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Implementation of Augmented Reality (AR) for Training CNC TU-3A Milling Machine Operators

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***Abstract* - The development of technology and the demands of Industry 4.0 in the present era are causing transformations in training and learning methods. These include the practice of production processes in training for computer numerical control (CNC) machine operator TU-3A. Despite the significant contribution, time constraints often hinder the effectiveness of training activities during practical sessions. Therefore, this research aimed to develop an Augmented Reality (AR) application to support practical training in production processes. The application was designed to provide instructions or basic training in operating the CNC machine TU-3A using the Unity platform and Vuforia Engine with the ground plane method. The design enabled the visualization of 3D model of the CNC machine TU-3A and data were obtained using quantitative methods. The results showed that the System Usability Scale (SUS) testing on AR CNC application, conducted through a questionnaire with 40 respondents, obtained a final SUS score of 71.13. This suggested that the AR CNC application was suitable for implementation as a supplementary medium for training/learning the fundamentals of operating the CNC machine TU-3A.**

Keywords: Augmented Reality, Production Process, Unity, Vuforia Engine, Black Box Testing, System Usability Scale.

I. INTRODUCTION

Augmented Reality (AR) is a technology widely recognized as a relevant topic of contemporary discussion. This technology is capable of integrating the virtual-world with the real-world in varying proportions, enabling a level of immersion that any other virtual equipment cannot achieve[1]. In AR, users can view the surrounding natural world while adding virtual objects generated by system[2]. This technology has been extensively developed for various purposes, such as surgery, hazardous environment monitoring, engineering, and training machine operators, including computer numerical control (CNC). When implemented in the training process of industrial operators, better communication between machines and humans can be achieved [3]. This suggests AR can accelerate the reconfiguration of production lines, support operator tasks, implement virtual assembly parts training, manage warehouse efficiency, enhance advanced diagnostics connected with modules, and minimize risks in the environment. Furthermore, companies can indirectly reduce training time and costs, such as downtime and assembly, along with the percentage of errors in terms of quality [4].

The development of AR technology is supported by the evolving phases of the industry, known as the Fourth Industrial Revolution, or Industry 4.0 [5]. In this industrial phase, automation, data exchange, robotics, and artificial intelligence become the main topics [6]. Industry 4.0 addresses the challenges of digitalization by including humans and introducing the 3I aspects (Intellect, Interaction, and Interface) for factories to enhance the adoption of smart technology toward the vision of smart manufacturing. According to the National Institute of Standards and Technology (NIST), smart manufacturing is a fully integrated, collaborative manufacturing system that adapts to demands in the supply network and customer needs in real-time[7].

The concept of "Operator 4.0" which refers to the modernization of workforce skills to meet industrial demands, shows the need for innovative training methods[8], [9]. Conventional methods of operator training are limited by time and resources. However, with the occurrence of technologies such as AR, training methods can be significantly transformed to enhance efficiency and effectiveness [4].

The development of AR application as a learning medium represents one of the latest innovations in the educational world[2]. Based on the description, this research aimed to implement an AR application as a learning medium, specifically for training/learning about the basics of operating the CNC TU-3A machine in the production process. To implement the application, several software tools were used, including Solidworks for modeling the 3D CNC TU-3A machine as well as Unity 3D and Vuforia Engine for integrating the system with the 3D model.

In this research, black box and usability testing through the System Usability Scale (SUS) method were applied to validate AR application. Black box is a functional testing method that designs test cases based on information and specification [10]. The SUS testing method was developed or initiated by John Brooke in 1986, which was recognized as fundamental for evaluating products and systems [11].

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II. METHODOLOGY

This research was carried out following several phases. The first phase included conducting a literature review on AR technology, focusing on exploring the principles of AR technology and implementation in the educational context.

The second phase included gathering data such as specifications and dimensions of CNC machine, to support the development of AR model. The third phase was the conceptual design of AR, where concepts were developed regarding the application to support training/learning on the basics of operating the CNC TU-3A machine in production process. After the concept was determined, the process was followed by developing AR application.

The fourth phase included testing the developed AR application to validate performance. In the fifth phase, analysis and discussion were conducted to determine the effectiveness of AR in assisting students/operators in learning about the CNC TU-3A machine.

2.1 Concept Design of AR Application Workflow

The first phase in developing AR application is to create a design/concept of the User Interface flow. This scenario shows the workflow of the developed application system. Figure 1 shows the workflow diagram of the AR application system for CNC TU-3A.

