The Virtual Reality Technology for Maintenance of Complex Machine in Manufacturing Training

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(Received: February 19, 2021; Accepted: August 20, 2021)

ABSTRACT

This research is the development of reality technology used to improve traditional maintenance training in manufacturing. The application of reality technology was adapted to use for 12.5% of training and learning, 7.33% of product design, 6.03% of safety, 5.17% of remote assistance, and 5.60% of telerobotic and robotics in the manufacturing community. Conventional practice is a lecture using text, images, or videos. Moreover, the method had to stop the machine from operating in the production line. Therefore, reality technology helps the trainee enhance their experience through training in virtual environments by simulating the machine's maintenance procedure. Additionally, the system offers convenience in learning and searching for information. However, this system was evaluated the satisfaction of the engineer for confirmation to be genuinely available. In the next stage, the system was tested by the expert engineer and comparing Mean Time to Repair and Mean Time Between Failure of the machine in the current. The experiment illustrated the maintenance time was reduced depending on training regularly.

Keyword: Reality technology, machine maintenance, complex machine, manufacturing training.

1. Introduction

The Hard Disk Drive (HDD) manufacturers have started implementing reality technology to improve the manufacturing process to transform it into an industrial 4.0 Smart Factory. Reality technology mixed the physical and digital world to present the new simulated world using all software and hardware forms, called immersive technology or reality technology [1]. Virtual instruction is currently an example of reality technology that has been widely applied to the gaming and entertainment industry. In the manufacturing industry, reality technologies are used to avoid risk. For example; Virtual Reality is used to assemble and disassemble a gearbox simulation for maintenance training in virtual environments [2]. Augmented Reality is used to make a guideline assembly and maintenance of machines [3]. Mixed Reality is used to simulate aircraft maintenance training, in which users can be immersed using a see-through Head Mounted Display (HMD) [4]. As the automated production-line machines are very complex; therefore, the maintenance of these machines is difficult. The reality technology is applied in manufacturing training for an employee learning enhancement.

The engineer maintained the machine according to its maintenance schedule in the production line following manual documents. Some failure cases are not indicated in manual documents. Therefore, the engineer had to find the solution and show descriptions more themselves. An unexpected failure leads to increased maintenance time. The engineer must get trained to enhance maintenance skills. Currently, traditional training is to use text, images, and videos in lectures. Moreover, the machine also must be stopped operating for training result in occurring downtime increasingly.

This research presents the development of reality technology in manufacturing to avoid various failures in the machine. Reality technology can help an engineer enhance his/her maintenance skills by training as often needed with a time limit using the application. The training is performed outside the production line without stopping the machine from operating to evaluate the training effectiveness. The engineer was asked to perform the survey of the system evaluation when they completed training. In the next stage, the expert engineer of 10 participants performed maintenance of the machine and compared the maintenance duration of 10 participants with the current period.

2. Related Work

This section presents the research study to help to find a suitable way that includes Reality technology, Virtual Reality, Augmented Reality, and Mixed Reality.

Reality technologies can be classified into Virtual Reality (VR) is a virtual object simulation from the real object by interacting in the virtual environment; Augmented Reality (AR) is a 3D virtual object simulation to overlay a real object; Mixed Reality (MR) is a combination of Augmented and Virtual Reality by interacting through hand-free [1].

Virtual Reality (VR) was used to improve maintenance training in the manufacturing industry. Some industry has operated 24 hours a day without stopping machines. Therefore, the virtual system can help users avoid provoking breakdowns and accidents to maintain actual machines. This paper described Virtual reality as used to train to assemble and disassemble a gearbox by using Head Mounted Display (HMD) called the "Virtual Reality for Training in Maintenance Tasks" (VR-TMT) system [2]. The result of experimentation illustrated user experience right awareness level on the VR platform from using and evaluating a survey for 27 industrial engineering students. However, the virtual system indicated the limited space of the device sensor of 250 mm for using the device on a workspace. Our work presents the difference from this paper using the HoloLens in maintenance training, which is not limited to space, and users can train independently.

Additionally, VR was used to simulate a manufacturing process in the elaborate production line by familiarizing users with virtual environments. For example, the virtual simulation was used to support decision-making for design and production in achieving smart factory [5]. Another paper presented the use of VR simulated the manufacturing process of flat-rolled steel products by describing the movement of hot gases that escape from the door of reheating furnace [6].

