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Revolutionizing CNC Lathe Education: Designing Instructional Media Integrated Using Augmented Reality Technology

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***Abstract* – Utilization of Computer Numerical Control (CNC) machines is crucial in modern manufacturing. Nevertheless, enhancing the skills of CNC machine operators remains a challenge in education and training. In response, the solution involves designing learning materials that simulate the machining process, particularly in innovative CNC learning integrated with Augmented Reality (AR) technology. The research utilizes the Multimedia Development Life Cycle (MDLC) model, encompassing steps like concept development, design, material collection, assembly, testing, and distribution. AR devices deliver additional visual information to CNC lathe students. The research results in learning materials using augmented reality to present 3D visualizations through markers, creating object representations to train 2-axis CNC lathes.**

These materials, designed as 3D virtual objects, offer real-time practicum experiences to learners. Black box testing confirms the effective implementation of augmented reality in CNC lathe training, providing cost savings in practicum materials and cutting tools during repeated testing on a 2-axis CNC lathe.

***Keywords* – Augmented reality, black box, computer numerical control, educational materials, multimedia development lifecycle.**

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1. Introduction

The transformation of educational and technological advancements highlights the critical need for equipping students with the competencies required to navigate the complexities of the digital era [1], [2], [3]. Nevertheless, traditional teaching methods in education lack interactivity and practical application in their approach. Moreover, the learning paradigm shift that was originally educator-centered is now more learner-centered [4], [5]. Meanwhile, technology-based learning has transformed conventional learning activities, enhancing student engagement and fostering more interactive, creative, and collaborative learning experiences [6], [7]. Utilizing technology as a pedagogical strategy to meet learning requirements has the potential to enhance teachers' tools and infrastructure. This technology-based learning approach can facilitate the development of cooperation skills and independence of students who are educated early on [8], [9].

Higher education fosters the development of students' potential, emphasizing critical, creative, and strategic thinking in alignment with the 21st-century education paradigm [10], [11].

Furthermore, universities play a crucial role in shaping teaching curricula and methods, emphasizing critical problem analysis and creative problem-solving through innovative projects [12], [13]. In higher education, students engage in discussions, seminars, and study groups, fostering critical thinking, logical analysis, and strategic decision-making skills [14]. To enhance higher education learning quality and student thinking skills, essential academic support, including guidance, counseling, and self-development programs, is crucial to help students overcome obstacles [15].

Universitas Negeri Padang's tertiary education sector employs a hybrid learning model, blending traditional face-to-face instruction with online technology-enhanced learning to provide students with a mix of in-person and virtual interactions [16]. The practice-based computer numerical control learning, where computers control manufacturing tools, is an innovative learning approach for Mechanical Engineering Vocational Students at Universitas Negeri Padang. However, shortcomings persist in implementing the CNC course, including limited access to virtual machines and reliance on traditional learning curricula [17]. Indeed, implementing this approach for the practicum process is less feasible, as the ideal scenario involves a fully face-to-face setup. The practicum aims to hone skills and apply CNC theory effectively.

Initial observations emphasize the need for CNC analysis, indicating that learning should focus on both theoretical and practical aspects of operating the 2-axis CNC lathe training unit [18], [19], [20]. Subjective observations from lecturers and students indicate that most learning models, particularly in the 2-axis training unit CNC lathe machine at Universitas Negeri Padang, are conventionally based. A limitation is noted in the practicum implementation due to 3-4 machine units, causing inefficiency in face-to-face lectures with 12 students. In response, technology-based media for varied hybrid learning is proposed as an alternative to achieve creative, innovative, and interactive thinking skills, aiming to impact education significantly. Consequently, the author intends to design augmented reality learning applications for the 2-axis CNC lathe machine training unit, focusing on the working principles of the X and Z axes. These applications will include features such as background sound, real-time 3D visual objects, and images of the machine axis, facilitating students in grasping the operational principles. The study formulates precise research questions to address and actively achieve the research objectives:

RQ1. What are the outcomes of designing CNC learning media for training unit-2A using AR technology?

