Immersive Learning Experience Design (ILXD): Augmented Reality Mobile Application for Placing and Interacting with 3D Learning Objects in Engineering Education

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Abstract—The CNC machine operates based on a numerical control program generated semi-automatically by a Computer Aided Manufacturing (CAM) system or manually by the operator. Repeated practice is required to operate a CNC machine. For an inexperienced operator (student), the practicum requires extensive use of materials and cutting instruments. In the meantime, the number of laboratory equipment for the CNC programming practicum remains limited, and the 3-axis CNC milling machine training unit is inadequate for the number of students. For this reason, we need a medium that can simulate the machining process to aid students in their early stages of learning. This research aims to create a mobile application for milling machine visualization based on augmented reality. This augmented reality (AR) application, "MM: CTU 3-Axis," or Machine Milling CNC Training Unit 3-Axis, was designed with 3D virtual objects to provide students with the knowledge and practical experience. The application development model used Multimedia Development Life Cycle (MDLC). This research yields an Android-based augmented reality (AR) application called "MM: CTU 3-Axis" that does not require markers. The development and verification results demonstrated that this application could aid in learning CNC programming and machining practicum, as well as reduce the cost of using cutting tools and the cost of using materials due to repeated experiments on CNC machines.

Keywords—augmented reality, mobile application, CNC milling machine, engineering education, immersive learning

1 Introduction

The educational paradigm has changed. The educational paradigm of the 21st-century can be defined as a system that requires everyone to be capable of using advances in information and technology communication in social life [1], [2]. The characteristics of the 21st century, known as the "age of information, computing, automation, and communication," undoubtedly impact the learning process. [3]. The learning paradigm, which was previously more teacher-centered, has shifted to one that is more studentcentered [4]; Learning that used to be one-way has now turned into interactive and collaborative learning. The learning paradigm change is driven by the rapid development of technology such as augmented reality (AR), virtual reality (VR), mixed reality (MR), artificial intelligence (AI), the internet of things (IoT), blockchain, non-fungible tokens (NFT), and metaverse, which world technology companies are currently developing. This latest technological advancement will become a trend in the coming year, bringing changes in various aspects of human life [5]. Technological and digital transformation was also triggered by the COVID-19 pandemic two years ago, which is still not over [6]. The Omicron XBB variant, which is said to have a higher transmission rate, has also spread to several countries worldwide. It can be said that the challenges of the 21st century are uncertain [7].

In the education sector, universities, especially in Indonesia, often experience changes in implementing learning from face-to-face (f2f) to online learning to mixed learning (limited f2f). It all started with the COVID-19 pandemic, followed by various government policies anticipating the virus's spread in universities. Learning during a pandemic must be carried out with limited f2f while still implementing health protocols or through distance learning. At Universitas Negeri Padang, throughout 2021–2022, the learning process has been carried out online for theoretical and practical courses. Specifically, the Computer Numerical Control (CNC) programming practicum course in the Mechanical Engineering study program at the Faculty of Engineering, Universitas Negeri Padang (FT-UNP), is also being held online. Of course, this becomes less effective because the practicum that should be done face-to-face eventually has to be shifted to an online system, even though practicum learning is aimed at students to test and implement what, in theory, occurs in real-life situations.

Based on the results of field observations and interviews with lecturers in CNC programming practicum courses, it is known that the number of pieces of laboratory equipment used for CNC programming practicum is still limited. Specifically, as many as 4-5 3-Axis CNC milling machine training units are insufficient for student needs because the number of students is more than 15 when the practicum takes place face-to-face, or it can be stated that students take turns using the tool. Of course, it takes a long time. Besides that, operating the 3-Axis CNC machine training unit requires repeated experiments, so it uses up practicum materials, and the price of a CNC milling machine is also not low [8], [9].

Meanwhile, in online learning, there are no practicum learning media that support CNC programming courses, so during the online learning process, lecturers and students experience difficulties in practicum activities. Besides that laboratory equipment may not be used during the pandemic, there is also no supporting media to carry out the practical simulation. An application or media to support practicum learning is needed to address the problems. So, we developed an AR-based mobile application named MM: CTU 3-Axis, or, according to its function, an application used to discuss the characteristics and working principles of the 3-Axis CNC Milling Machine Training Unit. This application provides various media features such as text, audio, images, and 3D object animations, making it easier for students to understand CNC milling machines' characteristics and working principles. This application is packaged as attractively as possible, is easy to use, and has a user-friendly interface [10].

