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Revolutionizing CNC training with augmented reality: design, testing, and evaluation of a smartphone application

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ABSTRACT

This study describes the development of a cutting-edge smartphone application for Computer Numerical Control (CNC) training that makes use of Augmented Reality (AR) technology. Through the smartphone camera, the program overlays simulated CNC machines onto the real-world environment, producing an immersive and dynamic learning experience that outperforms traditional approaches. The augmented reality-based training technique was created expressly to improve user engagement, information retention, and skill transfer in CNC training. The application's performance was thoroughly examined through extensive user testing, indicating significant gains in several areas when compared to traditional training methodologies. This study demonstrates the feasibility and efficacy of delivering AR-based training via a smartphone app, emphasizing the enormous potential of augmented reality in transforming CNC instruction in Vietnam as well as worldwide.

Keywords: App, Augmented Reality (AR), Computer Numerical Control (CNC), Learning experience, Smartphone.

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1. INTRODUCTION

Computer Numerical Control (CNC) machines have transformed the way industrial processes are carried out in the ever-changing manufacturing world. These computer-controlled machines provide accurate, automated, and efficient manufacturing capabilities, allowing enterprises to meet high-quality requirements while increasing output (Adam et al., 2022). As CNC machines improve and find uses in a variety of industries, the demand for a well-trained staff capable of operating and maintaining these machines grows. Traditional training techniques, such as classroom lectures and on-the-job training, have limits in terms of providing a thorough understanding of CNC machine operations and developing practical skills. Traditional training methods frequently lack the hands-on experience required to bridge the theoretical understanding and practical application divide (Marinakis et al., 2021). Trainees may struggle to visualize complicated machine components, comprehend machining processes, and gain proficiency in operating CNC machines. Furthermore, the possible dangers of human mistakes during CNC operations necessitate a high level of skill and precision from operators. Errors in programming, tool selection, or machine setup can result in expensive material waste, equipment damage, and compromised worker safety. As a result, there is an urgent need for creative training techniques that address these issues while also improving the overall effectiveness of CNC training programs.

Augmented reality (AR) is a technology that superimposes digital content on top of the actual world, providing the user with an immersive and engaging experience. AR has been used in a variety of fields, including entertainment, education, medicine, and engineering (Adam et al., 2021). Reiners et al. (1999) created an AR system based on vehicle door lock mechanisms. They created a 3D augmented reality system to describe the automotive door locking system and its installation. Tang et al. (2003) investigated the use of Lego toys to teach students how to build. Students can make 82% fewer assembly mistakes while using AR. Sääski et al. (2008) created the AR system for the installation of tractor power units at the Valtra Pic tractor manufacturing in Finland. The jointed parts in the pointer-based system are shown to work by the overlaid working-step instructions on the physical unit. Olwal et al. (2008) proposed using AR to combine continuum data with the workspace of an industrial CNC machine. Their ASTOR system was created as an autostereoscopic optical see-through spatial AR system that provided real-time 3D visual input without the requirement for extra user-worn equipment like Head-Mounted Displays (HMDs) or tracking sensors. ASTOR sought to improve the visibility of occluded tools and provide real-time data visualization within the machine's workspace's 3D area. The technology provided an intuitive representation of the machining process by geometrically aligning the images with the actual workspace, enhancing user understanding and simplifying machine control. Henderson and Feiner (2009) investigated the design of an AR system for normal maintenance chores on military armored vehicles. Technicians in their system wore HMDs that displayed textual information, labels, arrows, and animations to guide them through the required processes. The AR system was designed to provide real-time visual aids and instructions, assisting technicians in performing maintenance tasks precisely and efficiently. Güler and Yücedağ (2018) investigate the feasibility of using an AR application for CNC machine maintenance and repair. This technological solution allows for the viewing of a three-dimensional model, allowing for a thorough analysis of each component. Interaction is limited to a virtual object linked to a marker, allowing for a hands-on experience in a virtual environment. To improve the efficiency and efficacy of equipment maintenance, the authors propose using the AR application as a training simulator. It is important to note, however, that the authors do not evaluate the effectiveness of their technological approach using a real-world machine as an example. AR, in particular, has shown significant promise for industrial training, as it can give learners realistic and contextualized advice and feedback without compromising safety or quality. AR can also cut training costs and time by eliminating the requirement for real machines or materials.

In this paper, the development and testing of a smartphone application that uses AR to enhance CNC training are presented. The application aims to simulate the complete operation flow and processing information of a CNC machine and to provide hands-on training in a safe and convenient environment. The application uses a smartphone camera to recognize a marker placed on a real or mock-up CNC machine. It displays a virtual interface that allows the user to interact with the machine using touch gestures. The application also provides visual instructions, hints, and feedback to guide the user through the training scenario. The application seeks to promote skill development, knowledge retention, and user happiness in CNC training programs by combining theoretical information with practical exercises. Furthermore, the purpose of this article is to test and assess the performance of the AR-based training strategy, providing significant insights into the potential of AR technology as a revolutionary tool for CNC instruction.

The rest of this paper is organized as follows: Section 2 describes the process design of our AR application. Section 3 presents the process implementation and results. Section 4 discusses the findings and implications of our work, concludes the paper, and suggests future work.

2. PROCESS DESIGN

2.1 Model Selection

Fig. 1. shows the CNC Doosan DNM 5700 machine's illustration (Ammad, 2022). The DNM and DNM II series have an established track record, and the most recent DNM series version delivers improved performance and reliability. The new product line also includes environmentally friendly lubricants for guide rollers, demonstrating the company's dedication to sustainability. The DNM 4500/5700/6700 series is built with a high concept in mind, stressing rigidity, speed, and versatility for a wide range of applications. It comes standard with the largest machining area in its class, a direct-coupled spindle, roller guides, and thermal error compensation to provide optimal precision in machining processes. The DOOSAN 5700 machine, manufactured in Korea, has found favor with some manufacturers because of its low cost and three-step milling capabilities. The specifications of the CNC model are shown in Table 1. Because of its extended exposure time, it is possible to create a detailed 3D model, with each component detachable and an operating mechanism included within the virtual environment. The machine is also appropriate for internships. Its simplified functioning mechanism makes it a perfect object for simulation when compared to a lathe. Given that foreign private enterprises operating in the Vietnamese market frequently use the DOOSAN DNM machine, the author has access to and exports the machine's schematics via SolidWorks software, allowing for realistic representation and simulation in the virtual environment.

