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Innovative virtual reality solutions for technical training in heavy construction equipment repair and maintenance

Wirawan Istiono, Andhika Nugraha Wira Pratama
Department of Informatics, Faculty of Engineering and Informatics, Universitas Multimedia Nusantara, Tangerang, Indonesia

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ABSTRACT

The construction industry is significantly impacted by heavy construction equipment, including bulldozers, excavators, and vehicles. This equipment speeds up building, moves supplies, and builds infrastructure. Using heavy construction equipment correctly can boost productivity and shorten project timelines. Due to their complexity and scale, this equipment must be maintained and repaired. Poor maintenance and repair of heavy construction equipment can reduce performance, damage, and even cause accidents. Due to these problems, this study focuses on the design and development of a simulation training application to enhance the technical skills of workers in maintaining and repairing heavy construction equipment using virtual reality (VR) technology, the development of this application will be carried out using Unreal Engine 5 and thereafter tested and implemented at PT Menara Indonesia or M-Knows Consulting, Indonesia. At the end of this study, the design and development of a VR training simulation application for heavy equipment repair has been successfully completed. After testing the VR application and conducting user acceptance tests, it was concluded that the created VR application greatly assists M-Knows Consulting in training workers to perform maintenance and repair on heavy equipment, with a user acceptance rate of 84%.

Corresponding Author:

Wirawan Istiono
Department of Informatics, Faculty of Engineering and Informatics, Universitas Multimedia Nusantara
Jalan Scientia Boulevard Gading, Curug Sangereng, Serpong, Tangerang Regency, Indonesia
Email: wirawan.istiono@umn.ac.id

1. INTRODUCTION

Virtual reality (VR) technology first appeared in the 1960s, when scientist Ivan Sutherland developed a system called "The Sword of Damocles" [1]. This system comprises a head-mounted headset with an image display that is capable of detecting and responding to the user's head motions [2]. Despite its primitiveness and high cost, this technology serves as a foundation for the future development of VR [3], [4]. In the present era, VR technology serves not only as a means of entertainment but also as a valuable tool for training and education [5]–[8]. It finds applications in various domains, including medical practice simulations, driving simulations, virtual field trips, and other training [9], [10] or simulation activities [11]–[14].

M-Knows Consulting is a company operating in the field of management consultants which has served various companies with satisfactory work quality by managing public training and in-house training programs, according to their expertise and a consulting approach based on applicative, contemporary, high impact, and fun and motivational. M-Knows Consulting has provided services to numerous organizations in specific industries, including Hino, Astra International, and Mitsubishi in the automotive sector [15].

Heavy construction equipment is used to facilitate and expedite the construction process, such as building construction, road construction, bridge construction, port construction, and so on [16], [17]. As the

development progresses, heavy equipment models are becoming more sophisticated, complex, and modern, resulting in longer repair times. M-Knows Consulting also states that the utilization of heavy machinery in construction necessitates meticulous and high-quality maintenance. Apart from that, there are various types of maintenance and repairs on heavy construction equipment that require an expert who has special abilities [18]. To be able to have expertise in maintaining and repairing heavy equipment, of course a person must learn the skills, but learning to maintain and repairing heavy equipment requires a lot of money and time, because heavy equipment is not widely produced and the quantity is very limited, if an error occurs in the learning process it will bring a lot of losses, such as damage to heavy equipment, decreased performance of heavy equipment, and can also possibly cause dangerous accidents for workers [19]–[21]. Additionally, there are complications, such as the need to disassemble heavy equipment in order to conduct machine repair training. Consequently, the heavy equipment will be inoperable throughout the training and there is a risk of errors occurring that could negatively affect the equipment or the personnel who will operate it. Therefore, in order to reduce and eliminate the risk of incurred expenses and liabilities, the present study utilized and approved a simulation-based learning application to develop a VR-based construction scheduler [22] that would record and deliver technical knowledge. This research also aims to measure the level of user acceptance of the VR application simulating maintenance and repair of heavy equipment and it is hoped that the use of the VR simulation application can produce new experts in maintenance and repair of heavy equipment.