RQ2. What are the findings from black box testing on CNC training unit-2A learning media using AR technology?

2. Methodology

The study intends to create educational materials utilizing augmented reality (AR) technology. The investigation involved 60 Mechanical Engineering vocational students at Universitas Negeri Padang, utilizing a Google Forms questionnaire. Findings revealed that students initially encountered difficulties learning CNC basics, particularly in preparing G-Code programs from assigned job sheets. Incorporating Augmented Reality (AR) can enhance learning efficiency and student enthusiasm, aligning with modern technological advancements. The methodology employed is the six-stage Multimedia Development Life Cycle (MDLC): concept, design, material collection, assembly, testing, and distribution. AR devices present students with additional visual information about CNC lathe operations [21], [22].

Figure 1. Multimedia Development Life Cycle (MDLC)

1.1. Concept: Needs Analysis

Conducting a needs analysis is crucial in establishing the objectives for designing the AR environment application. The instructional media targets students as its end-users. The Android mobile devices used must meet minimum specifications:

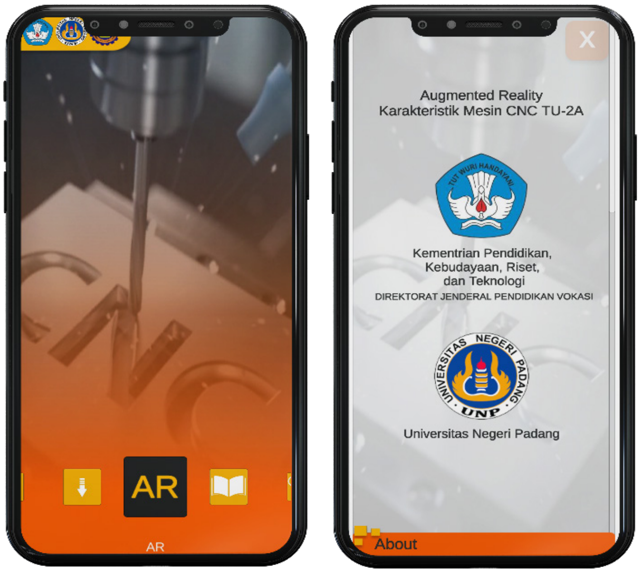
1. Any version of iOS 11 or later or Android 7.0.
2. Processor: Minimum ARMv8 with 64-bit architecture.
3. RAM: At least 2 GB, but 3 GB or more is recommended for better performance.
4. Sensors: Accelerometer, gyroscope, magnetometer (compass), and light sensor.
5. The camera should have a minimum resolution of 720p, with a higher resolution.

A thorough evaluation engages in order to analyze the semester learning plan of the CNC course. It focuses explicitly on the CPMK (Course Learning Outcomes) related to the 2-axis CNC lathe machine training unit. The primary outcomes involve operating numerically controlled machine tools with computers and applying command codes in machining components for the training unit.

1.2. Design: Application Blueprint

In designing augmented reality applications, several steps involve preparing software such as Unity, Android Studio, Blender, and Vuforia engine and engaging in C# programming [23]. Additionally, the design of the application layout is conceptualized through blueprints, and the user interface in this application is crafted using Unity. The creation of 3D objects is accomplished using Blender software. After acquiring all assets, the design outcomes are integrated into a Unity application following the needs analysis. The AR applications, designed as prototypes, are executed on Android devices, incorporating user account registration steps. Users activate the Android rear camera to materialize 3D objects through markers [24]. By pointing the mobile phone camera at the registered marker within its range, the 3D object appears in the marker area using the Vuforia engine. This appearance aligns with the layout detected by the camera on the Android phone.

Here is the initial appearance of the designed application, featuring a splash screen and main menu [25]. The application segment offers a detailed account of the research procedures. It is crucial to illustrate the research steps through a comprehensive presentation, like a research flowchart or framework, encompassing aspects such as algorithms, rules, modeling, design, and other elements related to the system design aspect.