Fig. 1. CNC Doosan DNM 5700 machine (Ammad, 2022)

Table 1. Doosan DNM 5700 machine's specifications

Specification	Parameters	Value	Specification	Parameters	Value
Travels	X-axis	1,050 mm	Spindle	Speed	8/12 × 10^3 rpm
	Y-axis	570 mm		Power	15/18.5 kW
	Z-axis	510 mm		Torque	118/286 Nm
	Rapid traverse X-axis	36 m/min	Table	Table size	1,300 × 570 mm
	Rapid traverse Y-axis	36 m/min		Max load	1,000 kg
	Rapid traverse Z-axis	30 m/min		Spindle-to-table distance	150–660 mm
Tooling	Shank	BIG PLUS CAT40	Machine size and weight	Length	3,145 mm
	Changer capacity	30 (Opt. 40/60)		Height	2,985 mm
	Max diameter	⌀80/125 mm		Width	2,221 mm + 1,128 mm
	Max length	300 mm		Weight	6,500 kg

2.2 The Process of Building a CNC AR Machine

As shown in Fig. 2. the development process of CNC AR software consists of three basic stages:

Stage 1: Learning about CNC Machines

This level consists of two phases. To begin, an investigation of the CNC machine's hardware components is performed to acquire a thorough grasp of its structure and performance. Second, a 3D model of the CNC machine is created, which includes all of its fine intricacies and specs.

Stage 2: CNC Machine Simulation

The simulation stage is the most difficult element of the procedure, with four parts. The CNC machine model is first mimicked within the program, with its behavior and operations replicated. Following that, each critical component of the machine is separated and isolated to allow for the integration of animations and motion mechanics. This stage improves the simulation's interactive and dynamic elements, giving consumers a more realistic experience.

Stage 3: Software Operability Check and Refinement

The final stage involves testing the software's functionality. If any faults or concerns are discovered, they are gradually handled and repaired to ensure the CNC AR software's completion and efficiency. This repeated procedure allows for software fine-tuning and refinement, assuring optimal performance.

Figure 2 depicts the three stages involved in developing the CNC AR software, emphasizing the sequential flow of work and the relationship between each level.

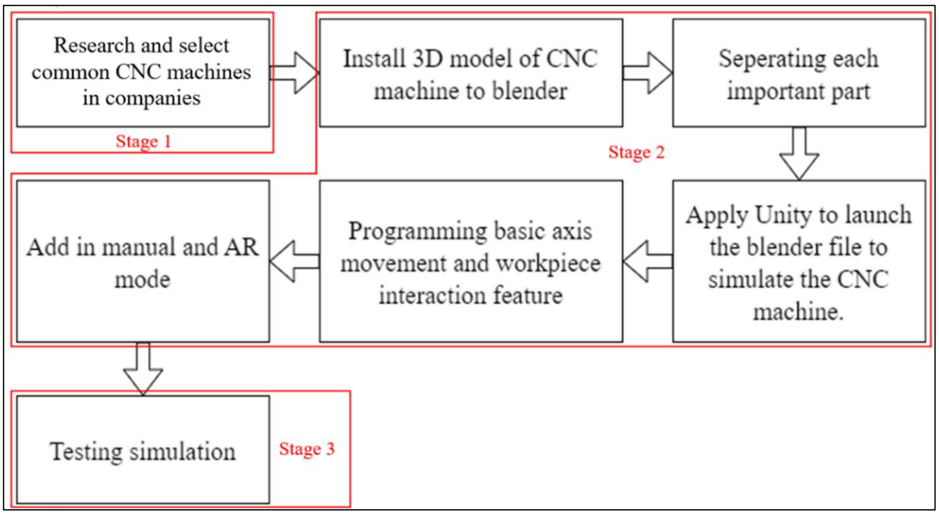

Fig. 2. Procedure diagram

3. PROCESS IMPLEMENTATION

3.1 CNC Milling Machine Modeling

After obtaining the 3D drawing of the CNC machine, the model is built and separated into different sections using the Blender, a complete 3D content production tool. Modeling, rendering, animation, rigging, video editing, visual effects, compositing, texturing, and simulations are all available in Blender. Each component of the CNC machine is split using Blender, easing the subsequent animation process. If the step of separating the pieces is skipped, creating the motion animation for each level of the milling machine will be significantly more difficult. The machine image is presented in Fig. 3 when the 3D file is loaded into Blender. Despite the lack of color, the image can perform fundamental activities. When you click on a machine part, you'll see three movement options along the X, Y, and Z axes, allowing you to move that exact part in the desired direction. There is also the option to rotate according to the chosen angle. The components of the machine are segregated, as indicated by number 1, allowing for individual operation by concealing specific external elements.

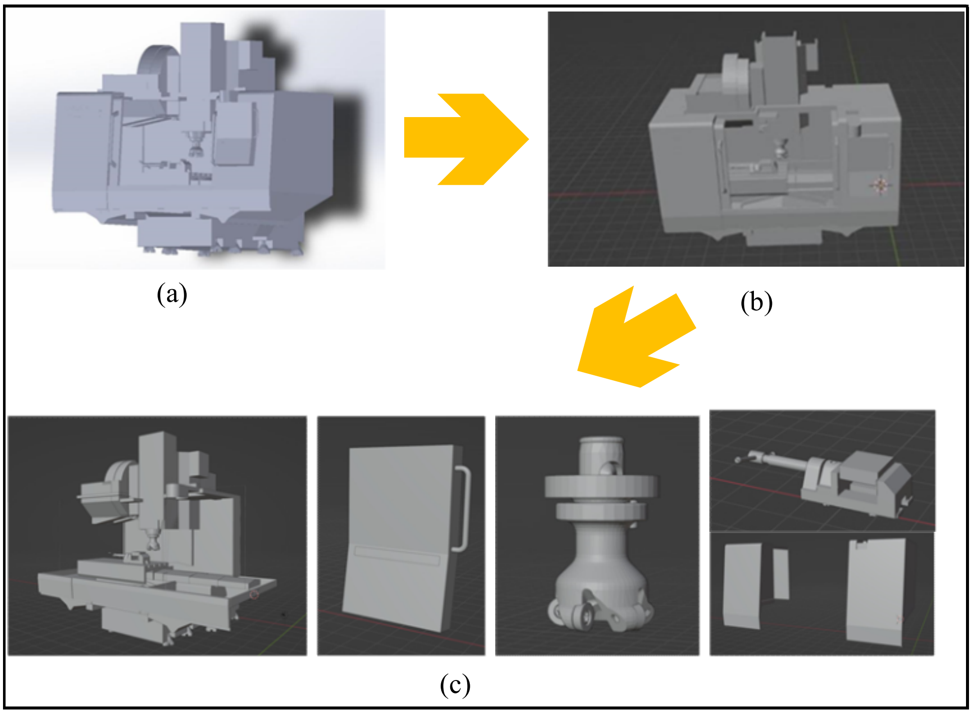

Fig. 3. Milling machine modeling with Blender; (a) 3D model in Solid works, (b) 3D model in Blender, (c) the machine's important parts are separated

A 3D design file of the model is required to produce 3D models within the simulation environment quickly, and SolidWorks is utilized in this work. Separate components are used to add the mechanics and animations, and the machine can be painted with unique colors to aid identification during operation. It is critical to implement movement limitations for the components to avoid collisions. To inform users, a collision-warning feature can be included. To avoid conflicts with previous versions, exercise caution when altering the public file. Unity, on the other hand, specializes in creating 3D worlds and simulations.