Besides, Virtual reality was also used for maintenance training in electric power energy plants [7]. The transformer of the electric power system was simulated operating procedures to the virtual scenario. The virtual scenario simulation allows users to understand the complex system of machines by interacting with computer- simulated environments. The interaction level of the system can be classified into four modes including a) The virtual scenario can be explored without doing any tasks by users in the discovery mode b) Users can learn the work procedure in presentation mode c) The guided mode offers assistance for users with doing any tasks step-by-step d) Free mode is complicated, which users have to complete doing tasks without assistance. The result illustrated that the 3D visualization reduced problems and difficulty disassembling the transformer without faults and damage to the actual machine. However, the VR device still was limited to space for usability. Our work presented the difference between the HoloLens device from this paper using VR goggles. Therefore, our work presented the difference between the HoloLens device from this paper using VR goggles. By means, the HoloLens can be used anywhere in the form of wireless.

Augmented Reality (AR) assists the user with complex assembly and maintenance tasks in an industrial environment. Due to the machine has the complexity of maintenance tasks. This paper described that users could get all information directly superimposed into the actual working environment using see-through Head Mounted Display (HMD) by computer-generated images called augmentations [3]. The HMD was developed to simulate the virtual object superimposed into the actual object by calibrating an optical see-through HMD, which uses algorithms to calculate the (X, Y, Z) axis position for the 3D projection. Even though the system is still under development, the result of this research illustrated the display in 3D augmentation superimposed smoothly. The disadvantage of an electromagnetic tracking system is fast responding to a metals environment, which is a disturbance of a working system. Another disadvantage of the system is to use a cable connected a sensor to a processing unit of a tracking system, which is not wireless. Therefore, workspace and user movement are limited. However, our work differs from this paper using the HoloLens device, a wireless device and can superimpose the actual object using an image tracking system. The number of AR applications adapted to use in the manufacturing community illustrated that 12.5% of training and learning, 7.33% of product design, 6.03% of safety, 5.17% of remote assistance, and 5.60% of telerobotic and robotics [8]. AR was used to simulate computer-generated virtual objects overlapping with actual objects in the practical manufacturing environment. For example, AR glasses can help workers control a sequence and equipment assembly methods by reading step-by-step instructions and assembling according to instructions [9]. AR was implemented to simulate missing objects in the production line by a system planner before an actual object implementation [10].

Mixed Reality (MR) technology was developed to train new workers by implementing the Head-Mounted Display (HMD) attached see-through camera for aircraft door maintenance in complex manufacturing training, which this system allows users can use collaborative interactions [4]. This paper described both training types between MR training and traditional face-to-face training by evaluating knowledge retention and knowledge interpretation test with eight questions questionnaires. The result illustrated that the knowledge obtained from both types of training was not different significantly. Moreover, users have effectiveness in the MR training was as good as the ones in traditional training. MR training has limited a workspace and motion capture system in the laboratory. Therefore, our work is different from this paper using the HoloLens to allow users to train anywhere.

Furthermore, the MR was developed for application in many manufacturing communities, including product design, training, maintenance, assembly, Etc. [11]. For example, MR can assist users in planning the workshop layout by simulating virtual equipment in the actual environment [12]. The structure information and monitoring data of production equipment were integrated into the MR system to assist maintenance tasks [13].

All three types of reality technology have differently prominent, as shown in Fig. 1. VR brings people into a virtual environment; AR is to simulate a 3D virtual object to overlay an actual object that users cannot interact with; MR combines AR and VR to present the new environment that the user can interact.

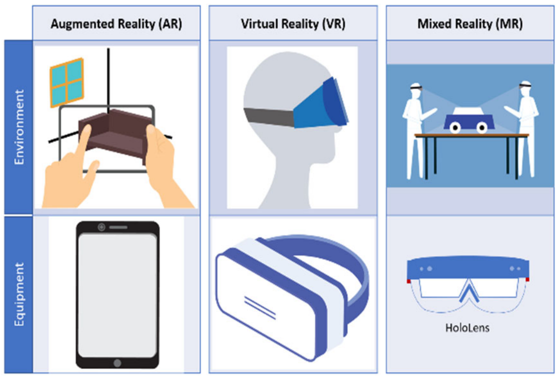

Fig. 1 Reality technology

Each type of reality technology has both advantage and disadvantage. First of all, AR and VR disadvantages are the limitation of interaction in the maintenance training, including AR is to use the device to display 3D visualization on a 2D touch-screen by scanning any QR-code or images. Therefore, users cannot fully interact with virtual objects. In the part of VR is to use the Head Mounted Display to simulate virtual environments. However, the VR has a limited space of 250 mm for user detection. The advantage of AR and VR was developed by using MR technology for HoloLens.

