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A Learning Platform for Computer Numerical Control (CNC) Laboratory

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Abstract: Information Technology has played a major role in education. Rajamangala University of Technology, Isan Sakonakhon Campus, is committed to promoting a 21st Century education. For example, the university provides an environment that supports this development by integrating the use of Computer Numerical Control (CNC) in teaching practices. The model of CNC machines used in teaching and learning is outdated though, resulting in slow and ineffective performance. However, their efficiency can be improved. The researchers aimed to develop CNC management platforms that increased the efficiency of old-model CNC machines to be used in teaching and learning. The platforms developed consisted of (1) a Wi-Fi Distribution Numerical Control (DNC) G-code platform, (2) a Queueing G-code Monitoring platform, (3) a Setting CNC Monitoring platform, (4) a Safety Control platform, and (5) a Camera and Internet of Things (IoT) Monitoring platform which consisted of temperature, power and vibration sensors. Based on the results, the Wi-Fi Distribution Numerical Control (DNC) G-code program helps decrease the risk of data transmission errors. The speed of transmission increased to 256 kilobytes per second (kb/s). It was found that the developed platforms help improve the efficiency of CNC machining management when being used in teaching and learning. This study can be used as a model for a 21st Century classroom that assists students in optimizing their abilities to respond to the Thailand 4.0 Policy and prepare them for an Industry 4.0 job market.

Keywords: Learning Platform, Internet of Things, Computer Numerical Control (CNC)

Introduction

The world in the 21st century is quite different from the past. The emergence of mobile technologies and other resources has been a vital force in globalization; building economic, social, and political connections between communities, countries, and regions. It is a given that preparing today's youth for 21st Century workforce development is essential. In other words, technological-based learning has become a crucial part of paving the way for students to survive and thrive in an era of globalization. The skills students should obtain include literacy, critical thinking, basic job skills, information technology skills, and life skills. The integration of information technology in the classroom can help to build up a learning environment for students to enhance these traits (Teo, 2019; Peña-Ayala, 2021; Hilliker and Loranc, 2022).

Rajamangala University of Technology, Isan Sakonakhon Campus, is committed to producing graduates with professional qualities who can contribute to the development of their communities along with a knowledge of local wisdom and resources. The university builds up a learning environment where students can enhance their skills through science and technology to become a professional with attributes equal to international standards. The University's goal is to develop and implement a 21st-century education. In response to this goal, the Department of Industrial Engineering, Faculty of Industry and Technology, has promoted hands-on learning and has applied the use of innovations in teaching and learning to produce graduates with work readiness. CNC is one piece of technology that has been used. A CNC machine is a machine with automated controls that works through the use of the software. It is used in machining materials into custom parts and designs. Figure 1 illustrates CNC machines that are used in courses such as Automatic Machine Engineering, Computer-Aided Design and Manufacturing, and Materials Processing. The machines are used in class to illustrate and simulate the processes of material design and how it would run in an industrial plant.

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(a) (b)

Fig. 1: Computer numerical control machine

In the aforementioned courses, the CNC machines are utilized in the classroom to enhance the practical learning experience. Students are also assigned to work with the machines to do an experiment of modem designing based on the developed programs either after school or on weekends. Through this instruction, students get to control the process of inserting or positioning materials and workpieces. When a machine does not run properly due to some errors such as incorrect alignment or an error with a machine, students are required to notify their instructor that a problem has occurred. In some cases, errors cannot be fixed by the instructors as they are not able to see the actual working environment. Furthermore, the machines that are currently used in the classroom are ones that were purchased in 1993, the year that the university was founded. The machines were expensive and designed to be used for specific tasks with specific tool kits designed for the models (Butdee, 2000; Muthupalaniappan *et al*., 2014). Hence, G-code data cannot be sent via the internet and there is no management system for the CNC machines to be used in an internet-based teaching and learning environment. Purchasing a new advanced machine that can be used with different types of technology is difficult for the University due to its high cost. According to the literature review, the researchers found that there are no research studies on the integration of platforms and the Internet of Things (IoT) in a CNC management system for teaching and learning purposes in Thailand. In Thailand, an IoT system is usually utilized and integrated into a production line in the industry (Nganwannakorn *et al*., 2018; Jindarat and Chaiwattanapong, 2018; Phurat and Silawarawet, 2020). Outside of Thailand, IoT is used alongside CNC machining, for example, sending G-code via Wi-Fi, sensors used in sound, temperature, power, and vibration control systems (Al-Saedi *et al*., 2017; Al-Naggar *et al*., 2021).