2 Literature review

2.1 3-Axis CNC milling machine

CNC is short for computer numerical control. This type of technology uses a combination of motors and computers to control the machine tools used in specific manufacturing industries [11]. A CNC machine can be broadly defined as a machine tool that has automatic movement and is controlled by numerical language and a computer system, as shown in Figure 1. This machine is referred to as a CNC TU 3A machine because it is a milling machine and has three main axes, namely: x, y, and z, like Figure 2 below. 3-axis CNC milling machines create three-dimensional objects from metal, plastic, or other materials. A 3-axis mill has two independent rotational axes and one linear axis. The three axes are linked by a mechanical or electrical linkage, which allows the cutting tool to rotate along each axis.

Fig. 1. 3-Axis CNC milling machine training unit

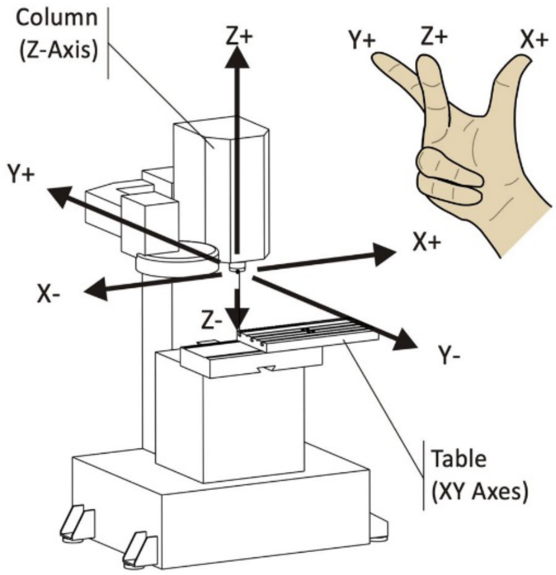


Fig. 2. 3-Axis CNC milling machine

A 3-axis mill works using three main movements shown in Figure 3:

1. Movement along the Z-axis, perpendicular to the cutting tool, adjusts the Z-feed so the latter can cut along the face of a workpiece (vertically).
2. Movement along the X-axis, parallel to the cutting tool, allows the milling head to move along the length of the workpiece and across the workpiece (horizontally).
3. Movement along the Y-axis, perpendicular to the cutting tool, allows the milling head to move on a workpiece from end to end (transverse).

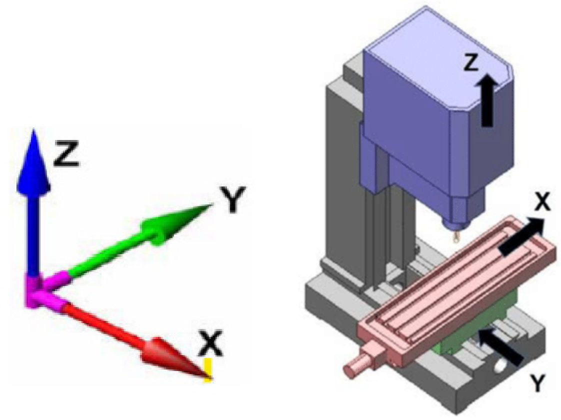


Fig. 3. X, Y, and Z axes

2.2 Augmented reality (AR)

Augmented reality, or AR, is a technology that integrates computer-generated digital content with the real world in real-time [12], [13]. AR allows users to see virtual 2D or 3D objects projected into the real world (Figure 4). AR can be viewed on various devices, including smartphones, smart glasses, cameras, screens, and webcams. These devices are output devices because they display information in videos, images, animations, and 3D objects [14]–[16].