Following the separation of each component, the Blender file is loaded into the Unity Hub software to begin the process of adding colors and creating animations for the machine. Unity supports a variety of open-source and closed-source file formats, including, fbx, dae (Collada), dxf, and obj. These file formats are widely supported and have reduced file sizes than proprietary formats, resulting in smaller project sizes and faster iteration. When feasible, utilize the fbx file format because it is the standard file format for Unity. The exported fbx or obj files can be re-imported into the appropriate 3D modeling tool to confirm successful information export.

When you first load the machine into Unity, it appears as a blank white form. Users can interact with the machine after importing the Blender file into the Unity Hub by pushing and holding the mouse button to rotate it or by clicking on any section to show the X, Y, and Z axes. Users can freely move the desired part to a precise spot using these axes.

In Unity, changing the colors of the CNC machine is simple. Users can easily customize the appearance of a gadget by employing its material information. To add the required hue, simply drag and drop the material onto the object. Two tweaking choices are available in the material settings. The first is the metal mode, which allows things to interact with light and appear metallic when viewed. The second option is smoothness, which improves visual aesthetics by adjusting the contrast between the background and the object. The whole image of the machine is now exhibited with the addition of colors, offering a more realistic and visually appealing depiction in the Unity environment (Fig. 4).

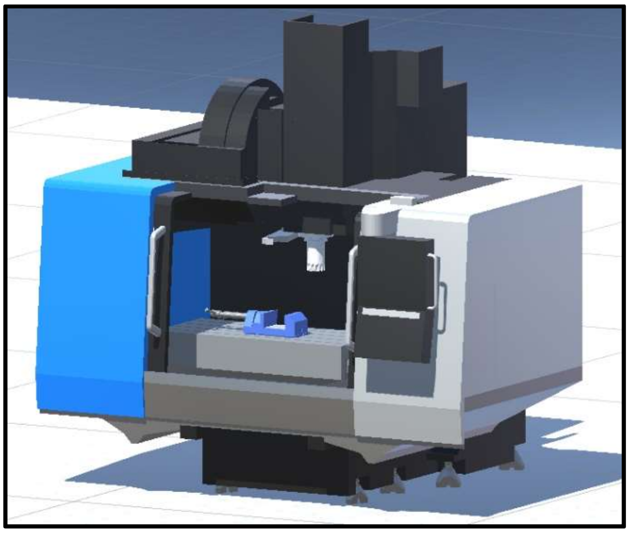

Fig. 4. Milling machine blender model after adding color in Unity

Furthermore, users in Unity can construct buttons that correspond to certain CNC machine functionalities. These buttons function as interactive controllers, allowing users to initiate a variety of activities and tasks within the virtual environment. Users can design and position the buttons in any way they like using Unity's user interface (UI) system. The UI system offers a variety of button customization choices, including size, shape, color, and labeling. Users can set specific functions to each button, mapping them to matching CNC machine actions or activities. Buttons can be created to start the milling operation, alter the spindle speed, manage the feed rate, or activate particular tooling functions, for example. Users can specify how the buttons behave and provide visual feedback, such as highlighting when pressed or displaying text or icons indicating the associated function (Fig. 5).

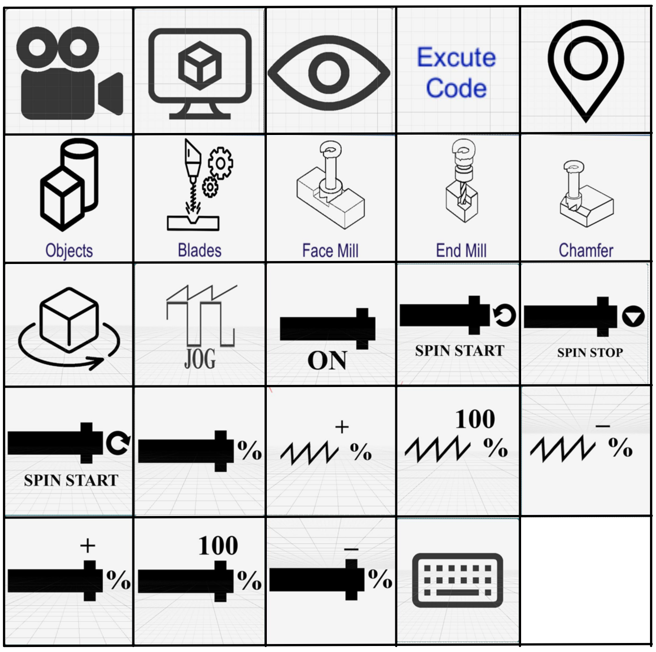

Fig. 5. CNC machine functionalities with Unity button-based controls

Interaction with these buttons improves the user experience by giving a simple and easy way to control the virtual CNC machine. Users may easily move through different functionalities and conduct specific actions within the Unity environment by simply clicking on the respective buttons. The ability to design customizable buttons in Unity allows users to virtually replicate and interact with the CNC machine's functions. This improves the training and learning experience even more by allowing users to get practical knowledge and hands-on familiarity with the machine's functions via straightforward button-based controls.

3.2 Animation Programming Based on DOTween

DOTween was chosen as the animation library for scripting movements for a variety of reasons. To begin, DOTween is a free and open-source, highly functional object-oriented animation engine for Unity. It is the favored alternative for the project due to its efficiency, speed, and safety. DOTween also has advanced features and capabilities, which add to its popularity. Another important reason for choosing DOTween is its compatibility with Unity versions 2021 and higher. Because the team is using Unity version 2021.3.8f1, compatibility assures seamless integration and optimal performance within the specified Unity environment.

Furthermore, DOTween supports a variety of operating systems, including Linux, iOS, Android, WebGL, and Unity WebPlayer. This broad compatibility allows the project to reach a larger audience while also ensuring consistent functionality across numerous platforms. It should be noted that DOTween is a development of HOTween, a previous Unity tween engine. DOTween provides a considerable advance over HOTween, being 400% faster, more effective, and more secure. This is accomplished by eliminating unnecessary GC (Garbage Collector) allocations, which results in improved performance and memory management. In the context of memory management, the Garbage Collector handles memory allocation and release in managed programs automatically. This automatic memory management aids in the prevention of issues such as memory leaks and attempting to use released memory.

3.3 Motion Control

This section demonstrates how to determine the rotational speed and coordinate the movement of the X, Y, and Z axes through programming using flowcharts. Upon selecting the tool and workpiece during the software launch, the main screen will display several buttons, each of which serves a specific role.