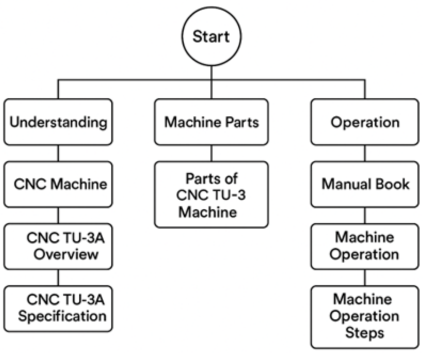

Figure 1: Workflow of AR Application System

2.2 3D Model Design of CNC TU-3A Machine

The creation of the 3D model of the CNC TU-3A machine serves as a visualization to be shown in the AR application, allowing users to easily observe the CNC machine through a 3D interface without direct physical access. This model was developed using Solidworks software and subsequently exported in .3dxml file format to enable importation into CAD Exchanger Lab. The CAD Exchanger software played an essential role in converting the file format to.fbx, facilitating integration of the 3D model into Unity 3D. Figure 2 shows the 3D model of the CNC machine TU-3A created with Solidworks.

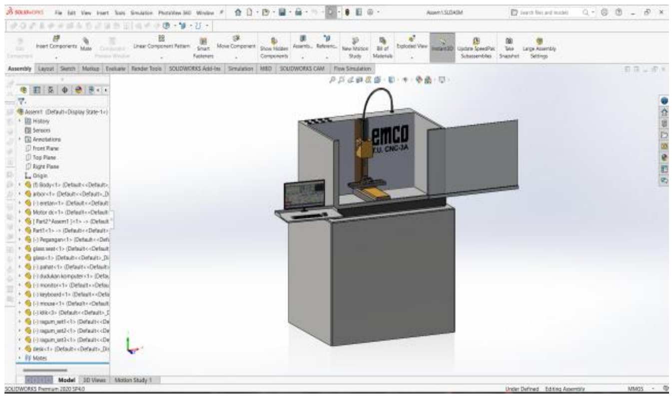

Figure 2: 3D Model of CNC TU-3A Machine

2.3 Development of Augmented Reality Application

The development of AR application focuses on its implementation as a supporting tool for training and learning the basics of operating the CNC TU-3A machine in production process practicums. This application offers a new experience with engaging 3D model visualizations. Figure 3 shows the steps included in developing the AR application for CNC TU-3A using Unity software and the Vuforia Engine Software Development Kit (SDK). Specifically, the SDK serves as an additional module to aid Unity in developing AR application, with several features such as efficient identification, rendering, and tracking [12].

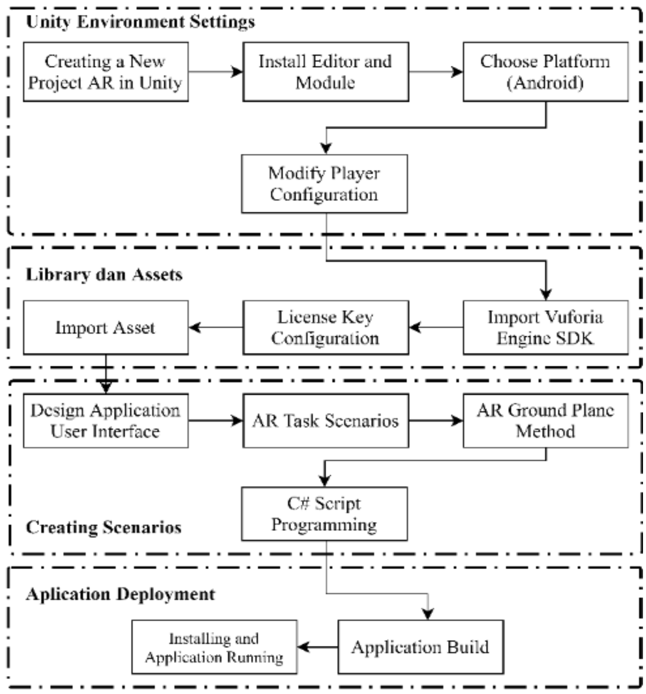

Figure 3: Workflow of AR CNC TU-3A Application Development

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2.4 Validation of Augmented Reality Application

The AR application for operating CNC machines was tested to validate performance using black box and usability testing. Black box testing focused on the functional aspects of the application [10], [13].