As a result, the researchers are interested in creating simulations of platforms developed for a CNC management system that can reduce the likelihood of it malfunctioning and that can increase the effectiveness of teaching and learning in the classroom. The platforms to be developed are platforms for Wireless data transmission over Wi-Fi, queue configurations of students' operations, monitoring workpieces and cutting tools, safety controls for a CNC operation, the monitoring of a working environment, and the application of IoT innovations for machine monitoring, etc. The results of the study can be used as a model for the 21st-century classroom that can help foster graduates of a new generation with qualities that align with the Thailand 4.0 policy and employability attributes that are desired in the industry 4.0 job market.

Related Works

In this section, the lists of research and studies on topics related to the development of a learning platform and the integration of an IoT application and CNC machines that have been reviewed are illustrated in Table 1. According to the literature review, studies related to the application of the Internet of Things (IoT) and management of old-model CNC machines for educational purposes in Thailand are not found. It is found that an Internet of Things (IoT) system is only applied in a manufacturing line in industrial plants while a purchase of a new CNC machine is usually not easy due to budget issues. Consequently, the researcher has the idea to develop a management platform for an old-model machine to be used in teaching and learning, alongside the utilization of the Internet of Things (IoT) for CNC machine monitoring with temperature, electricity, and vibration sensors.

Materials and Methods

The framework consists of two major parts (1) Users' part and (2) Developing CNC management platforms for educational proposes through a platform of IoT CNC Room as shown in Fig. 2.

According to Fig. 2, users enter the platform from a Smart Communication Tool such as a desktop computer, notebook, or mobile phone via the internet to log in to the Platform of IoT CNC Room which contains the following 5 platforms:

1) The Wi-Fi DNC G-Code platform
2) The Queueing G-code Monitoring platform
3) The Setting CNC Monitoring platform
4) The Safety Control platform
5) The Camera and IoT Monitoring platform

All the platforms control Haas TM-1 milling machines and OPTIMUM SINUMERIK 808 D lathe machines via a wireless CNC network with working processes Fig. 3.

According to Fig. 3, the working processes of the IoT CNC Room platform include (1) Users or students and (2) Administrators or instructors. Students and instructors must register in the Registration System via https://labcnc.cnc-rmuti.net/login. The system will send a verification code for a user to verify via E-Mail. The instructor can approve a student's log-in request, create questions and assign a task, as well as attach a file, and set up a due date for students. When students submit assignments into the system, instructors can see the number of students who submit assignments on time and who do not. Moreover, instructors can check student assignments and give them feedback online via the system.

When students log into the system, the students can access, download and attach the assignments the instructors give (must be an. NC file only). Students can also simulate G-code via the open software verifying program to check for correctness. After students submit assignments' files and specify the machines (milling or lathe machines), they need to wait for their instructors to check their files and give an "Approved" status. In case an instructor gives a "disapproved" status, students have to correct their work and resubmit it in the system until the instructor gives an "approved" status. Then, the platforms will begin their processes as shown in Fig. 4.

The Wi-Fi DNC G-code is a platform that helps students send G-Code programs to CNC machines over Wi-Fi through an Internet of Things (IoT) system which allows students to easily manage data and monitor the machines. In this study, the Wi-Fi DND G-code system's Block Diagram as shown in Fig. 5, is a block diagram of the Wi-Fi DND G-code system.

Application is a program that allows users to manage and send G-code data to the machines.

Raspberry Pi OS is an OS system operating the Raspberry Pi dashboard with applied Raspberry Pi 3 Model B + LCD screen to install in the milling machine and lathe machine.

G-code Protocol is a type of data used to control CNC machines.

