



Designing Augmented Reality (AR)-based Media for Training CNC TU 3A Machine

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Abstract. In the manufacturing industry, high production flexibility is crucial. The Computer Numerical Control Training Unit (CNC TU) 3-axis machine enables large-scale production through computer automation but still requires skilled operators. A lack of operator expertise can negatively impact production efficiency and workplace safety. Current training methods are often ineffective, inefficient, and noninteractive, making immersive technologies like augmented reality (AR) a promising solution for industrial manufacturing training. This research designs an AR-based training medium for the CNC TU 3A machine. The system was evaluated using the System Usability Scale (SUS) to assess ease of use and usefulness, and the short version of the User Experience Questionnaire (UEQ-S) to measure user experience impressions. The SUS evaluation yielded a score of 80.5 out of 100, categorized as "acceptable," with an "excellent" rating and a Grade B, indicating the AR system is feasible for use. Additionally, the UEQ-S test produced a mean score above 0.8, suggesting a positive user impression. This study concludes that the AR application demonstrates good usability and provides a satisfactory user experience, making it easy and comfortable for users to operate.

Keywords: Augmented Reality, Computer Numerical Control, Training, Mobile Application, System Usability Scale.

1 INTRODUCTION

With the advent of Industry 4.0, manufacturing challenges are becoming increasingly complicated, requiring fast fulfillment of customisation requirements as well as great production flexibility to remain competitive [1]. Computer Numerical Control (CNC) machines, which are noted for their high precision, low power consumption, and short manufacturing periods, are one technology that contributes to this versatility. According to [2], three-axis CNC machines, which cut from three sides, make it easier to treat materials like wood, plastic, and aluminum. However, humans are still required to set and manage processes on three-axis CNC machines. A lack of operator skills caused by low training quality might result in decreased efficiency and workplace safety [3]. Errors in input programs and tool changes can have a major influence on production quality and safety [4]. To reduce the harmful effects of operational errors, three-axis CNC machine operators must get adequate training through the CNC Training Unit 3A (TU 3A).

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Current CNC TU 3A training methods in the manufacturing industry remain conventional and are considered ineffective and inefficient, leading to difficulties for novice operators. The training program offered by the Ministry of Manpower of the Republic of Indonesia includes 11 competency tests and consists of 360 hours of face-to-face sessions, requiring four months with three hours of training per day. This approach is deemed inefficient. A survey of 30 Industrial Engineering students at Universitas Gadjah Mada who participated in the Production Process Practicum revealed dissatisfaction with conventional CNC TU 3A training, particularly concerning the information media, interactivity media, training duration, and supporting tools.

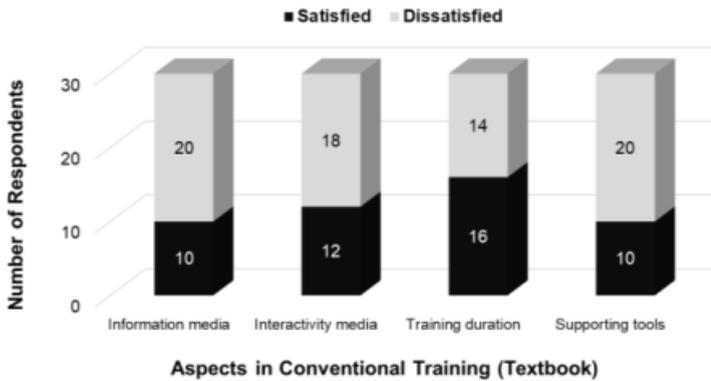


Fig. 1. Survey of user satisfaction in conventional training

To address these issues, immersive technology such as Augmented Reality (AR) is suitable for application in the manufacturing industry because it can reduce error rates in machining operator decision-making [5–7]. AR is more effective in reducing learning time by 17% and improving the quality of information received by 24% compared to written instruction-based training [8]. This research aims to design an effective and interactive ARbased training medium for the CNC TU 3A machine.

2 RESEARCH METHOD

The research involves several steps, as illustrated in Figure 2. First, a literature review is conducted to understand previous research and relevant theories. Second, a preliminary study ($n = 30$) measures student satisfaction with conventional CNC training to identify areas needing improvement. With a sample size of 30, the studentized sampling distribution closely aligns with the standard normal, making assumptions about the population distribution insignificant, as the central limit theorem ensures the sampling distribution is considered normal [9].

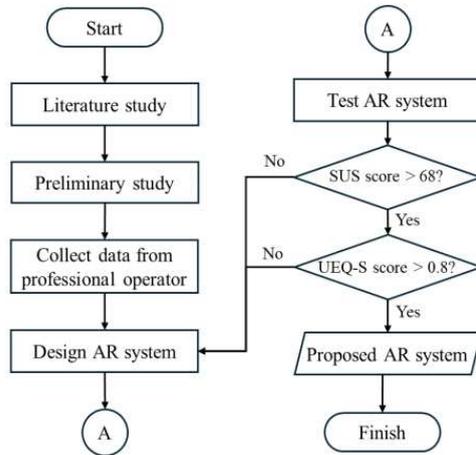


Fig. 2. Research methodology

Third, a questionnaire is developed to collect data from professional operators, followed by on-site interviews with certified CNC operators to gather training recommendations (n = 3). Fourth, 2D and 3D AR content is created using Adobe Photoshop and Autodesk Inventor, incorporating input from professional operators. The AR system is then built using Adobe Aero, which can detect the CNC TU 3A machine control image tracker and integrate 2D and 3D content. Finally, a usability analysis is conducted by testing the AR system with 30 respondents (n = 30), who complete the SUS questionnaire (Table 1) and the UEQS questionnaire (Table 2). The minimum SUS score is 68 [10], and the UEQ-S threshold is 0.8 [11], indicating that the AR system is feasible for use. If the values fall below these thresholds, the AR system must be redesigned and re-evaluated.