2. METHOD

Problem identification was the initial phase of the research conducted at M-Knows Consulting, Indonesia. During this phase, meetings were conducted with the head of M-Knows Consulting to ascertain the challenges and requirements of automotive companies that were collaborating with the organization. Following the interviews, issues were identified concerning the potential hazards associated with repairing heavy equipment. These include financial and time losses resulting from improper handling of heavy machinery, as well as potential delays in construction projects due to the unavailability of suitable heavy equipment. This research involved collaboration with the learning design and competency assesor (LECA) branch of M-Knows Consulting, which proved valuable for studying heavy equipment vehicles comprehensively. The findings will be utilized to develop simulation programs for training and repairing heavy equipment.

The second stage of this research is planning, where at this stage, a heavy equipment maintenance and repair simulation project design proposal will be made, which will be implemented by the M-Knows Consulting company. In the next step, there will be a discussion regarding the work plan for each week (timeline), features in the application, the user interface in the application, and the software and hardware requirements needed to develop a heavy equipment repair VR training simulation application. Then a discussion will be held with the LECA division regarding the syllabus that will be used for learning simulations on heavy equipment repair and maintenance, as well as to determine standard operational procedures and also determine performance assessments carried out on applications. After discussions, a proposal for software and hardware requirements will be made, where the proposal will contain equipment requirements, budget and an effective place for VR operations to the head of M-Knows Consulting. Once the proposal has been approved, development of the heavy equipment VR training and repair application will begin using Unreal Engine 5.

The work on the heavy equipment repair and maintenance training simulation application will last for approximately ten weeks. This project was developed using Unreal Engine 5 software and the C++ language. Unreal software was chosen because it has features that make it easier for developers to carry out programming in blueprint form [23], [24]. This equipment maintenance and repair training is designed to reduce costs, time, and the risk of damage that sometimes occurs when heavy equipment repairs are carried out, as well as the potential for accidents that occur when working with larger equipment, and the potential for delays in a construction project. if a piece of heavy equipment is damaged and requires immediate repair.

The heavy equipment repair and maintenance training simulation application will be made according to the stages determined by the LECA division. Starting from the user entering their full name first to enter the application, Then the user can choose to view the standard operating procedures (SOP) provisions for heavy equipment repair and maintenance assessment, or the user can directly carry out the simulation. When using the application, users will carry out repair or maintenance training three times. After the training is complete, the application will calculate the score from the results of the training. Users who get a low or below specified score will be returned to the assessment SOP menu to review the score criteria. Meanwhile, users who get a sufficient score or more will be immediately directed to the next simulation

training. If users achieve a minimum of two points from the three completed training courses, they will be considered to have passed the training. Figure 1 shows the flowchart of these application processes.