Usability testing is a method applied to evaluate the performance of a system in a product. The method used in usability testing is the System Usability Scale (SUS). This assessment method uses a questionnaire with 10 statements rated on a 5-point in scale, ranging from strongly disagree (1) to strongly agree (5). The calculated results provide a comprehensive and subjective assessment of usability[14]. Usability testing consists of 5 components, namely learnability, efficiency, memorability, errors, and satisfaction. The formula for calculating the SUS score is as follows:

$$SUS = \{[(Q_1 - 1) + (Q_3 - 1) + (Q_5 - 1) + (Q_7 - 1) + (Q_9 - 1)] + [(5 - Q_2) + (5 - Q_4) + (5 - Q_6) + (5 - Q_8) + (5 - Q_{10})]\} \times 2{,}5 \quad (1)$$

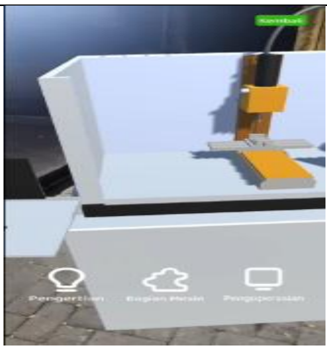
$$SUS = \{[(Q_1 + Q_3 + Q_5 + Q_7 + Q_9) - 5] + [25 - (Q_2 + Q_4 + Q_6 + Q_8 + Q_{10})]\} \times 2{,}5 \quad (2)$$

III. RESULTS AND DISCUSSION

3.1 Black Box Testing of AR CNC Application

The results are obtained from predefined scenarios regarding black box testing. When the test results match the predetermined outcomes, the values are considered valid. The black box testing results for the AR CNC TU-3A applications are presented in Table 1.

Table 1: Black Box Testing Result of AR CNC Application

No	Test Case	Scenario and Test Results			Validation Status
		Display	Testing Scenario	The Expected Outcomes	
1	Menu About		Navigate to the "about" scene containing explanations about the developed application	An exposition explaining the AR CNC application was created	Succeed
2	Menu "*Start*"		Navigate to the "AR" scene that activates the camera to scan the ground plane and display the 3D model of the CNC TU-3A machine	Displaying the 3D model of the CNC TU-3A machine and three functional buttons: Overview, Operating, and Machine Parts	Succeed

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3	Menu *"Instruction"*		Transitioning to the "instructions" scene containing guidance on how to use the application	Displaying instructions on how to use the application	Succeed
4	Menu *"Overview"*		Transition to the "overview" scene displaying 3 functional button: CNC Machine, CNC TU-3A, and CNC TU-3A Specifications	Displaying 3 functional button: CNC Machine, CNC TU-3A, and CNC TU-3A Specifications	Succeed
5	Button "CNC machine"		Switch to the "CNC machine" scene displaying a general explanation of the CNC machine	Displaying a general explanation of the CNC machine	Succeed
6	Button CNC TU-3A		Switch to the "CNC TU-3A machine" scene displaying a general explanation of the CNC TU-3A machine	Displaying a general explanation of the CNC TU-3A machine	Succeed
7	Button Specifications TU-3A		Switch to the "specification" scene displaying the specifications of CNC TU-3A machine	Displaying the specification of CNC TU-3A machine	Succeed

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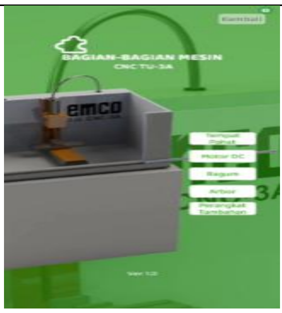
8	Menu Machine part		Switch to the "machine parts" scene displaying functional buttons, such as Arbor button, vice button, tool post button, Motor DC button	Displaying functional buttons, such as Arbor button, Vice button, Tool post button, Motor DC button	Succeed
9	Button Arbor		Displaying Arbor explanation panel	Provides an explanation of the Arbor	Succeed
10	Button Tool holder		Displaying tool holder explanation panel	Provides an explanation of the tool holder	Succeed
11	Button vise		Displaying vise explanation panel	Provides an explanation of the vise	Succeed
12	Button Motor DC		Displaying the explanation panel for DC motor	Providing an explanation about the DC motor	Succeed

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13	Button additional devices		Displaying the explanation panel for additional devices	Providing an explanation about additional devices	Succeed
14	Menu Operation		Switch to the “operation” scene and display several function buttons, namely “manual book” and “Checklist” buttons	Display the function buttons for the “manual book” and “checklist”	Succeed
15	Button Manual Book		Moving to the “manual book” scene, which contains detailed explanations about the operation of the CNC TU-3A machine	Provides comprehensive instructions on how to operate the CNC TU-3A machine	Succeed
16	Button Checklist		Moving to the “checklist” scene, which contains the items or steps that must be completed when operating the CNC TU-3A machine	Displaying the sequences of the steps required to operate the CNC TU-3A machine, accompanied by checklist to assist with the verification	Succeed

The black box testing result in Table 1 shows that AR application CNC TU-3A functions as expected, as indicated by the 3D model. However, the ground plane feature in Vuforia Engine has limitations on some smartphone models.