Table 1: A summary of the related works

No.	References	Summaries of the contributions
1	Muthupalaniappan *et al.*, (2014)	In this research, a web-based learning platform is developed for CNC machine learning. Due to the high cost of CNC related practical courses, some academies do not have the sufficient budget to purchase industrial machines for their courses. Consequently, this research develops an inexpensive two-axis lathe CNC prototype which cultivates a web-based learning platform to keep students attentive and enhances practical learning efficiency
2	Nganwannakorn *et al.*, (2018)	In this research, a device control system for a small-sized plant is developed through an IoT application used in managing a factory's lighting and CCTV surveillant systems in a factory
3	Jindarat and Chaiwattanapong (2018)	This research studies wireless sensor networks for production lines in factories by applies the Internet of Things (IoT) to control current temperature and relative humidity in the production line of the factory without checking the thermometer at the machine
4	Phurat and Silawarawet's (2020)	This research applies the Internet of Things (IoT) to develop a short production processing system by using the Internet of Things (IoT) in the production line of automobiles' air condition parts to monitor production systems or Mini-MES. The system reports delayed productions, which allows users to supervise as quickly as they want
5	Al-Naggar *et al.*, (2021)	This study applies the Internet of Things (IoT) for monitoring CNC machine conditions, controlling vibration, and predicting future maintenance, in which reports are presented to users in real time
6	Al-Saedi *et al.*, (2017)	This study integrates wireless technology and CAD/CAM systems for CNC-related work by integrating the Internet of Things (IoT) concept with the Bezier technique model. This the study also shows the manufacturing process begins with modeling in a CAD system via CAM system, sending NC codes to CNC, collecting machines' data, monitoring processes, manufacturing products, applying the Internet of Things (IoT) for temperature, accelerometers, and gyroscopes controlling
7	Siddhartha *et al.*, (2021)	This study applies the Internet of Things (IoT) for inspecting CNC machine conditions, controlling temperature, current, vibration, and coolant levels, inspecting CNC machine availability Moreover, if a CNC machine malfunctions, the system reports the malfunction immediately

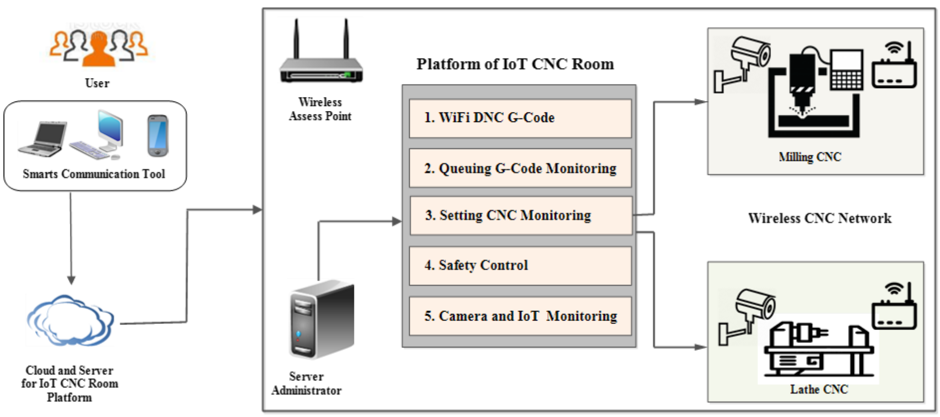

Fig. 2: The framework of learning platform processes in a CNC laboratory

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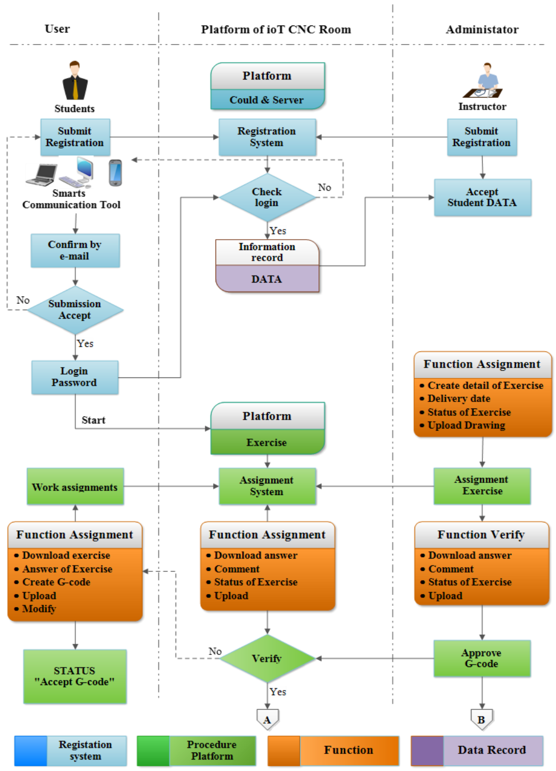