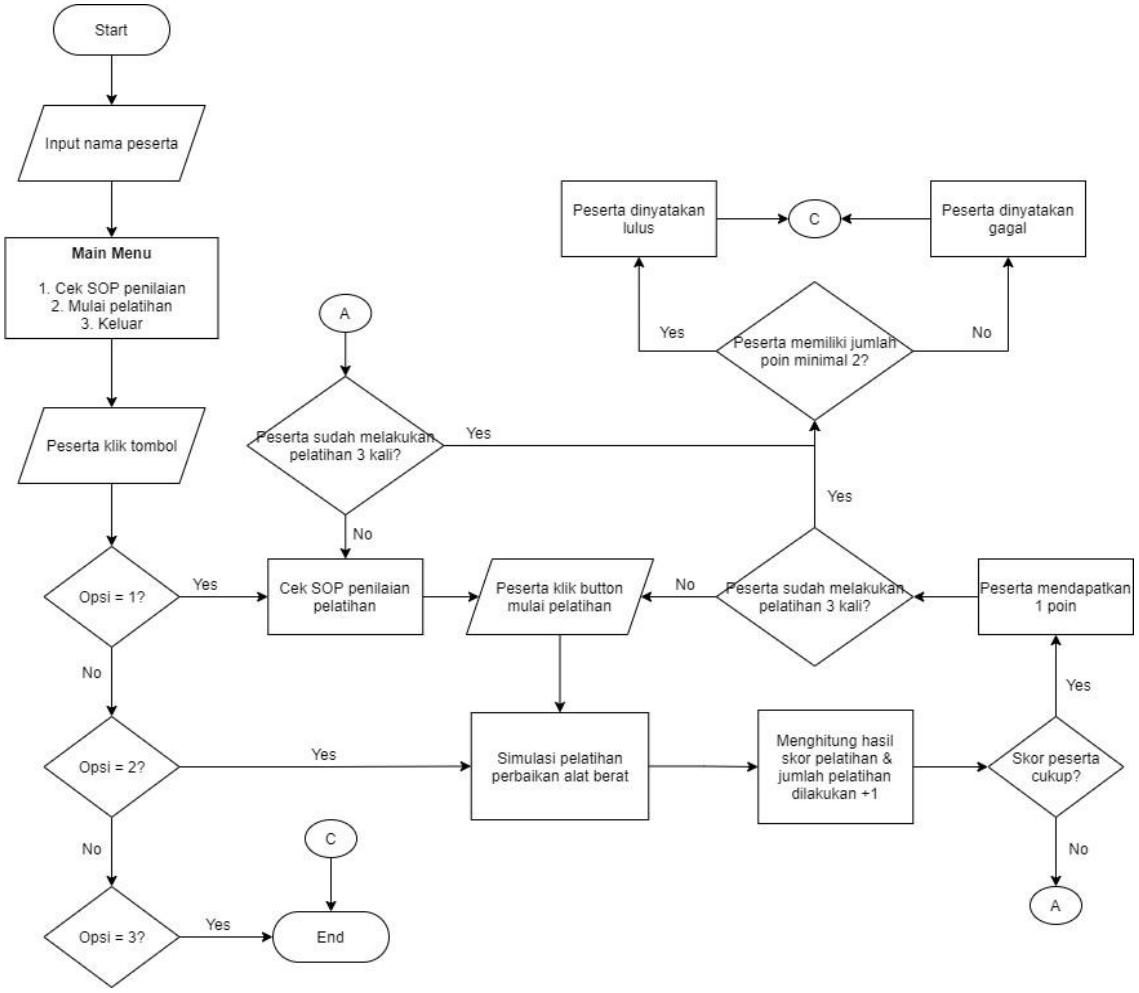
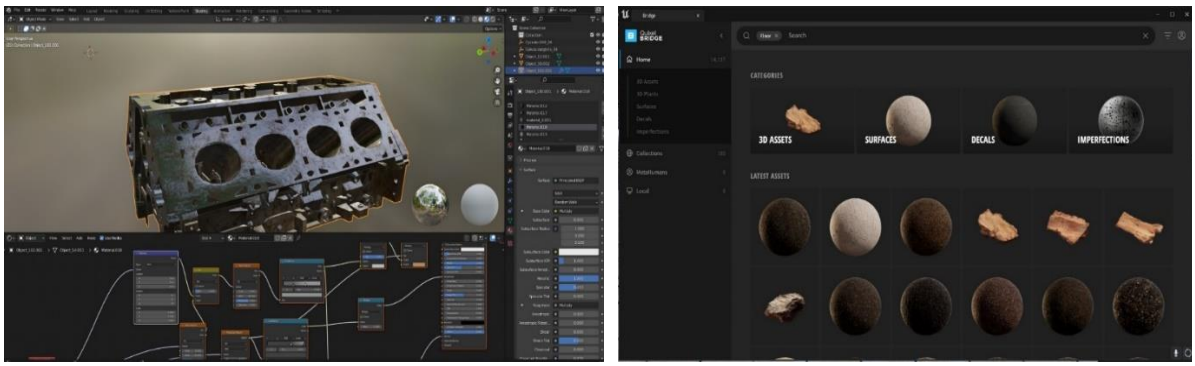


Figure 1. Flowchart of heavy equipment repair and maintenance training simulation application

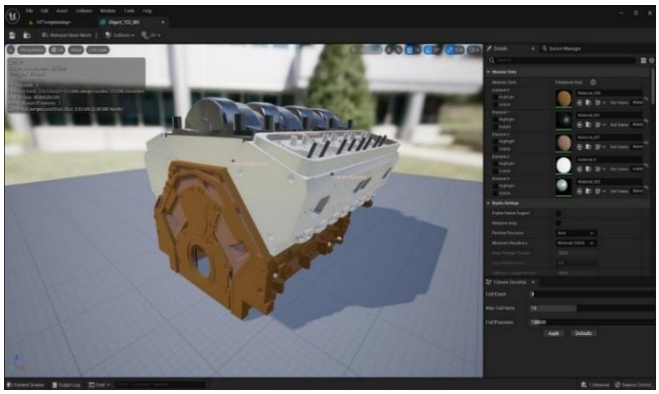
AR/VR/Open XR division and researchers will collaborate with the graphic design and video animation (DGAV) division in creating 3D models or 3D assets used in this VR-based training and improvement application. Most of the 3D assets were created using Blender 3D software and a small part was downloaded for free from the official Unreal Engine 5 asset store, namely Quixel Bridge [25], [26]. Engine asset creation using Quixel Bridge can be seen in Figure 2, where the rendering of the engine block part assets in Blender 3D can be seen in Figure 2(a). Meanwhile, Figure 2(b) shows the Unreal Engine 5 feature for searching for assets sourced from the official asset store called Quixel Bridge. Meanwhile, Figure 2(c) displays the results of the engine assets when they have been entered into the Unreal Engine worksheet which will then be encoded.