User can apply reality technology in virtual training. Moreover, these technologies were helpful to the user in many roles because they allowed them to design a virtual system such as a virtual environment, simulation, interaction, and instruction. The environment and situation are variable that a virtual teacher responded to users [14, 15]. On the job training, trainees found many problems making them get trained that is not full performance. Because of risks, cost, and time-limited. The training aims to create interactive training [16 - 22]. Furthermore, the user can train many times in the same scenario of virtual training. Trainees get help from virtual training to find suitable solutions [14, 18, 23].

Table 1 shows the problems found in these below systems, such as the number of trainees, unrealistic virtual training, the difficulty of interaction, and limitation of point-of-view. This project was designed to solve these problems by using each prominent of 3 types of reality technology, including VR, to interact with controlling through mouse and keyboard; AR can interact with virtual objects in the real environment; MR can interact with hand-free, which any virtual objects were designed from the actual size of objects for a more realistic training encouragement.

TABLE I

The type of training program

Paper	Stereoscopic	Hand-on	Lecture	Simulation	Case Study	Interactive	Coaching	Group Discussion
14	●		●		●			
15	●							
16				●				
17				●				
18	●			●	●			
19				●				
20	●			●				
21	●			●				
22	●			●				
23					●			
This project	●	●	●	●	●	●	●	●

3. Methodology

3.1 Experimentation

The classification of the target group to classify all to 3 groups includes the first group (group 1) is an expert engineer, the second group (group 2) is an experienced engineer, and the third group (group 3) is a beginner. Each group user experimented with all three applications, such as VR, AR, and MR applications. When users completed testing, they did a survey. All 30 copies of the survey are calculated by the SUS score and port a graph. The System Usability Scale (SUS) is a standardized questionnaire for system measurement [24].

In the next stage, the expert engineer of 10 participants performed maintenance of the machine and compared the maintenance duration of 10 participants with the current period using (1) Mean Time to Repair (MTTR) and (2) Mean Time Between Failure (MTBF) formula calculation.

$$\text{MTTR} = \frac{\text{Total Maintenance Time}}{\text{Total Number of Repairs}} \quad (1)$$

$$\text{MTBF} = \frac{\text{Total Operational Time}}{\text{Total Number of Failures}} \quad (2)$$

4. Implementation

4.1 System Overview

This section indicates a reality-based interaction system in which virtual and actual environments are integrated into new learning environments instead of learning in the production line. The difficulty of current learning is to stop the machine from running in teaching trainees, and consequently, the machine cannot produce the workpiece. The new system aims to protect the vulnerable during training in the production line by training outside in virtual environments. The virtual system is simulated from all the information in the production line by gathering and learning how it operates. The information gathered is spending extended times in learning as a consequence of the complexity of machine operations. Furthermore, 2D drawing and 3D visualization are used to describe the complex machine for facilitating trainee learning. The utilization of 2D and 3D information is a prerequisite for designing the system, described in the overview below of Fig. 2.