The name of one of these buttons is "Jog." When pressed, the X, Y, and Z axis direction buttons are displayed for the user to use as in the flowchart in Fig. 6. The user can change the X axis as needed by using these buttons. The movement's speed and coordinates are determined based on the X-axis's beginning position. Typically, it is configured to start with the base position for the X axis and then add the required real number value from there. When you press the button to move the X axis to the left, the actual value in the position programming formula changes slightly. The Y axis is programmed in the same way as the X axis, except the movement is in the other direction. The Y axis moves forward and backward along its axis, while the X axis moves left or right. The user has control over the Z axis's upward and downward movement. A reset button has also been added for convenience. When the user presses it, the axes revert to their default values. The flowchart shows the process for jogging the X, Y, and Z axes of the machine. The process starts with the user pressing the Jog button. The user can then select an axis to move (X, Y, or Z). The user is prompted to move the axis in a positive or negative direction. The coordinates are adjusted based on the button presses. The user can then confirm if they want to move to that position. If they confirm, the position value is updated based on the selected direction and increment. The process repeats until the user confirms the position or cancels. If the user cancels, the program will reset all the axes to their default positions.

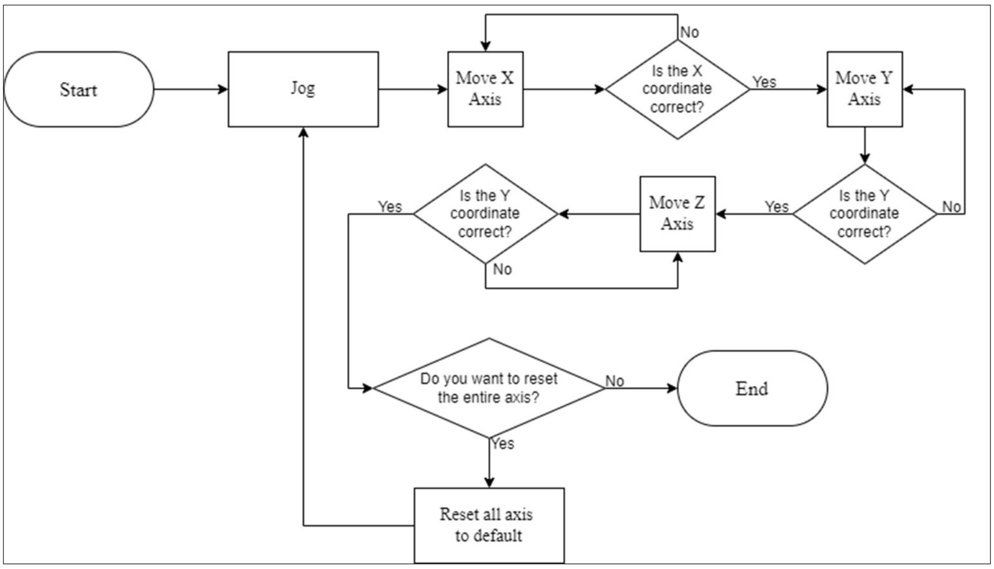

Fig. 6. Flowchart for X Y Z axis motions

Another crucial button is the "Spin On" button, which ensures that the tool movement's % value changes each time the software is used. When you first start using the software, the tool rotation percentage is set to 10% and rotates

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clockwise. A button for reverse rotation mode has also been included in the design. By repeatedly pushing the reverse spin button, a signal is transmitted to the tool spindle, causing the clockwise rotation of the blade to stop and counterclockwise rotation to begin. A push button is also accessible to signal the tool's rotating unit (the Z-axis tube) to stop revolving, so stop the rotating blade. The procedure is controlled based on the flowchart in Fig. 7.

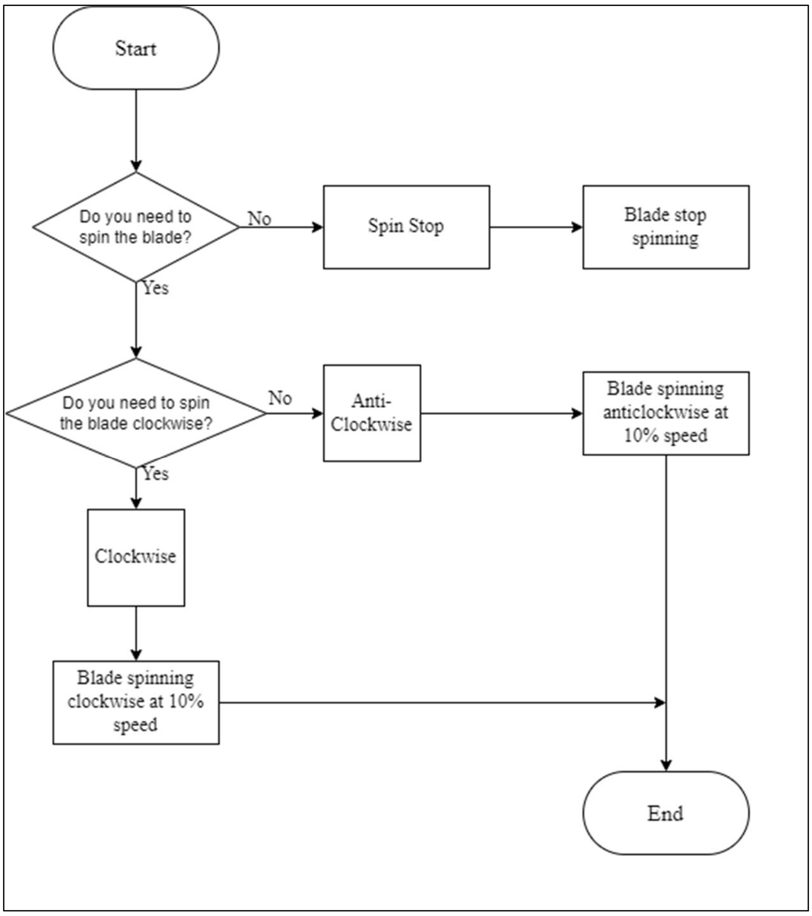


Fig. 7. Flowchart for Spinning

The user starts by pressing the “Spin On” button. The program checks if the user wants the blade to spin. If not, the blade stops spinning. If the user does want the blade to spin, the program checks if they want it to spin clockwise. If they do want clockwise rotation, the blade starts spinning clockwise at 10% speed. If the user doesn’t want clockwise rotation, the blade starts spinning counter-clockwise at 10% speed.

There are three buttons in the "Feedrate" section: (+) percentage, Default, and (-) percentage. The default button allows you to set the percentage value of the tool rotation to 100%. The button (+) increases the spin rate by 10% each time it is pressed. However, it won’t allow the spin rate to go above 100%, so pressing it when the spin rate is already at 100% will cause an error. The button (-) decreases the spin rate by 10% each time it is pressed. It won’t allow the spin rate to go below 10%, so pressing it when the spin rate is already at 10% will set it to the default value of 10%. The flowchart for the spin rate is shown in Fig. 8. The system starts by checking the current spin rate. If the user presses the “Default” button, the spin rate is set to 100%. If the user presses the (+) button, the system checks if the current spin rate is already 100%. If it is, the system displays an error. If the current spin rate is less than 100%, the system increases it by 10%. If the user presses the (-) button, the system checks if the current spin rate is already 10%. If it is, the system sets the spin rate to 10%. If the current spin rate is more than 10%, the system decreases it by 10%.