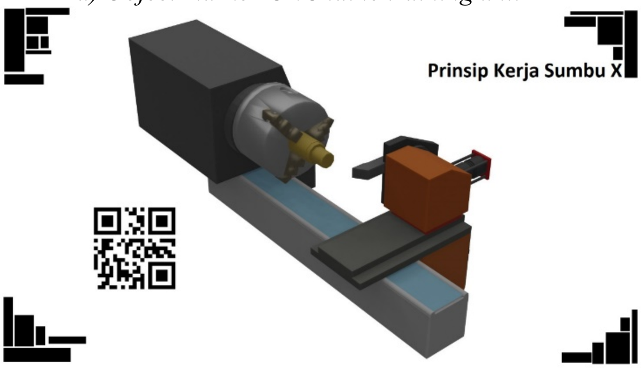


a) Menu Utama *b) About*

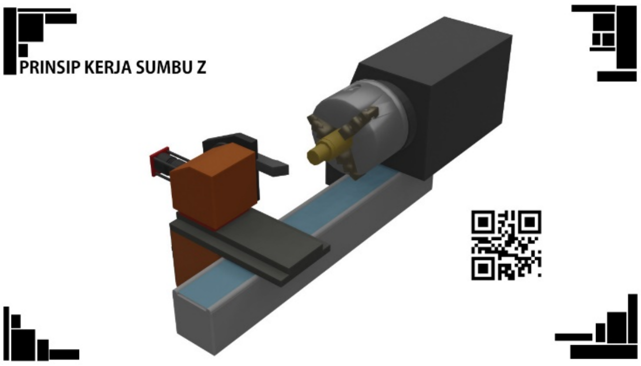
Figure 2. Application user interface

a) Object marker CNC lathe training unit-2A

b) Object marker CNC lathe tool training unit-2A



c) Object Marker of X-axis turning process of CNC lathe



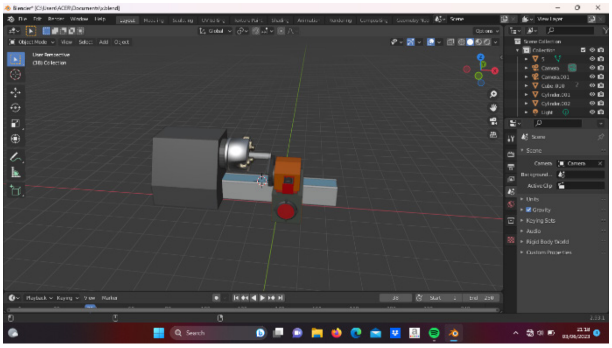
d) Object Marker of Z-axis turning process of CNC lathe

Figure 3. Object marker for augmented reality

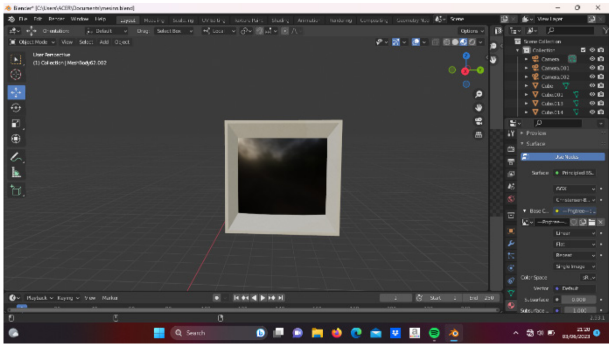
1.3. Material Collection: Asset Object 3D

The creation of 3D object assets employs Blender software [26]. The 3D modeling process initiates with shaping abstractly designed objects based on the characteristics and texture of the material used for lighting, achieving a lifelike representation of 3D objects.