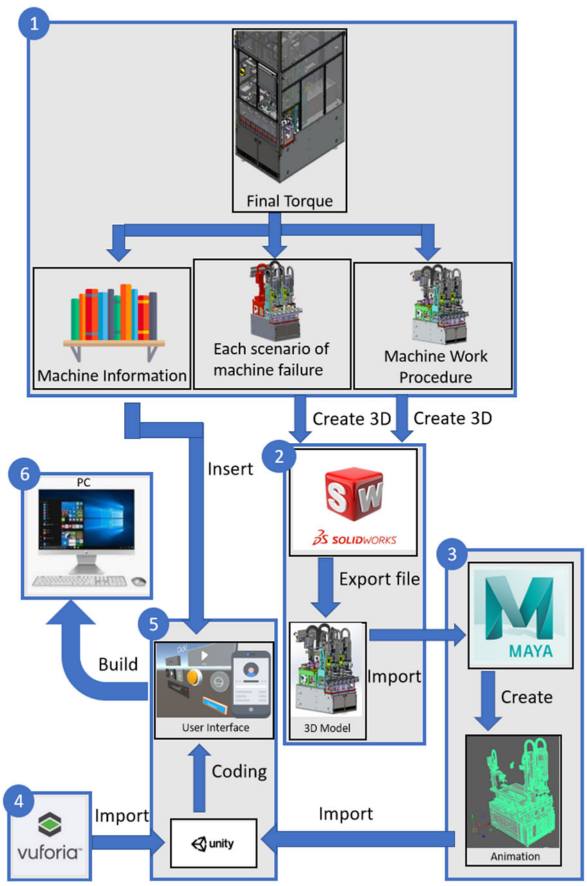

Fig. 2 System overview

4.1.1 The first step is to gather all the information

The information is gathered into an application such as manual documents, 2D drawing, and 3D CAD, as shown in Fig. 3.

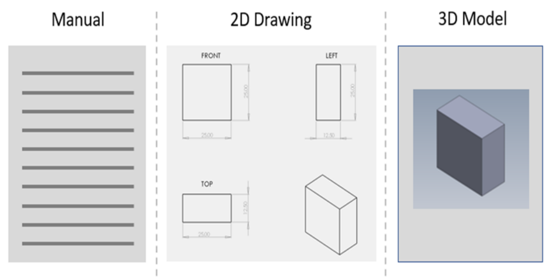

Fig. 3 Gathering 3 things of the information, including manual, 2D drawing and 3D model

All three things are different location files. Consequently, it is a waste of time searching for any file. However, to gather all files in the same location file for the convenience of searching. All three things above are used to design the machine in the production, called mechanical design. The machine design has two parts, include software development and mechanical design. The mechanical design started by designing the 3D CAD in SolidWorks. The next step is to set each axis's dimensions in a 2D drawing for creating the real object of implementation in the production. Another necessary step is to describe how the machine operator sets up and maintenance in manual documents. The software development is used to control machine operations through input/output devices in the controller cabinet. The software is running on the machine's touch screen monitor, which can adjust values in this interface, and the software detail was simulated in Adobe Illustrator for the realism of the training. Some button is used according to the maintenance procedure. Therefore, some detail is not necessary for interaction, as shown in Fig. 4.

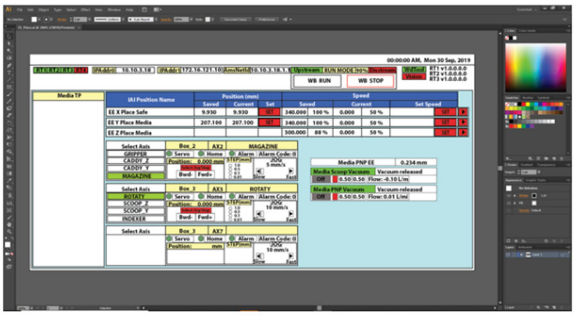

Fig. 4 Study the overall monitor of the machine in the production line

4.1.2 The second step is to edit a 3D CAD and Downsizing

Currently, the 3D CAD is designed by the mechanical designer, as shown in Fig. 5.

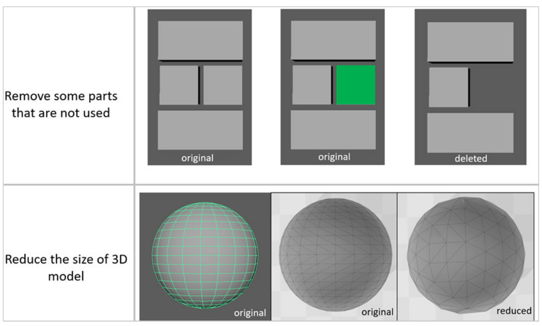

Fig. 5 Deleting some component of a 3D model that is not used for a file downsizing

The components of the mechanical part are used to assembly the machine. Some mechanical part is designed for movement. On the other hand, some mechanical part is designed for motionless. As mentioned in paragraph one of this section, the 3D animation is created by learning how the machine operates in the production line. The central problem of the 3D CAD design is the too large size. Thereby, the 3D CAD has been downsizing by reducing the surface area size for faster processing.

Moreover, the reduction of the surface area of 3d size is to animate the 3D smoothly. Another problem was often found, in which some 3D CAD files are disappeared or damaged. Nevertheless, the 3D CAD can be designed the new one by 2D drawing. The 2D drawing described the mechanical design details, including to set dimensions of each axis, width, length, height, and angle degree, as shown in Fig. 6.