AR/VR/Open XR division and researchers will be responsible for programming the features of the heavy equipment simulation application. The development of this heavy equipment training and maintenance application in VR was accomplished through the utilisation of the blueprint's method. Figure 3 displays the visual representation of the blueprints in Unreal Engine, as well as the low-code blueprint held in the virtual hand.

Figure 4 shows programming interactions with the blueprint feature where Figure 4(a) is a schematic representation that serves to control the interaction between the virtual hand and 3D elements. This blueprint includes functions that allow the virtual hand to grasp or make contact with every component of the machine. Figure 4(b) displays a schematic of machine assets that are configured to connect with other machine components. The socket capability is utilised to enable machine assets to connect with other machines.



(a) (b)



(c)

Figure 2. Engine asset creation using Quixel Bridge where (a) a sample of asset creation using Blender software, (b) searching assets and material from Quixel Bridge to combine with the engine, and (c) the rendered machine asset result that is ready to be inputted with code

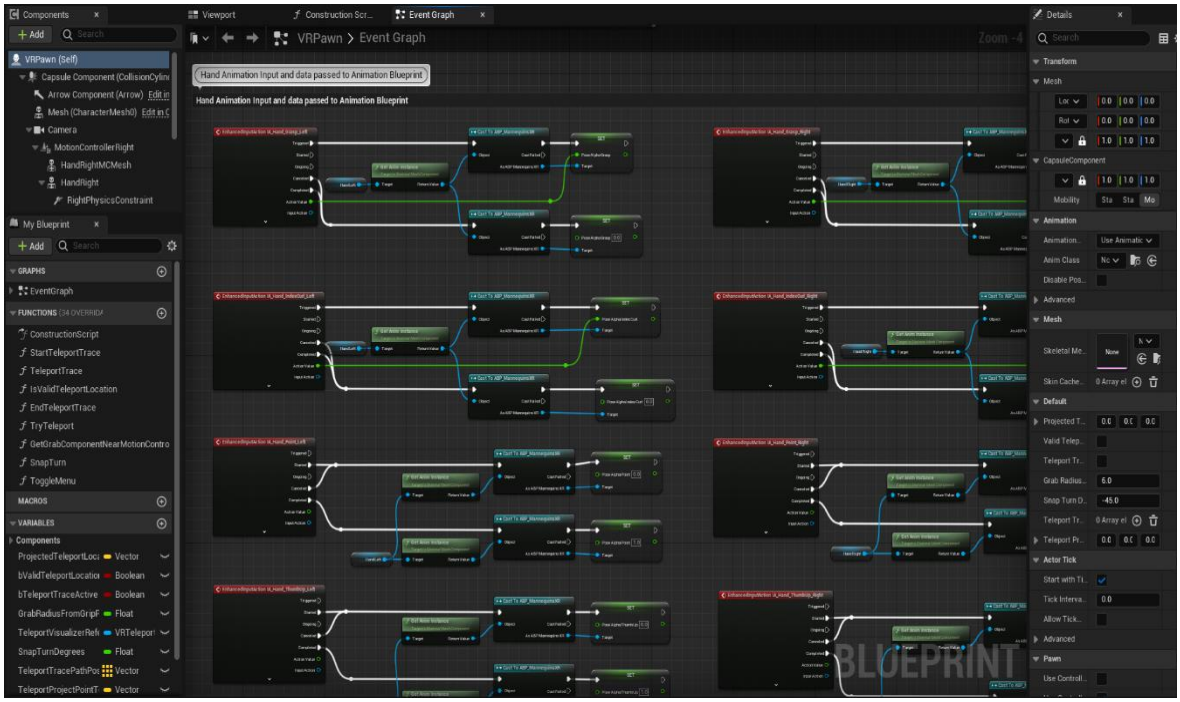
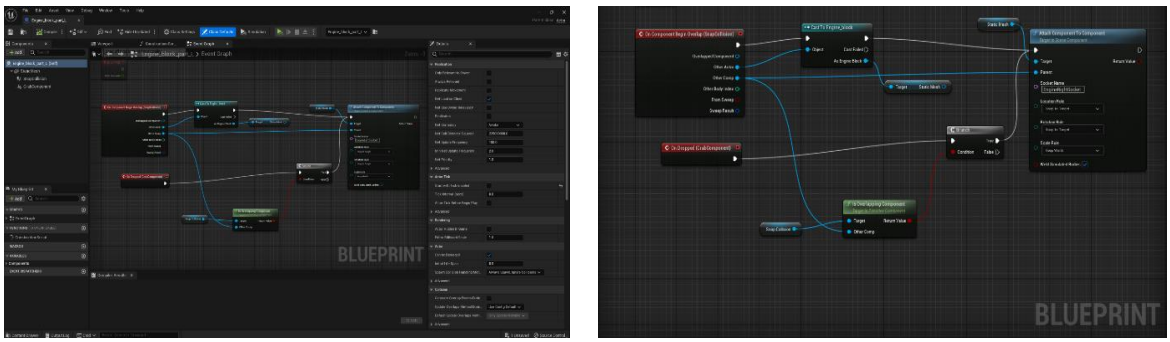