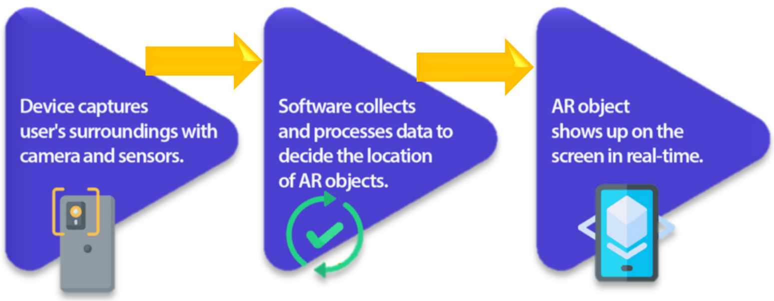


Fig. 4. Augmented reality workflow

The AR method is divided into two categories: marker-based tracking and markerless augmented reality [17], [18].

a) Marker-based tracking

Typically, a marker is a black-and-white square with a thick black border and a white background. The computer recognizes the position and orientation of the marker and creates a 3D virtual world with the point (0,0,0) and three axes, namely X, Y, and Z.[19].

b) Markerless augmented reality

With this method, users no longer need to use a marker to display digital elements. In the development of this application, the ground plane method is used [20].

3 Method

Before developing the application media, we first surveyed students. We use a questionnaire distributed using Google Forms. The number of samples or respondents is 151 mechanical engineering students who have taken CNC programming courses in July–December 2021. Based on the questionnaire results, it is known that 89% of students stated difficulties in online practicum, and 85% of students stated that learning media was essential to support practicum, especially regarding introducing the 3-axis CNC milling machine training unit. From the problems above, it is necessary to design an application that can support the online practicum learning process in the form of a mobile application, one of which is by utilizing augmented reality (AR) technology [21], [22]. Meanwhile, the development model approach used is Multimedia Development Life Cycle (MDLC). Multimedia Development Life Cycle (MDLC) consists of six stages: concept, design, material collection, assembly, testing, and distribution, as shown in Figure 5:

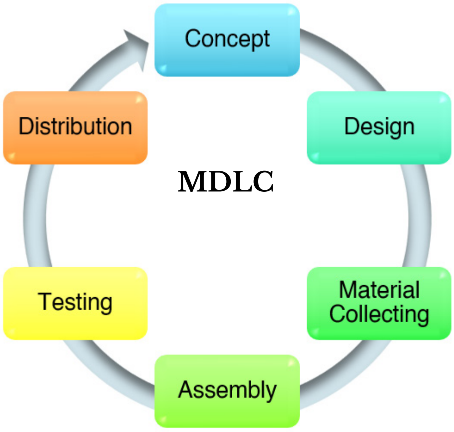


Fig. 5. Multimedia Development Life Cycle (MDLC) [23]

3.1 Concept: functional analysis

Functional analysis. The concept starts with determining the purpose of the application and who the users of the application are. Then, an application requirements analysis is carried out to detail the application's features and specifications. This application has the following features:

1. able to display 3D objects without using markers.
2. allows users to play sounds that support learning through applications.
3. allows users to rotate and zoom in on 3D objects.
4. capable of simulating the movement of a 3-axis CNC machine's x, y, and z axes.

The minimum system requirements for a mobile application will depend on the operating system and hardware the app is designed to run on. Below are the system requirements to run the application on the device: Minimum requirements: 1) Android 7.0 or later; 2) 2 GB of RAM; 3) 500 MB of free storage; 4) a quad-core 1,3 GHz CPU; and 5) a 5 MP camera. For recommended specifications, the device should meet the following: 1) Android 8.0 and up; 2) CPU quad-core 2.0 GHz; 3) RAM 3 GB; 4) Free storage 1 GB; 5) Camera 8 MP and above for good image quality.

Meanwhile, the hardware and software specifications required to support application development are as follows: 1) Processor: Intel Core i7 64-bit with SSE2 support; 2)

Minimum 8 GB RAM; 3) Graphics card with 4 GB RAM (NVIDIA GeForce GTX) 4) Mouse, pen+tablet, and 5) software: Windows 11, Figma, Unity, Blender, SDK AR, Vuforia, and Android.