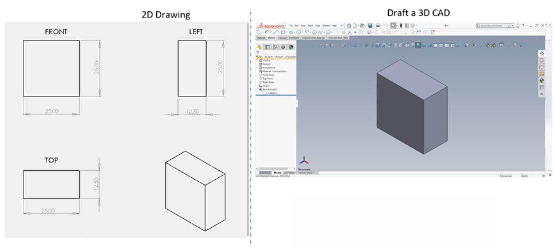

Fig. 6 3D CAD designing on SolidWorks

4.1.3 The third step is to animate a 3D CAD

The 3D CAD is used to create animation by moving objects in 3-dimensional space, as shown in Fig. 7. Nevertheless, the 3D CAD is exported from SolidWorks to Autodesk Maya, which found the color of 3D CAD disappeared and all file ungrouped. As mentioned, animation creation difficulty is increased accordingly by adding color and classifying the 3D CAD group. The animation creation started by moving objects independently from the position A to the position B according to the X-axis, Y-axis, and Z-axis. The position of objects is established to create animation in the keyframe. Each keyframe is an image computer-generated, in which the quick movement of an image depends on the frame per second (FPS), called animation. The animation is rendered to file with FBX extension and imported into Unity 3D.

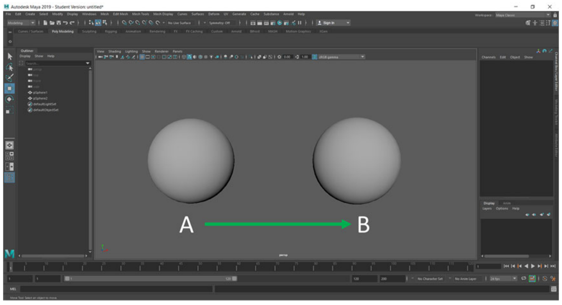

Fig. 7 Creating the 3D CAD animation

4.1.4 The *fourth step is to create a script of controlling by C# language*

The C sharp of the programming language is used widely to develop the game engine in Unity 3D by using Visual Studio. Fig. 8 shows that Unity 3D tools allow developers to design the system independently by using scripts for system control for developing the 3D application. Besides, the variety of Unity consists of creating animation, UX/UI design, multimedia, and others controlled by C# scripts. These scripts are attached to objects for controlling the behavior of objects. Scripting is a necessary component in application development. Moreover, Unity ability can assist developers in connecting other systems by using assets plugin to be integrated, such as OpenCV, Database, MySQL, and others. As continued from the previous paragraph, the animation was imported into Unity 3D. The script is used to be an animation controller and controlled the system.

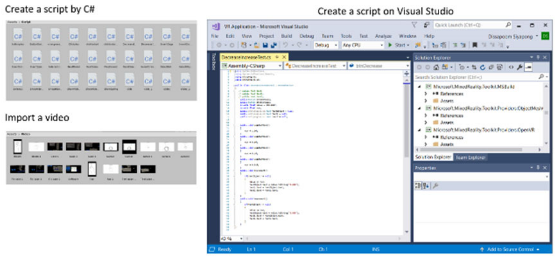

Fig. 8 A script of controlling by C#

4.1.5 The fifth step is to add a QR-Code to generate a position of marking for detection and showing a 3D CAD

As mentioned in the previous paragraph, Unity offers tools for supporting the development. The Software Development Kit (SDK) is an essential tool that can help developers access complex systems. Therefore, the Vuforia SDK is implemented by tracking the QR-code marker into AR applications, as shown in Fig. 9.

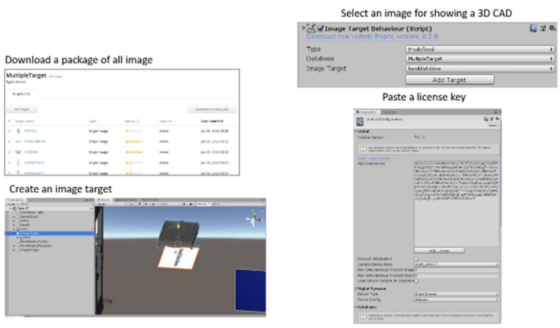

Fig. 9 Adding QR code or an image to Unity for displaying a 3D CAD

The QR-code is generated by importing it into Vuforia portal browser. However, computer vision detects the marker depending on an image is marked as a point in grayscale tone.