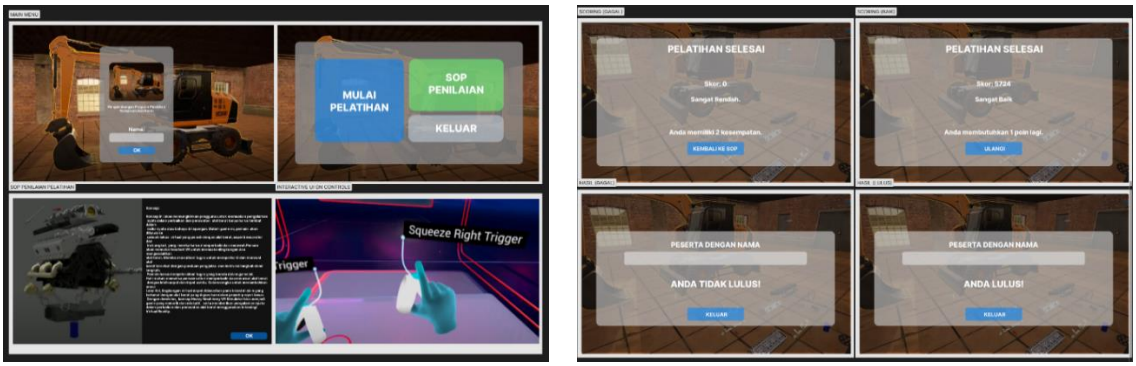
Figure 3. Blueprint on a virtual hand that is moved using a controller



(a) (b)

Figure 4. Programming interactions with the blueprint feature, where (a) is the blueprint usage view on a virtual hand moved using a controller and (b) is the view of blueprint usage to handle interaction between user and object

The next stage is to integrate into the application to facilitate interaction between users and the application. Figure 5 shows wireframe user interface for heavy equipment repair training simulation application where Figure 5(a) shows the application user interface wireframe design, where in the user interface, the user will be required to enter a name which will later be useful for storing user data and storing the scores that the user gets. Apart from that, the main display also provides information about the heavy equipment and also information on how to control it or how to use the VR application that has been created. Meanwhile, Figure 5(b) shows the design of the user interface that will be used to display the results of the training after the user has finished training using the application that was built.