3.2 Design: storyboard application

Initial design. Figma is used to design the appearance of an application. The splash screen page, main menu, and exit display are shown in Figures 1–3 below:

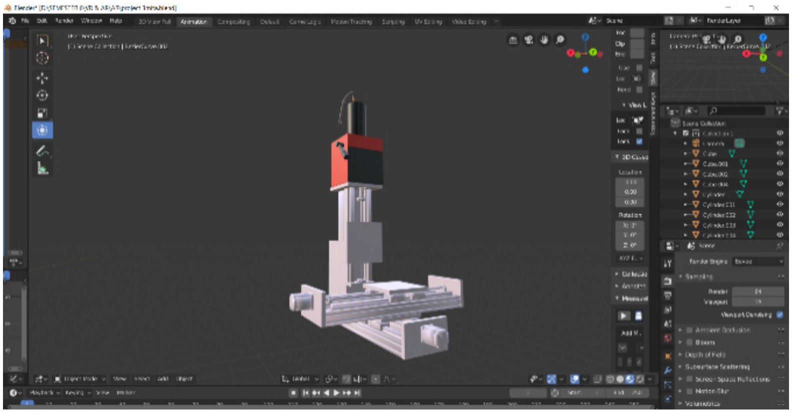
A. Splash screen B. Main menu C. Exit display

Fig. 6. Initial design

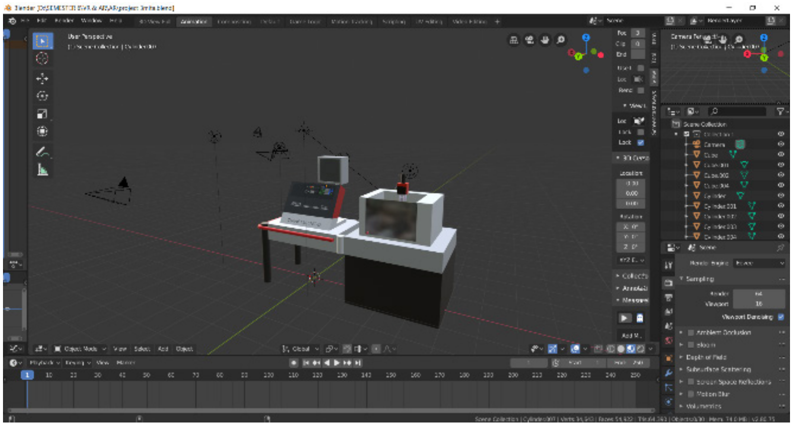
There are two options on the main menu: option one (01) is to display the 3D object from the TU-3A CNC machine, and option two (02) is to display movement simulations from the x, y, and z axes of the milling machine work system.

3.3 Material collecting: 3D learning objects

3D learning objects. Material collection is the process of gathering materials required for application development. Materials include clip art, assets, 3D learning objects, music, videos, and animation. The process of making 3D learning objects using Blender software version 3.1 is shown in Figure 7. Then, for the axis movement, animation movement is added to make the simulation of 3D objects look much more attractive and real-like.



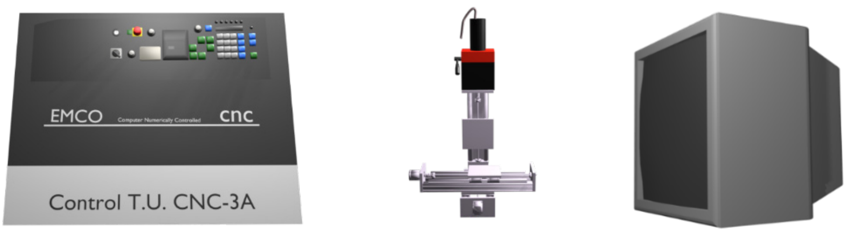
(A)



(B)

Fig. 7. Create 3D objects using Blender (A – B)

Here are some objects in 3D that were created (Figure 8):