4.1.6 The sixth is to build an application

Unity supports various platforms for building the application, including Universal Windows Platform (UWP), Android Mobile, IOS Mobile, Xbox, WebGL, PC, Etc. Fig. 10 shows the build setting started by using the scenes in the build panel, which the build setting depends on platform selection.

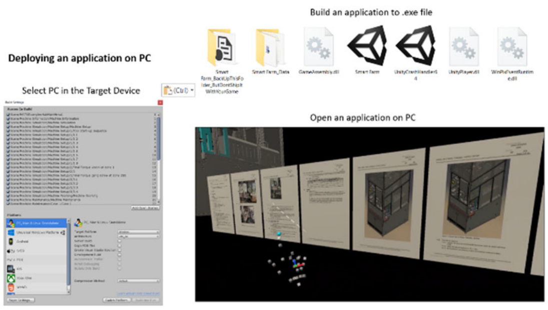

Fig. 10 Building an application

4.2 Process Flow of the application

The flowchart above indicates how the application operates, as shown in Fig. 11. The application is designed to suit an industrial by creating three functionalities: information, simulation, and maintenance. The information is gathered to retrieve machine information such as manual documents, 2D drawings, and 3D CAD. The manual documents describe how the machine set up and maintain, which is the traditional instruction. These documents are used to design the new instruction in three-dimensional simulation by creating the function of machine simulation. Machine simulation is an essential learning enhancement by using 3D visualization and animation, which classifies machine setup and machine operation. Also, the function of machine maintenance is designed to allow users can train an interactive virtual machine in the virtual environment. The maintenance training lets users learn to maintain

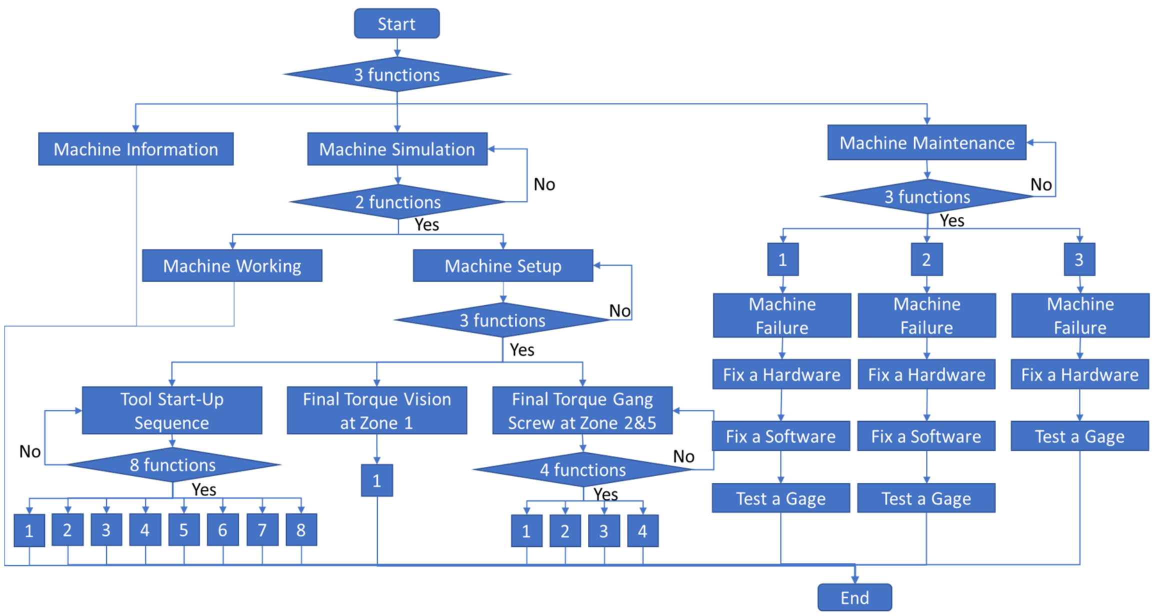

Fig. 11 Process flow of an application

both hardware and software for realistic training with the real machine in the production line.

4.3 The comparison of reality technology for application

The application was generated for two systems, as shown in Fig. 12, including the 2D desktop and the 3D fully immersive HoloLens.

