46	-				X		NVA	
8	Engineer walk to Talcum powder station	1.46	-		X				ENVA	
9	Engineer check Talcum powder	2.23	-	X					ENVA	
10	Engineer walk through Air tunnel and Get into changing room	1.00	-		X				ENVA	
11	Engineer wear Jumpsuit/BT	6.30	-	X					ENVA	
12	Engineer do Glove Washing and Air Dryer	2.37	-	X					ENVA	
13	Engineer walk to ESD Checking point and walk through Air Shower	0.15	-		X				ENVA	
14	Air Shower Process	0.25	-	X					ENVA	
15	Engineer walk to Production Line	0.20	-		X				ENVA	
16	Engineer Support maintenance	5.00	-	X					VA	
			Count:	10	5	0	1	0		
			Time per process step:	36.15	12.38	0	0.46	0		

Total VA	5		Total NVA	1		Total ENVA	10	
VA Time	23	Minutes	NVA Time	0.46	Minutes	ENVA Time	25.53	Minutes
Distance traveled	0	Meters	Lead Time	49	Minutes	VS Ratio	46.95%	

Guidelines:
A **Process Chart** is a table illustrating the sequence of actions within a process.
1st: List all activities within the process.
2nd: Identify the type of activities (operation, transport, inspection, delay or storage). Use only the character "X" under the symbols to identify the type of activity.
3rd: Classify each activity into value added, non-value added or essential non-value added (ENVA).

Figure 4.3: Process flow chart of the maintenance process after the prototype was tested.

Process Chart

Project: Data Visualization Dashboard for Automation Lines Development by Mixed Reality Technology

Process: Fail case happen - Process and Support Team can't solve problem

State: Future

Chart type: Man

Step #	Activity description	Time (minutes)	Distance (meters)	Operation ○	Transport ⇨	Inspection □	Delay D	Storage ▽	Value Category (VA.ENVA.NVA)	Inputs, outputs, rejection points, remarks, ...
1	Maintenance team take action	5		X					VA	
2	Process team monitor fail data and analyse problem	5		X					VA	
3	Process team support maintenance team	5		X					VA	
4	Process team mailing request support from engineer team	2		X					ENVA	
5	Engineer analyse problem and priority to get solution	3		X					VA	
6	Engineer Support maintenance	5		X					VA	
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
			Count:	6	0	0	0	0		
			Time per process step:	25	0	0	0	0		

Total VA	5		Total NVA	0		Total ENVA	1	
VA Time	23	Minutes	NVA Time	0	Minutes	ENVA Time	2	Minutes
Distance traveled	0	Meters	Lead Time	25	Minutes	VS Ratio	92.000%	

Guidelines:
A **Process Chart** is a table illustrating the sequence of actions within a process.
1st: List all activities within the process.
2nd: Identify the type of activities (operation, transport, inspection, delay or storage). Use only the character "X" under the symbols to identify the type of activity.
3rd: Classify each activity into value added, non-value added or essential non-value added (ENVA).