In addition to these functionalities, there is a "Keyboard" button that, when touched, displays a virtual keyboard similar to the Android keyboard. Users can use this keyboard to enter code into the display, which then sends a signal to the tool for execution (Fig. 9). The user presses the “Keyboard” button. A virtual keyboard appears on the screen. The user types in the code using the virtual keyboard. The user presses “Enter” on the virtual keyboard to send the code. The code is sent to the tool for execution if the code is right and the program coordinates are allowed. Otherwise, the program will raise an error to inform the user to revise the code.

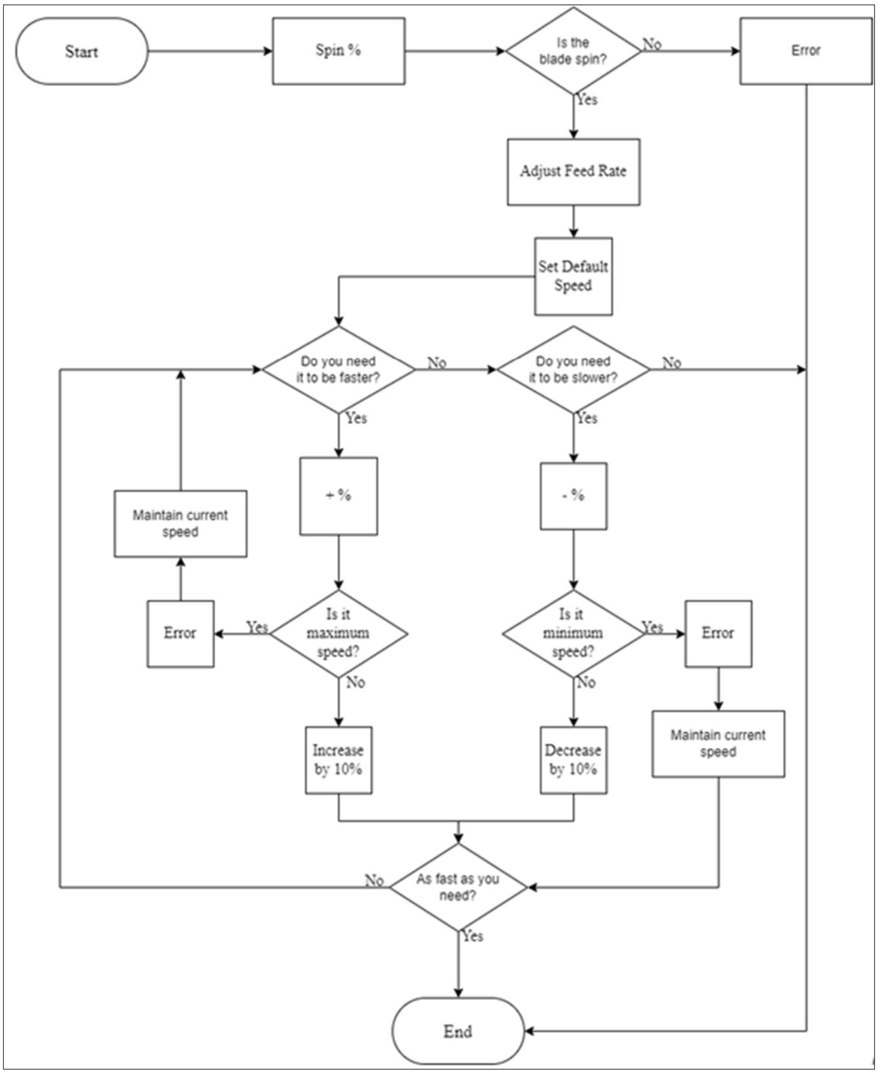


Fig. 8. Flowchart for Spin rate

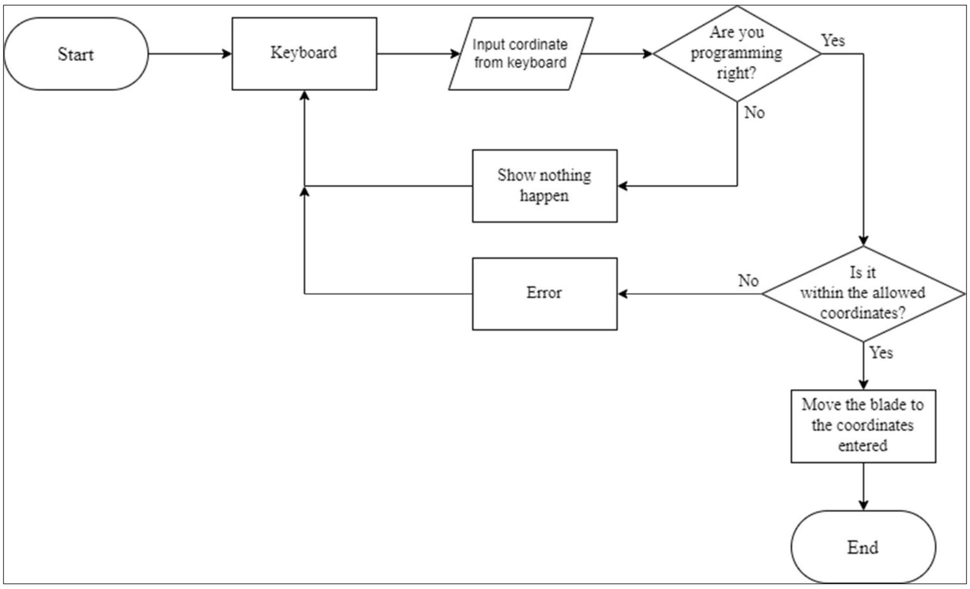


Fig. 9. Flowchart for keyboard

Furthermore, the application provides a variety of other capabilities that can be integrated to improve the user experience. Multilanguage support, undo and redo functionality, and zoom-in and zoom-out capabilities are among the features available.

Users can choose their chosen language for the program's interface thanks to the multilanguage support feature. This guarantees accessibility and accommodates people from various locations or languages. By allowing users to explore and interact with the software in their local language, the application becomes more inclusive and user-friendly.

The undo and redo option allows users to reverse or repeat their activities within the software. This capability is very valuable in CNC machining because it allows users to correct any unwanted movements or changes made to the workpiece. Simply picking the undo option will return the software to its previous state, undoing the most recent action. In contrast, the redo function allows users to restore any undone activities, offering flexibility and control during the machining process.