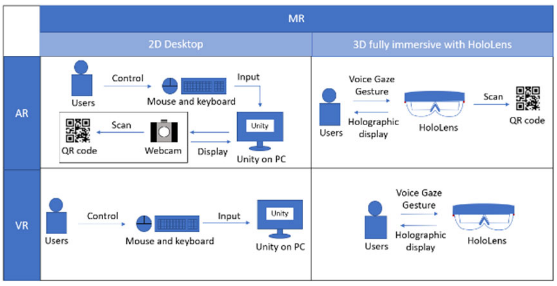

Fig. 12 Process flow of systems

However, both systems are different. The 2D desktop was used to display 3D visualization on a 2D screen monitor by interacting with a mouse and keyboard. While the 3D fully immersive with HoloLens was used to display the 3D holographic by users interacting with Hand-free to control the system. AR was used to assist users in fully interacting with virtual objects by a camera scanning QR-code or images to display 3D objects. Moreover, users can use the VR version without camera scanning.

The proposed system offers a difference in learning, in which the excellent performance of the technology is extracted by creating three types of reality technology, including Augmented Reality (AR) allows a user to enable a camera function of the system, as shown in Fig. 13, which is tracked by an image marker to display the 3D virtual object.

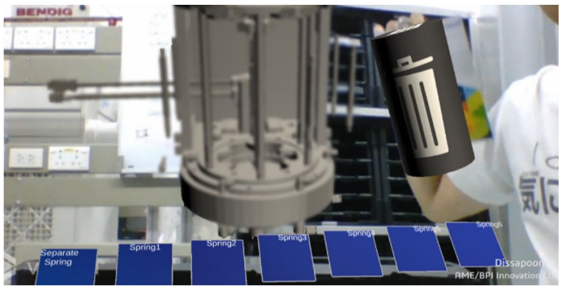

Fig. 13 AR application

The 3D virtual object is an overlay of the real object to increase the trainee understanding. Virtual Reality (VR) allows users to interact with the virtual machine in the virtual environment, as shown in Fig. 14.

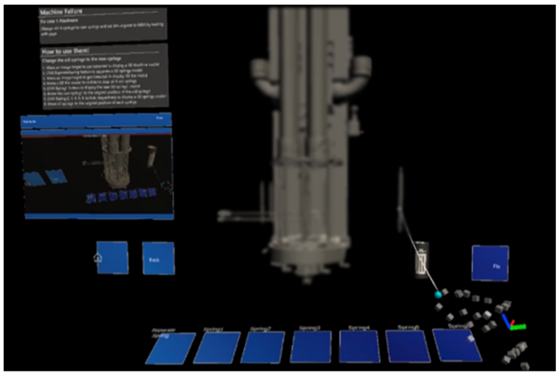

Fig. 14 VR application

The system provides users with a novel experience in which the virtual environment is similar to the actual environment. Mixed Reality (MR) allows a user to be immersive the 3D holographic visualization through Microsoft HoloLens, as shown in Fig. 15, called Head-Mounted Display (HMD). The system offers the interaction by using Hand-free to control the virtual object.

Fig. 15 MR application

5. Evaluation

A summary of the evaluation results is shown in Table 2. The 30 participants were asked to test the application system and make ten questionnaires of the SUS survey. This survey consists of 10 questions by classifying two parts, including positive questions and negative questions. In the part of positive questions, the first result is shown that 33.33% of participants strongly think that they would like to use this system frequently. Then, 30% of participants thought the system was easy to use. At the number of 20% of participants found the various function in this system was well integrated. The following result shows that 33.33% of participants would imagine that most people would learn to use this system very quickly. Then, 16.67% of participants felt very confident using the system.

On the other hand, the part of negative questions illustrated the first result is shown that 6.67% of participants strongly found the system unnecessarily complicated. At 23.33% of participants think that they would need a technical person's support to use this system. Then, the number of 13.33% of participants thought there was too much inconsistency in this system. Besides, 3.33% of participants found the system very cumbersome to use. Almost 36.67% of participants needed to learn many things before they could get going with this system.

TABLE II

Survey result (SD: strongly disagree, D: disagree, N: neutral, A: agree, 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 function in this system was will 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 get going with this system.	1	3	8	7	11

In the calculation, the SUS score, as shown in Table 3, there were 30 participants for testing the application and making the SUS survey by classifying three groups, which include (a) ten participants of group 1 were an expert engineer or machine owner. (b) Ten participants of group 2 were engineer experienced or other machine owners. (c) Ten participants of group 3 were new engineer or beginner. A green highlight is a user group with 68 scores for an acceptable user or okay in applying the application to the training program.