3.2 System Usability Scale Testing of AR CNC Application

The SUS testing included a questionnaire administered to 40 respondents, consisting of 5 laboratory assistants of CNC and mechanical engineering students (currently undergoing production process practicums). The questionnaire comprised 5 biometric questions and 10 statements for SUS assessment. Biometric questions were used to gauge respondents' familiarity with AR implementation. Table 2 shows the arrangement of biometric questions in the questionnaire.

Table 2: Biometric Questions

Code	Question
Q1	Are you familiar with the CNC TU-3A machine?
Q2	Have you ever operated the CNC TU-3A machine?
Q3	Do you find it challenging to understand the operation of the CNC TU-3A machine?
Q4	Are familiar with the Fourth Industrial

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	Revolution?
Q5	Are you familiar with Augmented Reality application systems?

The graph in Figure 4 shows the result of the biometric identification form filled out by the CNC Laboratory assistants group.

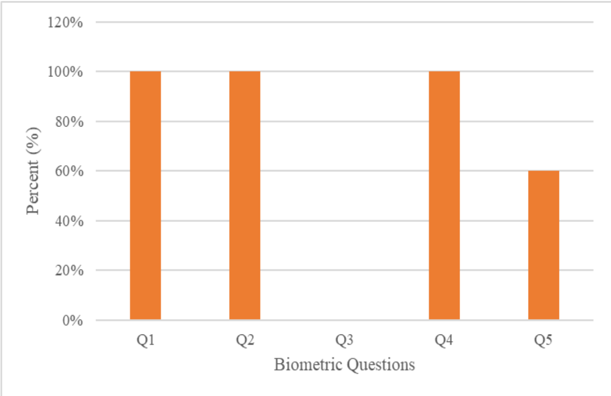

Figure 1: Graph of Biometric Identification of CNC Laboratory Assistants Respondents

Based on the graph shown in Figure 4, laboratory assistants do not encounter difficulty understanding the operation of the CNC TU-3A machine. The survey results demonstrate that participants exhibit a **high level of familiarity and operational competence** with the CNC TU-3A machine, as evidenced by the **100% positive response rates** for questions on machine familiarity, operational experience, and awareness of the Fourth Industrial Revolution. Conversely, familiarity with **Augmented Reality (AR) application systems** was markedly lower at **60%,** indicating a **knowledge gap** in emerging digital technologies. The absence of a significant positive response for the question regarding operational challenges suggests that the CNC TU-3A machine is generally considered **user-friendly and easily understood** by the participants.

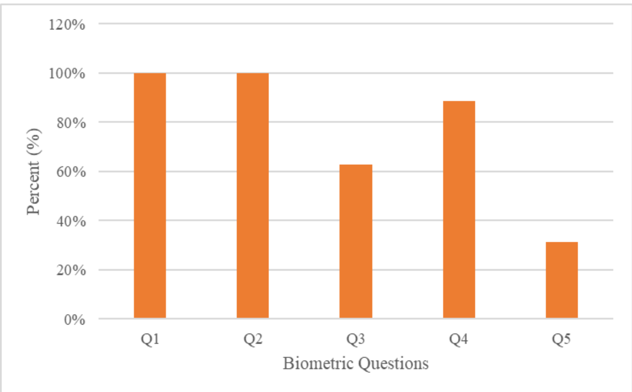

Figure 2: Graph of Biometric Identification of Fourth-semester Student Respondents

Based on the graph shown in Figure 5, all respondents have operated the CNC TU-3A machine before. However, approximately 60% of respondents still face difficulties in understanding the operation of the CNC TU-3A machine. This suggests that respondents' knowledge regarding AR application still needs to improve, as only 30% have understanding of the system. Table 3 shows the 10 statements used to asses SUS, comprising 5 negatively and 5 positively-toned.