Fig. 3: Working processes of the platform of IoT CNC room

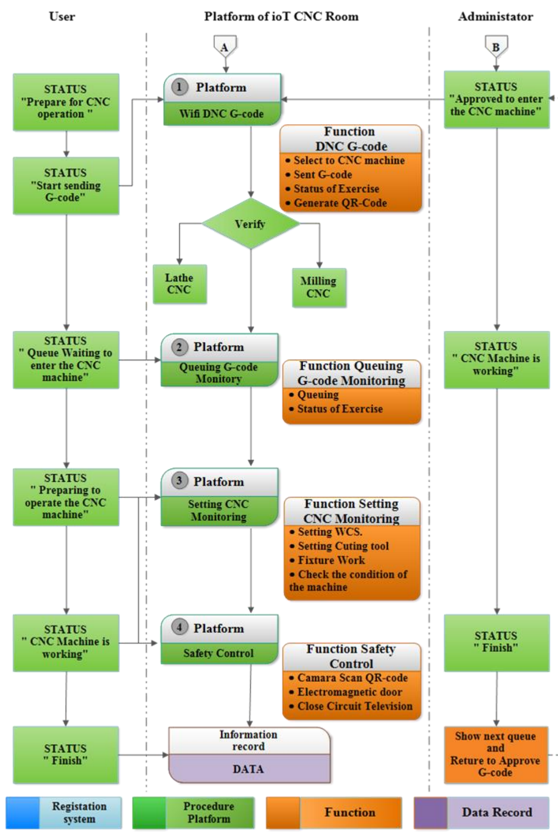

Fig. 4: Working processes of the platforms

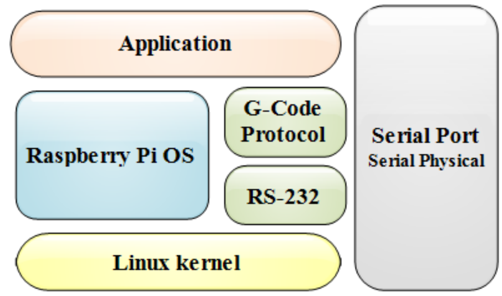

Fig. 5: A block diagram of the Wi-Fi DND G-code system

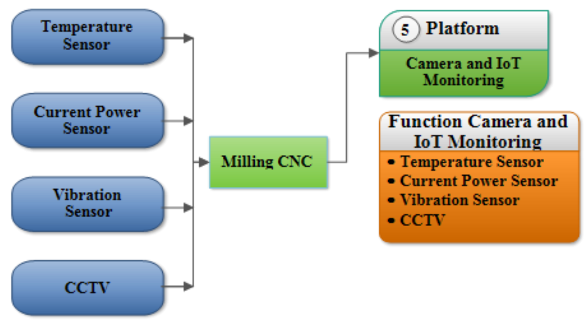

Fig. 6: Platform of the camera and IoT monitory

RS-232 is a Recommended Standard No.232, which is a protocol used in machine-to-machine communication.

Linux Kernel is a basic structure for software and hardware control.

Serial Port is a CNC machine serial communication port with RS 232 (Recommended Standard No.232)

Queueing G-code Monitoring is a platform for queueing students' assignment submissions and configured based on a queue structure, sorting data according to their entry and exit. The subsequent data will be processed later in a First-in, First-Out (FiFO) manner (Jáuregui *et al*., 2017; Patel, 2018; Lyu *et al*., 2021).

Students can use a CNC machine according to their queues (upon the instructors' approval) and the instructors have the right to cancel or swap students' queues.