CHAPTER 5

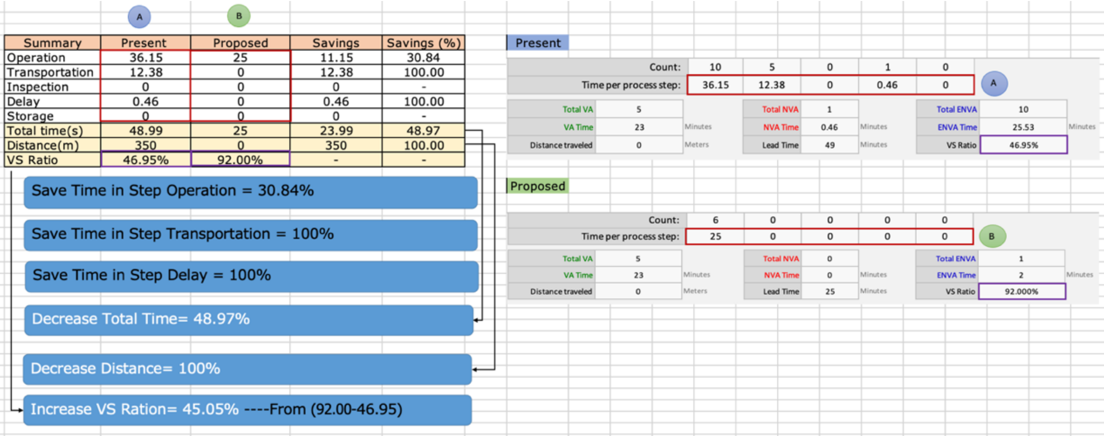
CONCLUSION AND SUGGESTION

From the analysis of the process flow chart of the maintenance process as shown in Figure 5.1, it was found that a data visualisation dashboard for automation lines development by mixed reality technology can help to reduce the time in the maintenance process of the automatic hard disk assembly machine by 23.99 minutes, representing 48.97%, or reducing the time by 48.97% per problem.

The result of the analysis of the maintenance process flow chart showed the reduction of steps 6–15, as shown in Figures 4.7 and 4.8, which took a total of 23.99 minutes, by substituting with a data visualization dashboard for automationlines development by the mixed reality technology, as shown in Figure 8.1, which can reduce the process of traveling between buildings for the engineering team and production building and reduce the procedure before entering the production line or cleanroom 100%

A data visualisation dashboard for automation lines development by mixed reality technology developed specifically for display on HoloLens devices only. For devices that support mixed reality technology, the system is yet to support. Further development is required for support on a wide range of devices.

Figure 5.1: Conclusion of the process flow analysis of the maintenance process



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APPENDIX

- **Evaluation of the conceptual framework by expert one**

แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลสำหรับผู้เชี่ยวชาญ
กรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลเครื่องประกอบฮาร์ดดิสก์อัตโนมัติ
ในรูปแบบจินตทัศน์ร่วมกับเทคโนโลยีความเป็นจริงผสม

ตอนที่ 1 สถานภาพของผู้เชี่ยวชาญ

คำชี้แจง โปรดกรอกรายละเอียดในช่องว่างตามความเป็นจริง

1. ตำแหน่งปัจจุบัน รองคณบดีฝ่ายวิชาการ
2. สังกัด คณะเทคโนโลยีสารสนเทศ มหาวิทยาลัยราชภัฏเทพสตรี
3. วุฒิการศึกษา
   - ปริญญาตรี ชื่อย่อวุฒิ วท.บ. สาขา วิทยาการคอมพิวเตอร์
   - ปริญญาโท ชื่อย่อวุฒิ วท.ม. สาขา เทคโนโลยีสารสนเทศ
   - ปริญญาเอก ชื่อย่อวุฒิ ปร.ด. สาขา คอมพิวเตอร์ศึกษา
   - อื่นๆ (โปรดระบุ) ....
4. ประสบการณ์ในการทำงาน 17 ปี

ตอนที่ 2 แบบสอบถามความคิดเห็นของผู้เชี่ยวชาญ

คำชี้แจง โปรดทำเครื่องหมาย " ✔ " ในช่องว่าง ที่ตรงกับความคิดเห็นของท่าน ซึ่งแบบสอบถามเกี่ยวกับความเหมาะสมของระบบการแสดงผลข้อมูล ประกอบด้วย 4 หัวข้อ โดยใช้มาตรฐานส่วนประมาณค่า 5 ระดับของลิเคอร์ท (Likert)

- ระดับ 5 หมายถึง ผลการประเมินอยู่ในระดับ ดีมาก
- ระดับ 4 หมายถึง ผลการประเมินอยู่ในระดับ ดี
- ระดับ 3 หมายถึง ผลการประเมินอยู่ในระดับ ปานกลาง
- ระดับ 2 หมายถึง ผลการประเมินอยู่ในระดับ พอใช้
- ระดับ 1 หมายถึง ผลการประเมินอยู่ในระดับ ปรับปรุง

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล

เรื่องที่ประเมิน	ระดับความเหมาะสม				
	5	4	3	2	1
1. ความเหมาะสมของส่วนติดต่อผู้ใช้งาน					
- ความเหมาะสมขององค์ประกอบ		✓			
- ความเหมาะสมในการแสดงผล		✓			
- ความเหมาะสมของการใช้งาน	✓				

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล (ต่อ)