Additionally, the program includes zoom-in and zoom-out features, allowing users to modify the magnification level of the display. This ability comes in handy when working with elaborate designs or detailed workpieces. By zooming in, users can closely examine specific areas of interest, ensuring precision and accuracy in their machining tasks. Zooming out, on the other hand, provides a broader view of the workpiece, allowing for a better understanding of the overall layout and proportions. This zooming flexibility enables users to work more clearly and make informed judgments based on a thorough visual depiction.

The user experience is enhanced by embedding these functionalities inside the software, which provides additional control, flexibility, and customization possibilities. Language preferences, the flexibility to undo and redo tasks, or the ease of zooming in and out are just a few of the elements that contribute to a more efficient and user-friendly CNC machining environment.

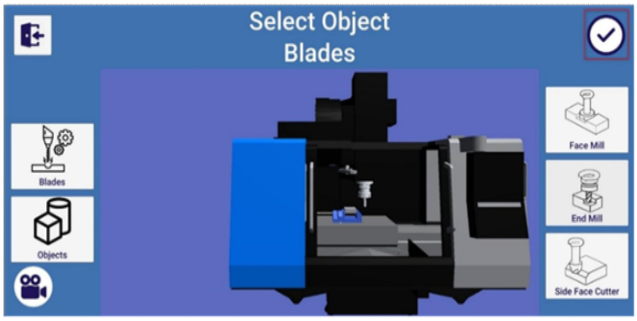
4. RESULT AND DISCUSSION

4.1 Application Interface

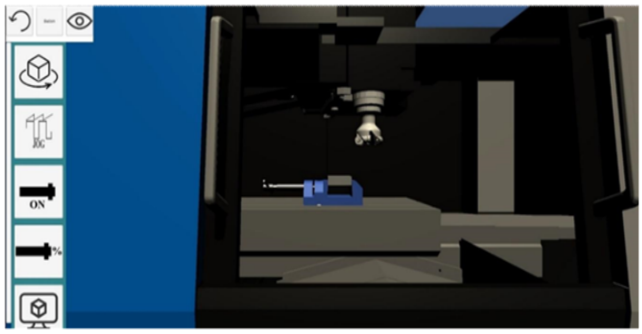
Users can change the language in the program's Settings to suit their needs. This can be done before continuing by selecting the Start button when the software is launched. After selecting the language, users can select the suitable workpiece from three popular types of CNC tools: face mills, endmills, and chamfers (Side Face Cutter) (Fig. 10a).

When all of the required steps have been completed, a tick symbol will show in the top right corner of the screen. Users can switch between two modes by clicking on this symbol: manual and AR. When the user selects Manual mode, the camera perspective shifts to reveal the interior of the DNM Doosan 5700 milling machine, as well as the previously selected tools and objects (Fig. 10b).

By giving these options, the application ensures that users may interact with the selected language and select required workpiece type. The Manual mode provides a thorough picture of the interior of the milling machine, allowing users to control and operate the tools and items in a virtual environment.



(a)



(b)

Fig. 10. Application user interface; (a) Operation choosing, (b) Manual mode

Specific activities, such as spinning the tool, modifying its rotational speed, and manipulating the X, Y, and Z axes, are under the user's control. To begin cutting and drilling operations on workpieces, the user must first click on the screen symbol that looks like an embryo-shaped icon in the lower left corner. This action launches a new screen for controlling the workpiece via cutting and drilling operations (Fig. 11a).

By pressing button number 1, the blade is automatically positioned according to the pre-programmed locations (Fig. 11b). Simply push-button number 2 to display the movement table for the X, Y, and Z axes (Fig. 11c). Button 3 displays a table that allows the user to rotate the tool or turn it off completely (Fig. 11d). The blade rotation speed control panel is revealed by pressing button number 4 (Fig. 11e). Button 5 activates the keyboard, allowing you to enter commands for the tool to execute (Fig. 11f). After typing the command, computer users can execute it by moving the cursor over the "Execute code" button. On mobile devices, the same function is performed by tapping the command button on the device's touch screen. Various command buttons can be found in the upper left corner of the screen. Users can utilize these buttons to conceal the toolbar, reset the tool and workpiece to their original settings, and change the camera angle (Fig. 11g). Because this application is a simulation of a CNC milling machine, there may be errors during drilling, milling, and X, Y, and Z axis adjustments. If the tool accidentally strikes the workpiece, for example, the blade will disappear and an error message will be displayed. The user can restore the blade and return it to a working state by pressing the reset button situated adjacent to the camera adjustment button (Fig. 11h). This button returns all items to their original state.

The users can start the AR mode instead of manual mode on mode selection screen. In AR mode, the screen scans the surroundings and identifies a flat surface using the camera on the user's mobile device. After detecting a suitable location, the 3D CNC milling machine model is loaded into that surface Fig. 12. After the software successfully starts the CNC machine model, the user can proceed by clicking the "done" button. In the event of an error, the user can click the "Reset" button and try again until everything works properly.

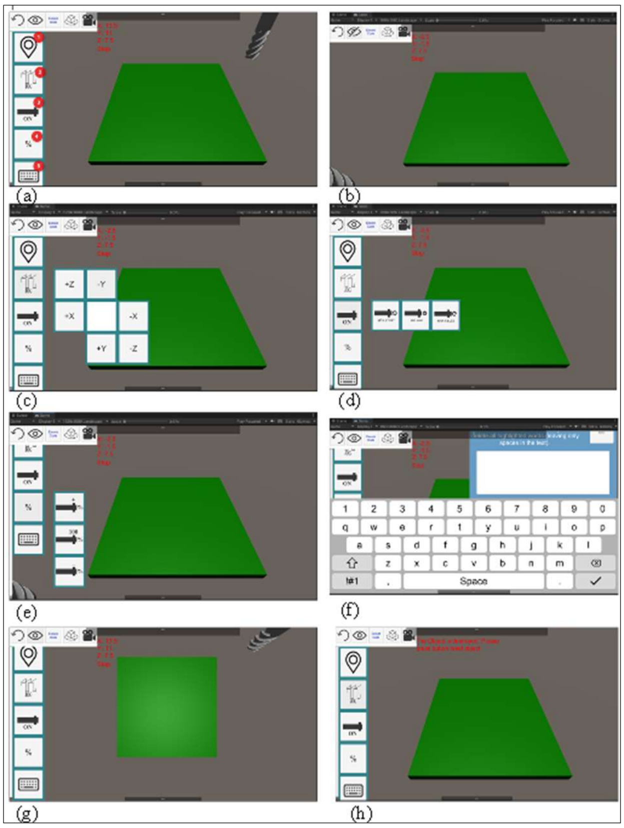


Fig. 11. Working interface; (a) Operation choosing, (b) Set home, (c) XYZ motions control, (d) Rotary control, (e) Speed control, (f) Keyboard command, (g) Camera control, (h) Error notification