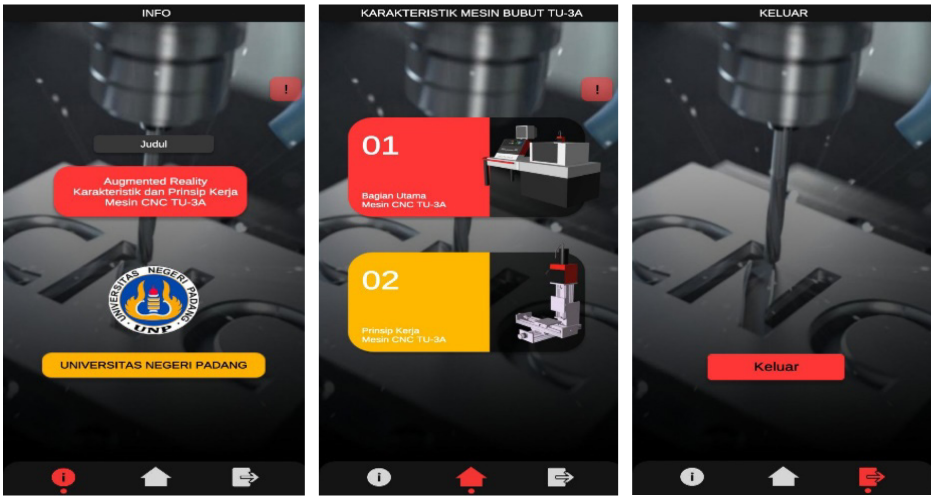
A. Controller B. CNC Machine C. Monitor

Fig. 8. Material collecting: 3D learning objects

4 Results

4.1 Assembly: Implementation of the design

Application design. The application design has been displayed at this stage, as shown in Figures 9 (A–C).



A. Splash screen B. Main menu C. Exit display

Fig. 9. Application design

The 3D object model of a 3-Axis CNC milling machine is made in an actual visual form, both in terms of shape, texture, and machine size, as shown in Figures 10 and 11. The coding process is also done at this stage.

Fig. 10. 3-Axis CNC milling machine training unit (3D)

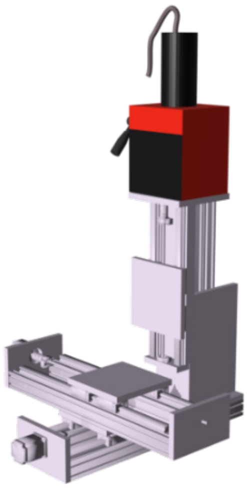
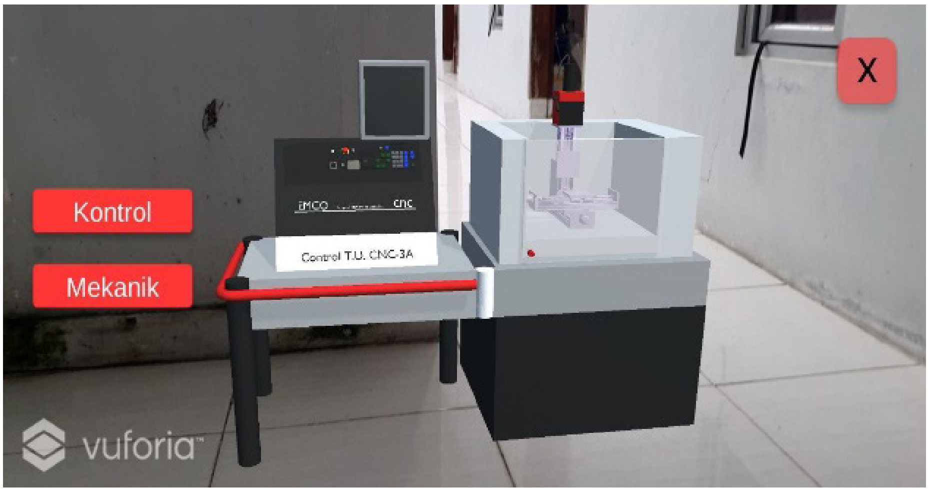