เรื่องที่ประเมิน	ระดับความเหมาะสม				
	5	4	3	2	1
2. ความเหมาะสมของระบบ					
- ความสามารถในการเชื่อมโยงข้อมูล	✓				
- ความแม่นยำในการสั่งงาน		✓			
- ความถูกต้องของข้อมูล		✓			
3. ความเหมาะสมด้านวัตถุประสงค์					
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยในการวิเคราะห์ข้อมูล			✓		
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยลดความเสี่ยงและความตึงเครียดในสายการผลิต	✓				
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยเพิ่มประสิทธิภาพในสายการผลิต	✓				
4. การพัฒนาระบบการแสดงผลข้อมูลมีความเหมาะสมในการนำไปใช้จริงในระดับใด	✓				

ข้อเสนอแนะ

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ลงชื่อ......กอรวี ot......

(......นางสาวกอรวี ศิริโภคาภิรมย์......)

ขอขอบพระคุณที่ให้ความอนุเคราะห์

ผู้วิจัย

- **Evaluation of the conceptual framework by expert two**

แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลสำหรับผู้เชี่ยวชาญ
กรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลเครื่องประกอบฮาร์ดดิสก์อัตโนมัติ
ในรูปแบบจินตทัศน์ร่วมกับเทคโนโลยีความเป็นจริงผสม

ตอนที่ 1 สถานภาพของผู้เชี่ยวชาญ

คำชี้แจง โปรดกรอกรายละเอียดในช่องว่างตามความเป็นจริง

1. ตำแหน่งปัจจุบัน ....อาจารย์ประจำสาขาวิชาคอมพิวเตอร์ศึกษา....
2. สังกัด ....คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยราชภัฏนครปฐม....
3. วุฒิการศึกษา
   - ปริญญาตรี ชื่อย่อวุฒิ ....วท.บ.... สาขา ....วิทยาการคอมพิวเตอร์....
   - ปริญญาโท ชื่อย่อวุฒิ ....คอ.ม.... สาขา ....คอมพิวเตอร์ศึกษา....
   - ปริญญาเอก ชื่อย่อวุฒิ ....ปร.ด.... สาขา ....คอมพิวเตอร์ศึกษา....
   - อื่นๆ (โปรดระบุ) ....
4. ประสบการณ์ในการทำงาน ....9.... ปี

ตอนที่ 2 แบบสอบถามความคิดเห็นของผู้เชี่ยวชาญ

คำชี้แจง โปรดทำเครื่องหมาย " ✔ " ในช่องว่าง ที่ตรงกับความคิดเห็นของท่าน ซึ่งแบบสอบถามเกี่ยวกับความเหมาะสมของระบบการแสดงผลข้อมูล ประกอบด้วย 4 หัวข้อ โดยใช้มาตรฐานส่วนประมาณค่า 5 ระดับของลิเคอร์ท (Likert)

- ระดับ 5 หมายถึง ผลการประเมินอยู่ในระดับ ดีมาก
- ระดับ 4 หมายถึง ผลการประเมินอยู่ในระดับ ดี
- ระดับ 3 หมายถึง ผลการประเมินอยู่ในระดับ ปานกลาง
- ระดับ 2 หมายถึง ผลการประเมินอยู่ในระดับ พอใช้
- ระดับ 1 หมายถึง ผลการประเมินอยู่ในระดับ ปรับปรุง

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล

เรื่องที่ประเมิน	**ระดับความเหมาะสม**				
	5	**4**	**3**	**2**	**1**
1. ความเหมาะสมของส่วนติดต่อผู้ใช้งาน					
- ความเหมาะสมขององค์ประกอบ	✓				
- ความเหมาะสมในการแสดงผล	✓				
- ความเหมาะสมของการใช้งาน		✓			

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล (ต่อ)

เรื่องที่ประเมิน	ระดับความเหมาะสม				
	5	4	3	2	1
2. ความเหมาะสมของระบบ					
- ความสามารถในการเชื่อมโยงข้อมูล	✓				
- ความแม่นยำในการสั่งงาน	✓				
- ความถูกต้องของข้อมูล	✓				
3. ความเหมาะสมด้านวัตถุประสงค์					
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยในการวิเคราะห์ข้อมูล	✓				
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยลดความเสี่ยงและความตึงเครียดในสายการผลิต		✓			
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยเพิ่มประสิทธิภาพในสายการผลิต	✓				
4. การพัฒนาระบบการแสดงผลข้อมูลมีความเหมาะสมในการนำไปใช้จริงในระดับใด	✓				

ข้อเสนอแนะ

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ลงชื่อ.................. ....