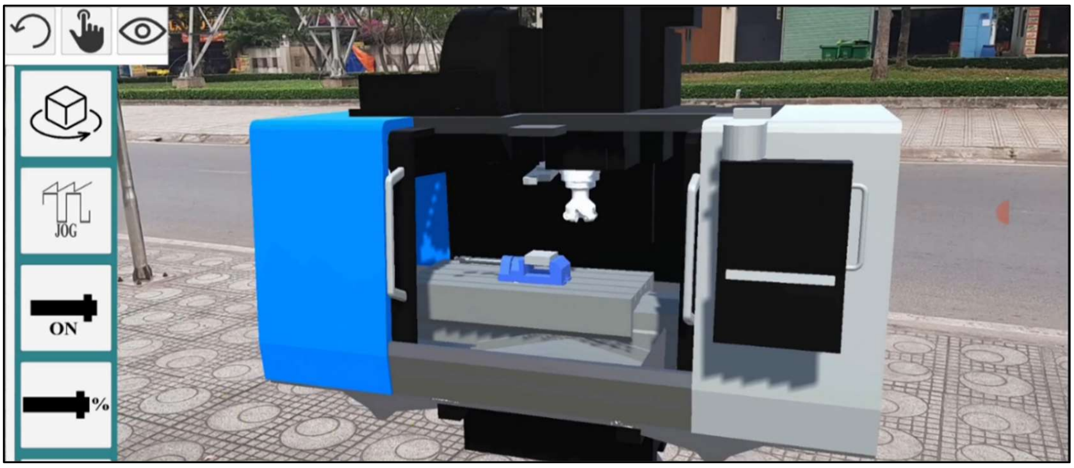


Fig. 12. CNC training using AR mode

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The machine control system remains the same whether the operator selects manual or AR mode. On the left side of the screen, a table of buttons will appear, allowing users to do basic activities such as controlling the machine's X, Y, and Z axes. Users can also change the tool rotation speed and toggle the tool rotation on and off. In manual mode, there will still be a button in the lower-left corner of the screen that allows you to drill or cut. Users can perform drilling and cutting operations on the workpiece in a way comparable to manual mode by pushing this button.

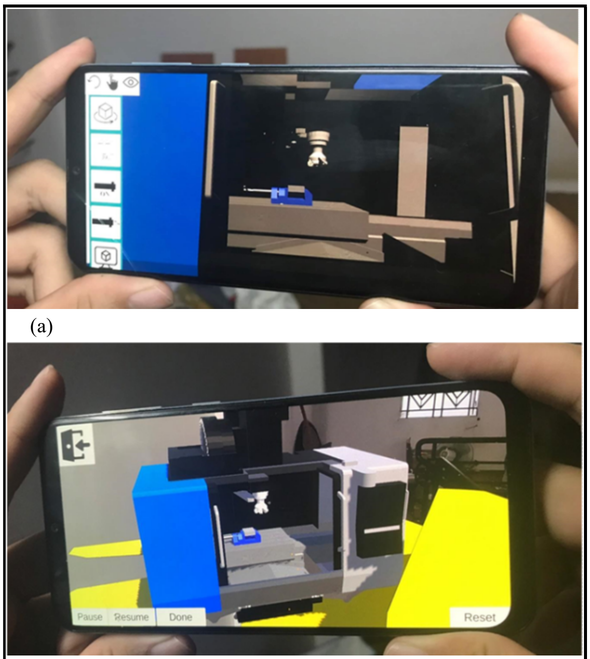
4.2 Mobile Application

Thanks to Unity's capability for exporting files intended expressly for mobile devices, obtaining and installing the files on a phone is a simple process. This is simply accomplished by users by following a few simple procedures. They only need to click "Build and Run" on the display panel for Unity to start creating an APK file specifically optimized for Android mobile devices. When the user clicks "Build and Run" on the Unity display panel, the software begins producing the APK file. Unity uses its built-in tools and functionalities to compile the project, optimize it for performance, and package it in an Android-compatible format. Unity guarantees that all necessary assets, scripts, and configurations are included in the final APK file throughout the build process. Graphics, music files, 3D models, textures, and any other resources required for the application to work effectively on a mobile device are all included. Unity also conducts several optimizations to improve the application's performance on the target platform. It optimizes the rendering process, shrinks file sizes, and employs compression techniques to reduce memory footprint and load times.

Unity generates the APK file, which is the installation package for Android devices, once the construction process is complete. This file contains all of the compiled code and assets required to run the application on the phone independently. Users can then transfer the APK file to their Android smartphone through a USB connection, email, or cloud storage. They may simply locate the APK file and begin the installation procedure once it is on the device. The installation manager on Android will walk customers through the steps required to install the application on their phone. After the installation is finished, users may launch the app from their device's app drawer and begin using the software they produced with Unity. The program will function smoothly, and efficiently utilizing the device's resources to provide the user with a seamless and immersive experience (Fig. 13).

4.3 Operation

Drilling and cutting animations are precisely programmed on the workpiece's surface to give a seamless and realistic experience. The animations are handled flawlessly as the blade glides across the surface, with no glitches or errors. Every feature, from the blade movement to the contact with the workpiece, is meticulously developed to replicate the real-world process. Development ensures that the animations appropriately portray the drilling and cutting motions during the programming process. To generate a visually beautiful and precise picture of the machining process, they meticulously specify the direction, speed, and depth of the blade's movement (Fig. 14).



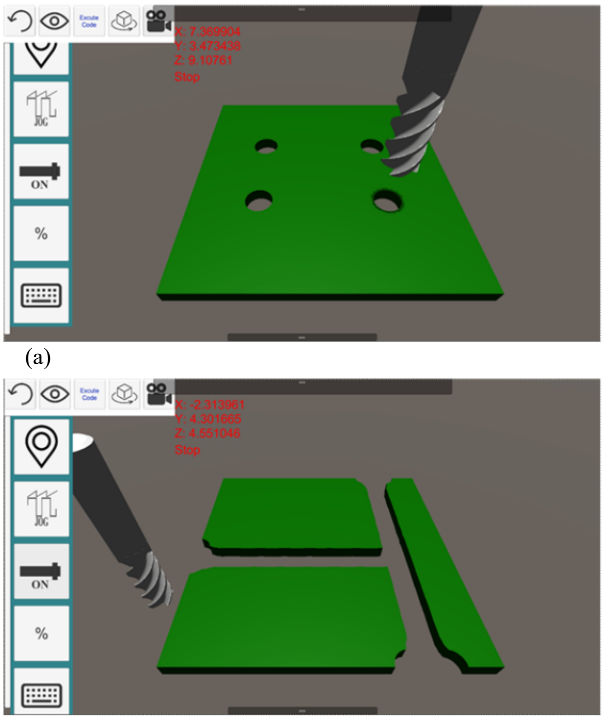
(a)

(b)

Fig. 13. Mobile Application; (a) Manual mode, (b) AR mode.