Table 2: System Usability System Testing Statements

Code	Statement
Q1	I would love to use this application
Q2	I need to find the AR application system to be simpler to use
Q3	I think this application system is easy to use
Q4	I need assistance from laboratory assistants to use this application
Q5	I think various functions and data displays in this application are well-integrated
Q6	There are too many functions and inconsistent displays in application system
Q7	I believe other users will quickly understand how to use this application to operate the CNC TU-3A machine
Q8	I think the system in this application is not practical to use
Q9	I am confident in using this application
Q10	I need to learn a lot before I can start using this application

The range of scores used for the SUS assessments is shown in Table 4.

Table 3: Range of SUS Testing Score

No	Answer	Score
1	Strongly Disagree	1
2	Disagree	2
3	Neutral	3
4	Agree	4
5	Strongly Agree	5

Table 5 shows the calculation results of SUS scores filled out by all respondents.

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Table 4: SUS scores

Respondents	Score										SUS Score
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
1	5	3	4	2	5	2	4	2	4	2	77,5
2	5	3	4	2	5	3	4	2	4	2	75
3	4	2	5	2	5	1	5	1	4	2	87,5
4	3	3	4	3	4	3	5	3	3	3	60
5	5	3	3	3	5	3	3	2	4	3	65
6	3	3	3	3	3	3	3	3	3	3	50
7	3	3	4	2	3	3	4	2	3	2	62,5
8	4	2	4	3	4	2	5	2	3	3	70
9	3	2	4	3	3	2	4	3	3	2	62,5
10	4	3	4	3	5	3	3	2	4	3	65
11	5	2	5	1	5	1	5	1	5	1	97,5
12	3	2	4	3	4	2	4	2	4	3	67,5
13	4	3	4	3	4	2	4	1	4	2	72,5
14	4	2	4	2	4	3	4	3	3	3	65
15	4	2	4	2	4	1	4	2	4	3	75
16	4	3	5	3	5	2	5	1	5	3	80
17	4	2	3	3	4	2	5	2	4	4	67,5
18	4	3	3	3	4	3	5	2	4	4	62,5
19	4	2	4	2	4	3	4	2	4	3	70
20	5	3	4	3	5	1	5	1	5	2	85
21	3	3	3	2	3	2	3	3	3	3	55
22	4	2	4	2	4	2	4	2	3	3	70
23	4	2	3	3	4	2	3	2	4	2	67,5
24	4	3	4	3	4	2	5	2	4	2	72,5
25	3	3	3	2	4	3	4	3	3	3	57,5
26	4	3	3	2	4	3	3	2	3	1	65
27	5	2	4	3	3	2	4	1	4	4	70
28	4	2	4	2	4	1	5	1	5	4	80
29	4	2	5	1	4	2	5	2	4	2	82,5
30	3	3	3	3	3	3	3	3	3	4	47,5
31	5	3	4	2	4	3	5	2	4	3	72,5
32	5	1	5	1	5	1	5	1	5	3	95
33	4	2	4	3	5	2	4	2	4	3	72,5
34	4	2	4	2	4	2	4	2	4	4	70
35	4	3	3	2	3	3	4	2	3	3	60
36	5	3	5	3	5	2	5	2	4	3	77,5
37	4	2	3	2	4	2	4	2	3	3	67,5
38	5	2	4	2	5	2	4	1	5	3	82,5
39	5	2	4	2	4	2	5	2	4	2	80
40	4	2	4	2	5	2	5	1	4	2	82,5
Total											2845
Average SUS Score											**71,13**

As shown in Table 5, the calculation results of SUS score indicate that the average value across all respondents is 71.13. The formula used for calculating the SUS score is expressed below:

$$\overline{x} = \frac{\sum x}{n}s$$

$$\overline{x} = \frac{2845}{40} = 71.125\ (71.13)$$

Note:

$\overline{x}$ = Average value

$\sum x$ = Total SUS value

n = Number of respondents

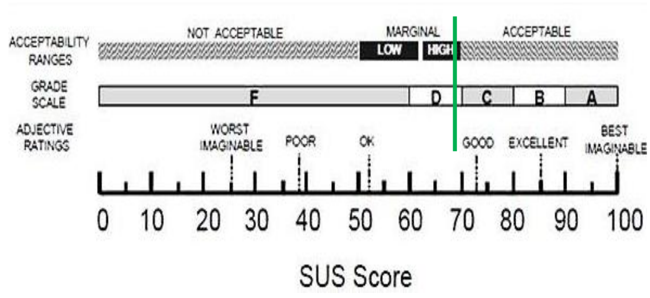

Figure 3: System Usability Scale (SUS) Scores from All Respondents

Based on Figure 6, the combined SUS score obtained from all respondents is 71.13. The value falls within the range of 70 to 80, which correlates to a grade category of C and an "OK" rating on the adjective rating scale. This shows that according to all respondents, the use of AR application for CNC machines is relatively good. In terms of acceptability ranges, correlating the SUS score obtained from all respondents places the application in the "acceptable" range. Therefore, AR application is considered suitable for use as a support tool for training in operating the CNC TU-3A machine.