(........อาจารย์ ดร.จรินทร อุ่มไกร........)

ขอขอบพระคุณที่ให้ความอนุเคราะห์

ผู้วิจัย

- **Evaluation of the conceptual framework by expert three**

แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลสำหรับผู้เชี่ยวชาญ
กรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูลเครื่องประกอบฮาร์ดดิสก์อัตโนมัติ
ในรูปแบบจินตทัศน์ร่วมกับเทคโนโลยีความเป็นจริงผสม

ตอนที่ 1 สถานภาพของผู้เชี่ยวชาญ

คำชี้แจง โปรดกรอกรายละเอียดในช่องว่างตามความเป็นจริง

1. ตำแหน่งปัจจุบัน ผู้อำนวยการ สำนักวิทยบริการและเทคโนโลยีสารสนเทศ
2. สังกัด มหาวิทยาลัยเทคโนโลยีราชมงคลพระนคร
3. วุฒิการศึกษา
    - ปริญญาตรี ชื่อย่อวุฒิ คอ.บ. สาขา วิศวกรรมคอมพิวเตอร์
    - ปริญญาโท ชื่อย่อวุฒิ วท.ม. สาขา เทคโนโลยีสารสนเทศ
    - ปริญญาเอก ชื่อย่อวุฒิ ปร.ด. สาขา คอมพิวเตอร์ศึกษา
    - อื่นๆ (โปรดระบุ) ....
4. ประสบการณ์ในการทำงาน 19 ปี

ตอนที่ 2 แบบสอบถามความคิดเห็นของผู้เชี่ยวชาญ

คำชี้แจง โปรดทำเครื่องหมาย " ✔ " ในช่องว่าง ที่ตรงกับความคิดเห็นของท่าน ซึ่งแบบสอบถามเกี่ยวกับความเหมาะสมของระบบการแสดงผลข้อมูล ประกอบด้วย 4 หัวข้อ โดยใช้มาตรฐานส่วนประมาณค่า 5 ระดับของลิเคอร์ท (Likert)

- ระดับ 5 หมายถึง ผลการประเมินอยู่ในระดับ ดีมาก
- ระดับ 4 หมายถึง ผลการประเมินอยู่ในระดับ ดี
- ระดับ 3 หมายถึง ผลการประเมินอยู่ในระดับ ปานกลาง
- ระดับ 2 หมายถึง ผลการประเมินอยู่ในระดับ พอใช้
- ระดับ 1 หมายถึง ผลการประเมินอยู่ในระดับ ปรับปรุง

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล

เรื่องที่ประเมิน	**ระดับความเหมาะสม**				
	5	4	3	2	1
1. ความเหมาะสมของส่วนติดต่อผู้ใช้งาน					
- ความเหมาะสมขององค์ประกอบ	✓				
- ความเหมาะสมในการแสดงผล	✓				
- ความเหมาะสมของการใช้งาน	✓				

ตารางที่ 1 แบบประเมินกรอบแนวคิดการพัฒนาระบบการแสดงผลข้อมูล (ต่อ)

เรื่องที่ประเมิน	ระดับความเหมาะสม				
	5	4	3	2	1
2. ความเหมาะสมของระบบ					
- ความสามารถในการเชื่อมโยงข้อมูล	✓				
- ความแม่นยำในการสั่งงาน		✓			
- ความถูกต้องของข้อมูล		✓			
3. ความเหมาะสมด้านวัตถุประสงค์					
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยในการวิเคราะห์ข้อมูล	✓				
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยลดความเสี่ยงและความตึงเครียดในสายการผลิต	✓				
- ความเหมาะสมด้านวัตถุประสงค์ของการช่วยเพิ่มประสิทธิภาพในสายการผลิต	✓				
4. การพัฒนาระบบการแสดงผลข้อมูลมีความเหมาะสมในการนำไปใช้จริงในระดับใด		✓			

ข้อเสนอแนะ

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ลงชื่อ..........[illegible]..........

(..........[illegible]..........)

ขอขอบพระคุณที่ให้ความอนุเคราะห์

ผู้วิจัย

BIODATA

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