If the user inappropriately contacts the workpiece, error-handling methods have been created to detect and handle such occurrences. If an inappropriate touch is detected, an error case is triggered. This error notice comes on the screen immediately, informing the user of the improper interaction and providing instructions on how to resolve the problem. These mistake situations are intended to help users comprehend and acquire the proper approaches for managing the workpiece. The software seeks to improve the user's skills and reduce any potential mistakes that could lead to damage or errors in the machining process by offering rapid feedback and coaching.

The emphasis on a smooth user experience and attention to detail ensure that the drilling and cutting animations on the workpiece's surface are not only visually beautiful but also functional and instructional. Users can interact with the software with confidence, knowing that their interactions are appropriately reflected and that any faults will be resolved and reported via the error messages displayed on the screen. The software provides users with an immersive and educational experience by combining realistic animations with good error handling, allowing them to effectively learn and practice the skill of CNC machining in a virtual environment.



(a)

(b)

Fig. 14. Operation (a) Drilling, (b) Cutting

Various programs on the market allow users to imitate their surroundings, however, a common problem with many of these apps is the excessive heat generated by the user's mobile device while in use. This temperature rise frequently causes performance slowdowns and, in some circumstances, program crashes. Compounding the situation is the fact that many users neglect to save their work regularly, potentially resulting in data loss. To address these issues, the author set out to find a dependable app that would not overburden their smartphone. Several smartphones were examined by installing various simulation programs, with priority given to those that feature AR mode, which produces less heat than manual mode.

The program was installed on numerous cellphones and the AR mode was enabled after picking an app that satisfied these criteria. After that, the CNC machine model was installed in the augmented environment to begin testing. It was critical to monitor the app's performance over time to ensure that it remained stable and did not cause overheating or severe slowness. The software was rigorously tested, with each session lasting 15 to 30 minutes. Various operations and interactions were carried out throughout this time to assess the app's performance and its impact on the temperature of the smartphones. The results were very positive, as the app continued to function normally even after 30 minutes. The mobile devices showed no signs of considerable temperature rise or performance deterioration.

These findings reassure the user that the chosen software is dependable and efficient, providing a solid simulation experience without taxing the user's smartphone. Lack of a overheating issues and performance deterioration suggests that customers can use the app for extended periods without fear of data loss or app crashes.

The author has overcome the main issues associated with simulation apps by undertaking extensive testing and carefully picking an app that prioritizes excellent performance and user experience. This enables users to interact with the program without jeopardizing the operation of their cell phones or risking data loss.

4.4 Comparisons

The comparisons with related works are shown in Table 2. In comparison to previous works, this study distinguishes itself by emphasizing AR mode, which allows users to scan their surroundings and visualize a 3D depiction of the CNC machine in their environment. When compared to standard manual mode simulations, this approach gives a more engaging and realistic experience. The incorporation of AR technology allows users to better grasp the spatial relationship between the CNC machine and their workpiece, allowing for more accurate and efficient machining processes. While previous studies on CNC machine simulations and virtual machining have been conducted, the addition of AR technology adds a new level to the user experience. It improves the simulation's visualization and interaction capabilities, making it more engaging and intuitive. The work expands on previous research in virtual machining by utilizing AR technology to produce a more immersive and user-friendly interface. The generalizability of the study results is noteworthy. This study's application demonstrates the feasibility and usefulness of using AR in CNC simulations. The findings can be applied to comparable applications and sectors that use CNC machines. The concepts and approaches used in this work can be used to support future research and development in the realm of virtual machining and CNC simulations.

Table 2. Comparisons of AR Technologies that were used in CNC Training

References	Title	Scope	Technology	Hardware	Remark
Güler and Yücedağ (2018)	Developing an CNC lathe augmented reality application for industrial maintenance training	CNC Lathe	Marker-based AR system	Mobile device	A three-dimensional model of a CNC lathe was modeled. No operation mode yet.
Kovalev et al. (2021)	Development of a mobile application for training operators to work with machine tools with CNC systems using augmented reality	CNC machines	AR	Mobile device	Mobile applications in AR mode can visualize data from technological equipment for CNC machines. No operation mode yet.
Marinakis et al. (2021)	Augmented reality for cad-cam training featuring 3d interactive geometric transformations	Mechanical Drawing	AR	Mobile device	The application can track and recognize 3D CAD models with the use of real-world markers printed on a hard copy of a Mechanical Drawing textbook
Méndez et al. (2021)	Implementation of augmented reality applications to reduce errors in the CNC machining process	CNC machines	AR	PC	Operators and technicians scan markers or QR codes in Datasheets to show 3D objects, animations, and data in AR so that the user can identify the default information and the type of machining process to be carried out. No operation mode yet.
Prasetya et al. (2021)	Improved learning outcomes of CNC programming through augmented reality job sheet learning media	CNC Lathe	AR	PC	Using AR job sheet learning media to display a 3D object, the animation of the process of working on the object with a CNC machine. No operation mode yet.
This paper		CNC Milling machine	AR	PC, Mobile device	The design process, implementation procedure, and control flowchart are presented. Operation modes are developed allowing user interactions.

5. CONCLUSION

Finally, the author has created a comprehensive CNC AR application that allows users to do rudimentary CNC machine operations. In establishing a virtual environment, mimicking the CNC machine, and allowing user interactions, the app displays efficiency and dependability. The program swiftly generates the virtual environment and allows users to interact with the CNC machine simulation using a scanning procedure that normally takes only a few minutes. There are two modes available in the app: AR and Manual. In AR mode, users can scan their surroundings with their mobile devices' cameras to build a realistic 3D representation of the DOONSAN DNM 5700 CNC machine. Compatibility includes both PCs and mobile devices, ensuring cross-platform accessibility. Notably, the program is lightweight and does not overheat even when used for extended periods, delivering a smooth and stable user experience.

Several roaming features can be added further to increase the possibilities of the CNC machine simulation of program. These features are designed to give customers more control, convenience, and an immersive experience. It can include a mechanism that stores data automatically after cutting operations. This feature would ensure that important cutting data, such as parameters, tool trajectories, and workpiece specifications, are automatically recorded and conveniently accessible for future reference or analysis. Users may focus more on the machining process by automating data storage, reducing the danger of losing crucial information. The simulation parameters of the complete machining process with machining results (accuracy, precision, surface roughness) can also be added to the simulation program.

In conclusion, the author's CNC AR application demonstrates remarkable capabilities, allowing users to participate in CNC machine operations via an intuitive and realistic virtual environment. With continual improvements and dedication to user happiness, app promises to become invaluable tool for both CNC machining hobbyists and professionals.

APPENDIX

List of tools used in the paper:
SolidWorks: https://www.solidworks.com/
Blender (3D model): https://www.blender.org/
Unity 3D engine: https://unity.com/
C# Visual studio: https://visualstudio.microsoft.com/

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