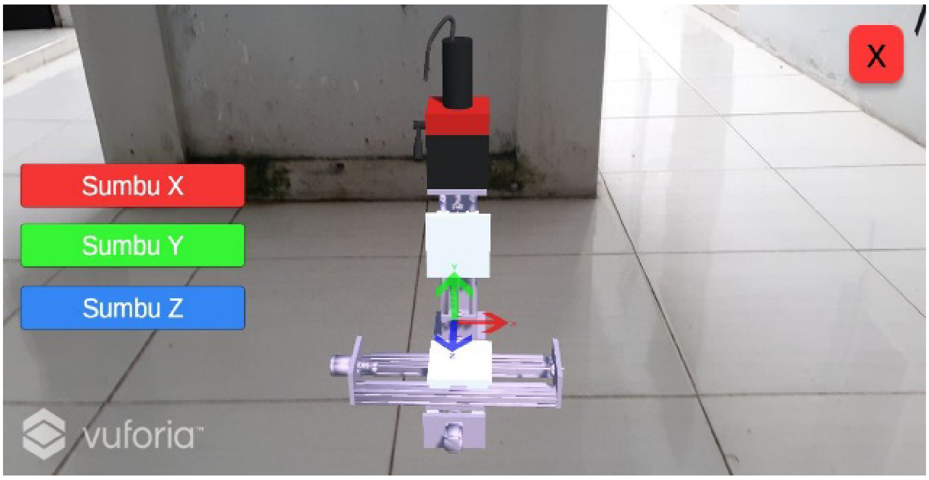
Fig. 11. Sledge of 3-Axis CNC milling machine (3D)

4.2 Testing: Blackbox testing

Blackbox testing. The goal of application testing is to determine whether the application is running properly and of high quality. The application can display 3D learning objects very well, as shown in Figure 12 (A-B). Then we can rotate objects and increase their size. Then, movements run smoothly to simulate the x, y, and z axes.



(A)



(B)

Fig. 12. Application testing (Blackbox)

The testing stage in the development of this application is still in the process of alpha testing. In alpha testing, application testing is done by internal developers only [24]. The Blackbox technique determines the functionality of each application feature and whether it can run properly or not [25]–[27]. The following are the results of application testing in Table 1.

Table 1. Application testing results

No	Description	Results
1	The main menu page appears properly	√
2	The application user guide page appears well	√
3	The navigation function of the application goes well	√
4	It can be run on various android-based mobile devices	√
5	Able to display 3D objects properly	√
6	Able to play audio clearly	√
7	Able to display a description page	√
8	Able to display animations of X, Y, and Z axes well	√

4.3 Distribution

This application was developed using the markerless method, which is certainly different from other AR applications that use markers to display objects. Markerless has the advantage that it does not require special knowledge (markers) about the user's environment to display its virtual object at a certain point. This markerless technology utilizes the ground plane to display 3D objects so that objects occupy space like they would in a real environment. However, the downside is that it requires a bit more time and an ideal position so that 3D objects can be displayed correctly in actual conditions according to reality. Ground planes can work indoors and outdoors in a variety of conditions. For a base that performs well, consider having: stable lighting conditions (neither too bright nor too dark); avoid glare and dark shadows; surface details aid accuracy and performance. Based on the results of alpha testing, the functionality meets the requirements, and the application distribution process can begin in the *.apk format distributed through the Google Play Stores.

5 Conclusions

A mobile application named "MM:CTU 3 Axis" based on augmented reality has been successfully developed using the Multimedia Development Life Cycle (MDLC) approach. This application is used as a learning medium to support practicum activities in CNC programming courses. Based on the test results, this application has been shown to be able to display 3-axis CNC milling machine training units in 3D objects and support the availability of 3D animations to understand the working principles of the X, Y, and Z axes on CNC machines. The results of testing this application are also very good, as all application functionality runs according to the storyboard or scenario design that has been prepared. However, this application is limited to only supporting the Android operating system. The advantage of this application is that students can use it anywhere without the need for internet access or practicum tools. For further development, it would be better to support other operating systems, such as iOS, so that users of different operating systems can use this application. The development and verification results show that this application can help learn CNC programming and machining practices. In addition, it also reduces the cost of cutting tools and materials due to the trial process, which often occurs repeatedly when the practice is carried out directly in the lab. It is hoped that in the future, this application can be developed by increasing the user's interactivity function with 3D objects in the application, for example by moving 3D objects in the application by touching the screen, or by developing this application in the form of a virtual environment or virtual CNC laboratory, so that students experience a more comprehensive learning experience. as real as the real environment in the laboratory.

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