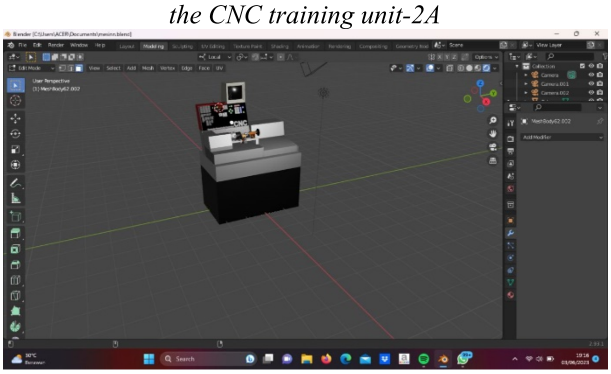
The rendering phase computes materials, lighting, and effects to generate images or animations [27]. Additionally, the X and Z-axis movements are incorporated into the features of the 2-axis CNC lathe machine training unit. This involves a 3D object animation simulation model, serving as an interactive visual aid to facilitate students in comprehending the motion of the central axis points.



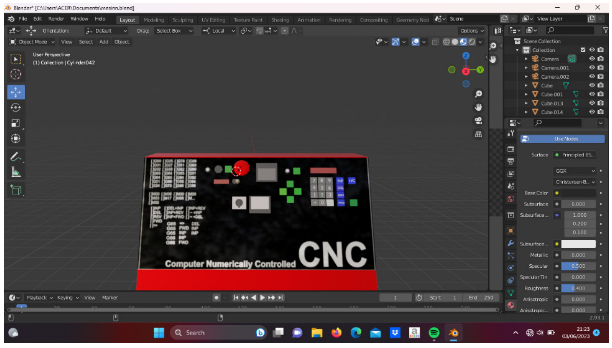
a) The design includes the toolhouse, chuck, and sled for the CNC training unit-2A



b) Computer monitor design CNC training unit-2A



c) Virtual CNC lathe machine Training Unit 2A



d) Control panel of lathe machine CNC Training Unit-2A

Figure 4. Asset object 3D

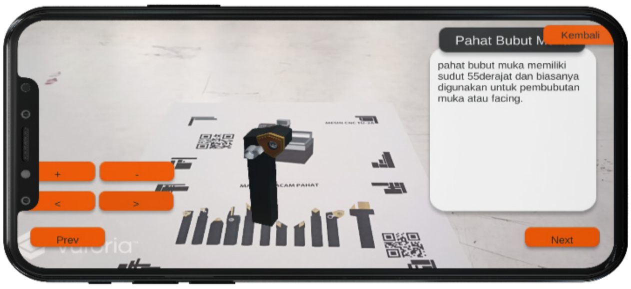
3. Results and Discussion

The primary goal of this study is to transform CNC lathe education by developing learning materials integrated with augmented reality (AR) technology, validated through black box testing.

3.1. Assembly: Design Implementation

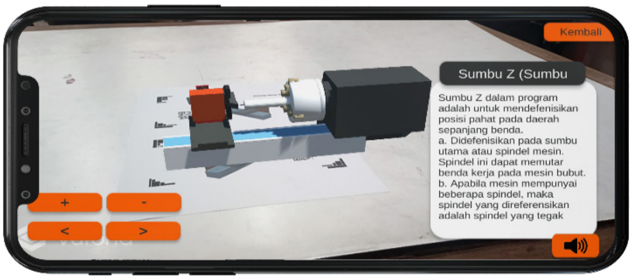
This study designs AR technology-based learning for a 2-axis CNC lathe training unit. It offers 3D object animation simulations, allowing students to enhance their knowledge in manufacturing. The AR system utilizes marker-based tracking marker types, requiring image markers for analysis through the smartphone camera. The analysis involves reading the captured marker, enabling real-time realization of 3D virtual objects with accompanying material and description panels [28]. Coordination points must be defined in the system for detecting markers, facilitating the real-time display of 3D objects on marked markers, and ensuring ease of management in usage. When applied to scanned objects, Markers can illustrate abstract 2D concepts and generate images of 3D objects, aiding in the analysis of their physical structure. The dominant interpretation of AR involves enhancing a physical environment by incorporating data or digital assets.

a) Realization of 3D objects animation of lathe machine



b) Types of CNC lathe tool 3D objects

c) X-axis point simulation of CNC lathe training unit-2A



d) Z-axis point simulation of CNC lathe training unit-2A

Figure 5. Display CNC lathe machine Training Unit 2A of instructional media using an augmented reality

3.2. Testing: Black Box

Black box testing techniques are utilized to evaluate prototype applications within the AR environment, focusing on the functionality of features within the 2-axis CNC lathe machine training unit [29]. This testing aims to verify the suitability of the functions listed in Table 1.