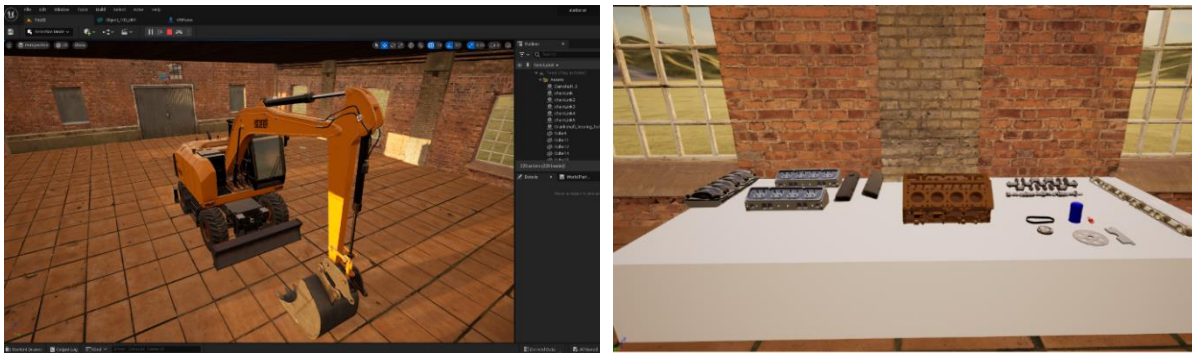


(a) (b)

Figure 5. Wireframe user interface for heavy equipment repair training simulation application, where (a) is the home page's user interface wireframe, the heavy equipment's information wireframe, and the application's usage instructions wireframe, and (b) is the wireframe that will show the results obtained by training participants after completing the training

3. RESULTS AND DISCUSSION

The The results of designing and creating heavy equipment repair and maintenance training simulation applications using VR technology can be seen in Figure 6. Where in Figure 6(a) shows the atmosphere of a garage with heavy equipment for carrying out training on repair and maintenance of heavy equipment, where in the garage room there is built-in lighting from Unreal Engine 5 to provide a more realistic lighting effect. The garage space is also provided with floor collisions, which function so that users can walk, apart from that, this application also provides wall collisions which function to limit the user's movement space, so that users cannot move out of that place. Apart from that, in the same room, as shown in Figure 6(b), tools or devices have also been provided that can be used to assemble or repair heavy equipment. The asset or machine part device shown in Figure 6(b) has been programmed using a blueprint so that it can be interacted with by the user, apart from that, the asset or device has also been programmed so that it can be attached to one another.



(a) (b)

Figure 6. Implementation results of the heavy equipment repair training simulation application, where (a) is garage space with heavy equipment for repair training and (b) is a machine assets that can be used for machine assembly training

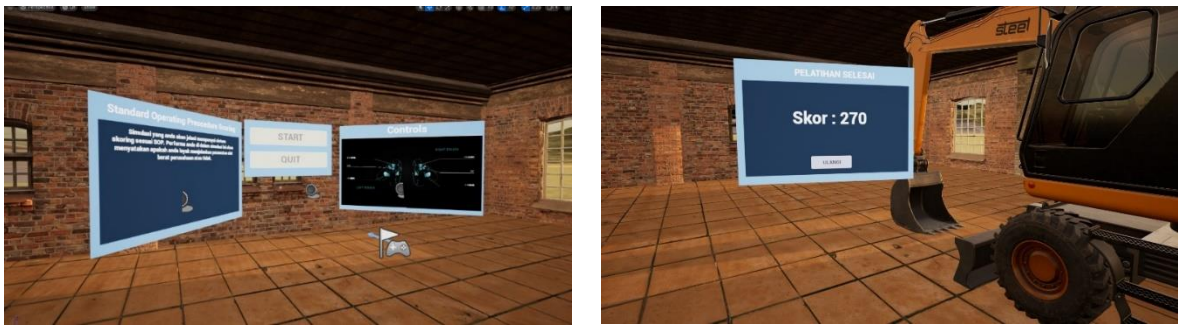
After the application has been designed and built, the next stage is to test it on users, where the users who carry out the test are employees of M-Knows Consulting who have experience in maintaining or repairing heavy equipment. Figures 7 show a direct trial of the application by the user in operating the heavy equipment maintenance and repair VR application using the Oculus Quest 2 device. Where Figure 7(a) shows user view performing movements in the virtual training world and Figure 7(b) shows the user view interacting with the machine. In this trial the controller from the Oculust Quest has been programmed so that the user can walk and interact with machine assets. existing in applications that have been built.