Table 1. System Usability Scale (SUS)

No	Item
Q1	I think that I would like to use this system frequently.
Q2	I found the system unnecessarily complex.
Q3	I thought the system was easy to use.
Q4	I think that I would need the support of a technical person to be able to use this system.
Q5	I found the various functions in this system were well integrated.
Q6	I thought there was too much inconsistency in this system.
Q7	I would imagine that most people would learn to use this system very quickly.
Q8	I found the system very cumbersome to use.
Q9	I felt very confident using the system.
Q10	I needed to learn a lot of things before I could get going with this system.

Table 2. The short version of the User Experience Questionnaire (UEQ-S) [11]

No	Item	Range
1	Obstructive - Supportive	
2	Complicated - Easy	
3	Inefficient - Efficient	
4	Confusing - Clear	
5	Boring - Exiting	-3 to +3
6	Not interesting - Interesting	
7	Conventional - Inventive	
8	Usual - Leading edge	

3 RESULT AND DISCUSSIONS

In this study, an AR system was designed based on recommendations from professional CNC machine operators. Three certified operators, each with over five years of experience, were consulted to gather the necessary information for training novice operators on the CNC TU 3A machine. This information includes details about the machine's axes, buttons, switches, manual and automatic operations, program codes, program structure, and cutting tools.

The 2D and 3D AR content was developed using Adobe Photoshop and Autodesk Inventor, and then implemented in the Adobe Aero application. The AR system is equipped with visual and audio elements triggered by specific actions (as depicted in Figure 3), such as changing colour or movement when a button is pressed or playing audio instructions and animations when an option is selected. A screenshot of the proposed AR system's user interface is shown in Figure 4. The training includes both audio and text instructions. To enhance interactivity, the movement-cutting tool, which follows the machine's axes (x, y, z), is animated by pressing a button (as illustrated in Figure 5).



Fig. 3. Trigger of AR system



Fig. 4. Proposed visualization of AR system



Fig. 5. Illustration of AR system (text, audio, and animation)

Usability testing was conducted with 30 students ($n=30$), aged 18-23 years old, from Universitas Gadjah Mada who had never used augmented reality (AR) before. They used tablets to follow the CNC machine operation procedures in the AR system application (as shown in Figure 6). The results of the SUS questionnaire showed an average score of 80.5, indicating that the AR system falls into the "Acceptable" category with an "Excellent" rating and a Grade Scale of B (as depicted in Figure 7). Additionally, the UEQ-S test showed that a mean scale value greater than 0.8 represents a positive evaluation, with all values exceeding 1 on the scale (ranging from -3 to +3), indicating favourable user perception (as shown in Figure 8).



Fig. 6. Respondents using the AR system



Fig. 7. SUS measurement for the AR System

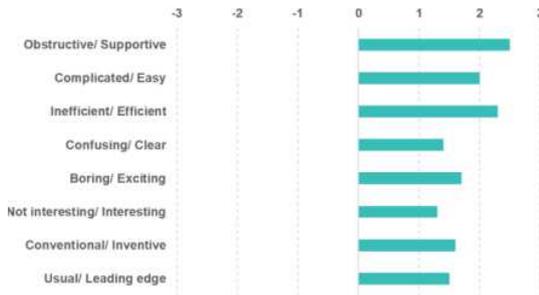


Fig. 8. UEQ-S measurement for the AR System

Overall, based on the evaluation test, the proposed AR system is feasible and ready for use in training on the CNC TU 3A machine. The AR system provides digital overlays in both two and three dimensions, including 2D designs for control information and operation procedures, as well as 3D designs to illustrate spindle movements and clamping table operations.

4 CONCLUSIONS

Augmented Reality (AR)-based training media for CNC TU 3A have been successfully developed. The material or content is created by adapting an existing textbook and modifying it with suggestions from a professional operator (n = 3). Adobe Aero was used to construct an AR application, which was successfully deployed on handheld devices such as tablets and mobile phones. The AR system was evaluated using a SUS, and the score was 80.5, indicating strong acceptability with an Excellence grade and Grade B. Furthermore, the UEQ-S test yielded a mean score above 0.8, indicating a favourable user perception. This study concludes that the AR application has good usability and delivers a satisfactory user experience, making it easy and comfortable for users to operate.

Future studies should compare the proposed AR system with conventional media training using user performance indicators to confirm its effectiveness and efficiency. Moreover, ambient ergonomics elements like noise and temperature that may affect operator workload and performance during CNC TU 3A machine training should be considered in the performance evaluation. Additionally, as handheld devices (HHDs) currently require manual involvement throughout the training process, investigating the usage of headmounted devices (HMDs) such as smart glasses should be taken into consideration as a potential way to improve the efficiency and efficacy of training.

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