IV. CONCLUSION

In conclusion, this research successfully developed and implemented AR application CNC TU-3A using the ground plane method to show 3D objects. However, this method only showed 3D objects on specific Android devices. The black box testing obtained the expected results, confirming that all menus and buttons in the application function according to the planned workflow. Usability testing including 40 respondents produced a good outcome, with a final SUS score of 71.13 and was in the C category grade. When correlated with adjective rating scales, the value was within the "OK" range, showing acceptable results.

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https://doi.org/10.47001/IRJIET/2025.905002

REFERENCES

[1] S. Ceder, Augmented reality technology, no. 17. 2019. doi: 10.4324/9781351044196-11.

[2] D. Rohendi, S. Septian, and H. Sutarno, "The Use of Geometry Learning Media Based on Augmented Reality for Junior High School Students," IOP Conf. Ser. Mater. Sci. Eng., vol. 306, no. 1, 2018, doi: 10.1088/1757-899X/306/1/012029.

[3] L. Damiani, M. Demartini, G. Guizzi, R. Revetria, and F. Tonelli, "Augmented and virtual reality applications in industrial systems: A qualitative review towards the industry 4.0 era," IFAC-PapersOnLine, vol. 51, no. 11, pp. 624–630, 2018, doi: 10.1016/j.ifacol.2018.08.388.

[4] J. Jetter, J. Eimecke, and A. Rese, "Augmented reality tools for industrial applications: What are potential key performance indicators and who benefits?," Comput. Human Behav., vol. 87, pp. 18–33, 2018, doi: 10.1016/j.chb.2018.04.054.

[5] N. J. Harahap, "Mahasiswa Dan Revolusi Industri 4.0," Ecobisma (Jurnal Ekon. Bisnis Dan Manajemen), vol. 6, no. 1, pp. 70–78, 2019, doi: 10.36987/ecobi.v6i1.38.

[6] N. J. Harahap and M. Rafika, "Industrial Revolution 4.0: and the Impact on Human Resources," Ecobisma (Jurnal Ekon. Bisnis Dan Manajemen), vol. 7, no. 1, pp. 89–96, 2020, doi: 10.36987/ecobi.v7i1.1545.

[7] J. Jwo, C. Lin, and C. Lee, "Smart technology – driven aspects for human-in-the-loop smart manufacturing," no. 2021, pp. 1741–1752, 2021.

[8] E. Kaasinen et al., "Empowering and engaging industrial workers with Operator 4.0 solutions," Comput. Ind. Eng., vol. 139, no. xxxx, p. 105678, 2020, doi: 10.1016/j.cie.2019.01.052.

[9] J. Kim, M. Lorenz, S. Knopp, and P. Klimant, "Industrial Augmented Reality: Concepts and User Interface Designs for Augmented Reality Maintenance Worker Support Systems," Adjun. Proc. 2020 IEEE Int. Symp. Mix. Augment. Reality, ISMAR-Adjunct 2020, pp. 67–69, 2020, doi: 10.1109/ISMAR-Adjunct51615.2020.00032.

[10] S. Nidhra, "Black Box and White Box Testing Techniques - A Literature Review," Int. J. Embed. Syst. Appl., vol. 2, no. 2, pp. 29–50, 2012, doi: 10.5121/ijesa.2012.2204.

[11] A. M. Wichansky, "Usability testing in 2000 and beyond," Ergonomics, vol. 43, no. 7, pp. 998–1006, 2000, doi: 10.1080/001401300409170.

[12] M. Romilly, "12 Best Augmented Reality SDKs," Dzone IoT. p. 1, 2019. [Online]. Available: https://dzone.com/articles/12-best-augmented-reality-sdks

[13] P. M. Jacob and M. Prasanna, "A Comparative analysis on Black box testing strategies," Proc. - 2016 Int. Conf. Inf. Sci. ICIS 2016, pp. 1–6, 2017, doi: 10.1109/INFOSCI.2016.7845290.

[14] J. Brooke, "SUS: A Retrospective," no. June, 2013.

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