(a) (b)

Figure 7. Showing user trials for the heavy equipment repair training simulation application, where (a) is the user view performing movements in the virtual training world and (b) is the user view interacting with the machine

When the user starts using the heavy equipment maintenance and repair VR application, the user will be presented with the main menu shown in Figure 8, where the main menu can be controlled by the user using a VR controller. The position of the user interface in the application has also been shaped like interacting with the screen in a virtual space. Apart from that, in this menu, users can see the SOP for assessment that must be fulfilled by players in order to get a good score and after the user understands the SOP, the user can start the improvement training simulation.

After the user has finished carrying out maintenance or repairs using the VR application that has been built, the user will get a score indicating the user's accuracy in carrying out maintenance or repairs on heavy equipment as shown in Figure 8(a). Meanwhile, Figure 8(b) displays the scoring menu when user have finished simulating heavy equipment repair or maintenance training. After the user has tested the application, a user satisfaction test is also carried out using the user acceptance test (UAT), where the number of respondents is 4 people, who are employees of M-Knows Consulting. Table 1 shows a list of questions and user satisfaction test scores.



(a) (b)

Figure 8. Heavy equipment training user interface display that can be used by users, where (a) is the main menu display that can be used by users to view SOPs and how to use the application and (b) is a display of the score menu before and after completing the training

Table 1. User acceptance test result

No	Question	Grade					Percentage				
		Very agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Very disagree (1)	Very agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Very disagree (1)
1	The VR application simulating maintenance and repair of heavy equipment has an attractive user interface	3	1	0	0	0	75%	25%	0%	0%	0%
2	By using the VR application simulating maintenance and repair of heavy equipment, it helps me understand the provisions or SOPs for carrying out maintenance and repair of heavy equipment	0	2	2	0	0	0%	50%	50%	0%	0%
3	By using the VR application simulating maintenance and repair of heavy equipment, it helps me understand the heavy equipment maintenance process	3	1	0	0	0	75%	25%	0%	0%	0%
4	By using the VR application simulating maintenance and repair of heavy equipment, it helps me understand the process and how to carry out heavy equipment repairs	2	2	0	0	0	50%	50%	0%	0%	0%
5	The VR application simulating maintenance and repair of heavy equipment is easy to use because it has good controls	0	2	2	0	0	0%	50%	50%	0%	0%

Based on the results of the user satisfaction test table which can be seen in Table 1, after calculations were carried out using a Likert scale, it was found that the final result of user satisfaction was 84%, which can be concluded that users strongly agree that this simulation application is very useful. However, based on the results of user acceptance, it can also be seen that many improvements need to be made in the control section and also clarify the provisions and SOPs in the application, because there are poor values at this point.

4. CONCLUSION

Based on the results of the user acceptance test and direct interviews by the M-Knows Consulting supervisor, it was stated that the design and function of the heavy equipment repair simulation application have been designed and built according to the company's needs. In addition, it can be concluded that this VR-based heavy equipment repair and maintenance training simulation application can be used by the M-Knows Consulting company to conduct heavy equipment maintenance and repair training. After conducting a user acceptance trial using the user acceptance test, the user acceptance score was 84%. This shows that users strongly agree that this VR simulation application is very useful and functions well, but there are still suggestions for improvement from users, namely clarifying the provisions and SOPs contained in the application. In addition, it is also recommended to improve application controls to make it easier for users to use. Based on the deficiencies found, it is recommended to conduct further discussions with the company regarding the SOP that must be attached and also to increase control over the VR applications that have been created.

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BIOGRAPHIES OF AUTHORS

Wirawan Istiono received his masters of Computer Science degree from Budi Luhur University, Indonesia, in 2018, focusing on the software engineering field. He is currently a lecturer and researcher at Universitas Multimedia Nusantara and also serves as the head coordinator of the Game Development Laboratory. He has supervised and co-supervised more than 10 undergraduate students. He has authored or coauthored more than 70 publications, with 6 H-index and more than 220 citations. His research interests include requirements engineering in software application development, computer engineering, information system, and human computer interaction. He can be contacted at email: wirawan.istiono@umn.ac.id.

Andhika Nugraha Wira Pratama is a student majoring in informatics at the Faculty of Engineering and Informatics, Universitas Multimedia Nusantara, in Tangerang, Indonesia. He currently works as a programmer for XR, VR, and AR projects at Kampus Gratis, Indonesia, where he previously interned for this position. Prior to his current role, he gained experience through an internship as a web developer and analyst intern at Universitas Multimedia Nusantara. He can be contacted at email: andhika.nugraha@student.umn.ac.id.