TABLE III

The calculation of 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

The SUS formula calculated the score of 30 participants. There were 7 participants of Group 1, 2 participants of Group 2, and 3 participants of Group 1 at having 68 points or more. Fig. 16 indicates the chart graphs of SUS calculation had many participants having less than 68 points. There were only 10 participants of 3 groups having 68 points or more. A score of 68 points illustrated these participants' acceptance of using the application. However, a lower SC ore of 68 illustrates the unaccepting of using the application from these participants. The majority of the participants were Group 1 at having 68 points or more, as Group 1 had more machine knowledge than Group 2 and Group 3. Therefore, Group 1 had several participants with 68 points or more, which is more than the other groups.

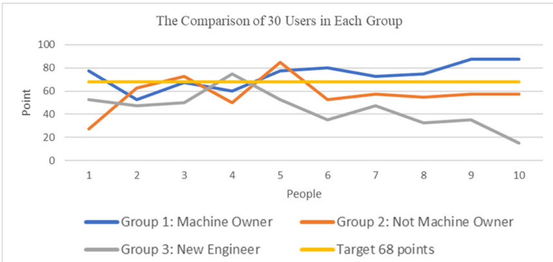

Fig. 16 The survey calculation of 10 questionnaires

Moreover, there were participants at having less than 68 points, as these participants unknown reality technology. Therefore, these participants avoided using new technology instead of older methods. However, the participants need to learn about reality technology first to know the new technology and the learning enhancement effectively.

In the next stage, the expert engineer of 10 participants performed maintenance of the machine and compared the maintenance duration of 10 participants with the current period of one month, as shown in Table 4.

TABLE IV

The current maintenance times

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

There are three failure cases of the machine selected from 21 failure cases for the case study. That machine is 22.7 hours of run time which is not operating 24 hours. As a result of the production line always has to be cleaning and stop working. Case A indicated the failure occurred two counts using a maintenance time of 7 minutes in 1 time and stopping operating the machine of 238.28 hours. Case B indicated the failure occurred one count using a maintenance time of 83 minutes in 1 time and stopping operating the machine of 475.93 hours. Case C indicated the failure occurred one count using a maintenance time of 29 minutes in 1 time and stopping operating the machine of 476.83 hours.

Nevertheless, these failures have the uncertain occasion to occur in the machine within the production line. Our work presented these failures case simulated in the laboratory for experimentation, which is the equivalent machine.

Each participant performed maintenance of the machine and counted a maintenance time in each case. The result illustrated that the average of case A is 6.49 minutes, case B is 75.39 minutes, and case C is 27.57 minutes, as shown in Table 5. The majority of maintenance time was reduced from the current information. We hypothesised that the Mean Time To Repair the machine reduced according to the maintenance time of 10 participants. Moreover, Mean Time Between Failure decreased as well.

TABLE V

The maintenance time of 10 participants in each case

Participants	Case A (min)	Case B (min)	Case C (min)
1	6.54	76.57	27.53
2	6.49	72.46	28.38
3	6.56	74.51	28.15
4	6.51	76.34	27.49
5	6.47	75.28	27.55
6	6.44	78.14	26.59
7	6.52	74.43	28.03
8	6.43	72.23	27.21
9	6.41	77.44	26.56
10	6.53	76.54	28.20
Avg	6.49	75.39	27.57

6. Conclusion

Both systems of the application have different advantages and disadvantages. 2D desktop systems are worth the investment of training for using several computers with much among people at the same time. Nevertheless, this system displays 3D visualization on the 2D screen monitor, which users cannot fully interact with. While the 3D fully immersive with HoloLens can allow users to interact with virtual objects anywhere fully. However, the HoloLens has a too high price and is not suitable for an investment of use with many people in training.

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

The instruction of reality technology is applied to the training program to teach users by one-point lessons (OPL), which users take a shorter time than the instruction with documents. The reality technology system is applied to industrial for the most effective, depending on people who know the machine and new technology. Moreover, the maintenance time reduced according to maintenance skills increased. The training of workers constantly will be improved maintenance skills. In the future, we will have added another 18 failure cases in the application for comprehensive of all cases.

7. Acknowledgement

This author would like to acknowledge Western Digital (Thailand) Co., Ltd. and graduate school, Bangkok University, for all the supports on this research.

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