Table 1. Blackbox testing results of 2-Axis CNC lathe machine training unit

No	Components Tested	Test Scenario	Testing Results	Description
1	Splash Screen	Press the "Tap to Play" Button	Black Box	(√) Successful
2	Main Menu	Press the "Tap to Play" Button	Black Box	(√) Successful
		Press the "Instructions for Use" Button	Black Box	(√) Successful
		Press the "App Developer Info" Button"	Black Box	(√) Successful
		Press the "Marker-AR" Button	Black Box	(√) Successful
		Press the "Augmented Reality Simulation" Button	Black Box	(√) Successful
		Press the "Module" Button	Black Box	(√) Successful
		Press the "KDKI" Button	Black Box	(√) Successful
		Press the "Exit" Button	Black Box	(√) Successful
3	Instructions for using a menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
4	Application Developer Information Menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "Slide Up and Down" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
5	Marker-AR Menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "Link Url Marker" Button	Black Box	(√) Successful
		Press the "Swipe Left and Right" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
6	Augmented Reality Simulation Menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "TU-2A CNC Lathe Components" Button	Black Box	(√) Successful
		Press the "Tool Assortment" Button	Black Box	(√) Successful
		Press the "CNC-AR Working Principle" Button	Black Box	(√) Successful
		Press the "Start or Pause" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
7	Module Menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "Swipe Left and Right" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
8	KDKI Menu	Press the "Home" Button	Black Box	(√) Successful
		Press the "Navigation" Button	Black Box	(√) Successful
		Press the "Swipe Left and Right" Button	Black Box	(√) Successful
		Press the "Back" Button	Black Box	(√) Successful
9	Exit Menu	Press the "Exit" Button	Black Box	(√) Successful

Black box testing of the AR-enabled instructional media in the CNC course confirms its successful operation. The analysis indicates that the augmented reality app effectively meets goals and expectations with high compliance, validating its development success. Access this link to view the accomplished application: bit.ly/AugmentedReality-CNCTU-2A. In enhancing the research process, a hyperlink is supplied for recording the application simulation: bit.ly/SimulationVideosARCNCTU-2A. The testing process is ultimately confined to outcomes from the application design on the Android platform.

3.3. Distribution

Utilizing the marker-based method, it was developed to create 3D objects on CNC lathe material. Images or objects are the central reference for placing virtual elements in AR visualization, improving user experience, and broadening AR applications by ensuring clear visuals and accurate object tracking in physical space. This ensures a stable and coordinated user experience. Additionally, educational augmented reality enhances material comprehension, retention, and interactivity. However, limitations include reliance on physical markers and potential tracking issues in specific environments. Successful black box testing validates the application's functionality, meeting criteria for widespread distribution in *apk format.

4. Conclusion

Augmented reality instructional media for CNC courses was successfully developed using the MDLC method. Black box testing evaluates augmented reality applications, focusing on specified instrument indicators. The 2-axis CNC lathe machine training unit test results showcase 3D object animation simulations and X-Z axis working principles aligned with the application's initial needs analysis. Notably, the instructional media offers offline development without the Internet access but imposes restrictions on Android devices. The designed applications, featuring e-modules, learning videos, and animated simulations for the 2-Axis CNC lathe machine training unit, aim to boost student motivation and enhance learning outcomes. These applications include background sound and information panels. The hope is that augmented reality instructional media becomes a hybrid learning alternative, fostering increased interactivity and creativity among students and developing creative and innovative competencies in the future.

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