Setting CNC Monitoring is a platform for monitoring a workpiece and cutting tools, which is a procedure that students are encouraged to perform before using CNC machines as follows:

1) The monitoring of a workpiece set-up and alignment of the World Co-ordinate System (WCS)
2) The monitoring of cutting tools
3) The monitoring of machine conditions
4) The monitoring of workpiece alignment

Safety control is a platform that controls students' safety while using automatic CNC machines. In this study, an electric lock system is used to manage a digital

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door's lock. The system verifies the scanned QR-code that students receive from the platform of IoT CNC Room, unlocks the doors, and gives access to students to use the CNC machines.

Moreover, the researcher set up a CCTV (IR Camera) surveillance system for instructors to inspect students' workpiece installation before running the CNC machines as set in students' G-Code programs. At the end of the process, students must remove their workpiece and tools and clean the working area.

Camera and IoT Monitoring is a platform for monitoring CNC's conditions and malfunctions with the utilization of an Internet of Things (IoT) system as shown in Fig. 6. This study applies an Infrared Day and Night Camera CCTV system for monitoring students' working environment in a CNC laboratory. An Internet of Things (IoT) system is also applied for monitoring milling CNC machine malfunctions by installing a Z-axis motor spindle with temperature, current power, and vibration sensors (Mishra *et al*., 2018) as illustrated in the following details.

Temperature Sensors: Sense IoT wireless humidity sensors are wireless relative humidity and temperature measuring tools that can measure in solid liquid and gas stages. It is suitable for air temperature and humidity-controlled areas such as cold storage, laboratories, and computer-controlled rooms.

Current Power Sensors: Split core current transformer (Model SCT-013-000) are sensors used for voltage and current monitoring based on a magnetic field sensing principle. The maximum voltage rating of a device is 100 Amps.

Vibration Sensors: Wireless Vibration Sensors (Model ES-P/N 0160-0680-8) are convenient and precise tools that help create a plan for a laboratory's CNC machine maintenance with vibration measuring technology and a small wireless easy-to-install sensor.

After designing the platform working processes, the platform of IoT CNC Room is developed for teaching and learning in relevant courses.

Results and Discussion

The Development of the Designed Platforms

Regarding a communication protocol for users, the researchers implemented JavaScript as a programming language in developing a web server and MySQL as a database used in a registration system, an assignment system, the DNC G-code platform for G-code transfer to CNC machines, the Queueing G-code Monitoring platform and the Setting CNC Monitoring platform for inspection of tasks and cutting tools. Examples of the platform development are illustrated in Fig. 7 and 8.

As illustrated in Fig. 7, when an instructor assigns a task, a student can log in to the platform to check the assigned task. A student can download a task sheet and check for the task details such as a task specification, a machine type to be used, and a task due date (See image No. 1). Students are required to attach a file with the.NC file extension (See image No. 2). Besides this platform, students can use a Simulation G-code test to check for correctness before submission (See image No. 3).

According to Fig. 8, after logging in, instructors can view the number of students who submit their tasks by the deadline and those who do not submit their tasks. Tasks can be downloaded or marked online anytime. Instructors can also give feedback to students via the platform (See mark No. 1 in the Figure). When an assignment is approved to pass by an instructor (See mark No. 2 in the Figure), the students are required to amend and resubmit their assignment until it is approved to pass by the instructor (See mark No. 3 in the Figure). The details of the platform development in this section are as follows.

The development of the Wi-Fi DNC G-code platform enables students to transfer a G-Code program to a CNC machine over Wi-Fi through an IoT system. A system transfers the program data from a Raspberry Pi board to a machine set up by a student after approval from an instructor (Fig. 9) (Kim *et al*., 2019; Abdulhamid *et al*., 2020). In case the data is accidentally or unintentionally deleted, or a program crash occurs, the existing data are stored in a cloud platform and computer database server. Data of G-code tasks are stored in Memory Raspberry Pi.

The development of the Queueing G-Code Monitoring platform is a queue configuration for transferring students' programs. Figure 10 illustrates how students' programs are respectively queued.

Figure 10 illustrates how students' programs are queued for transfer. After an assignment is submitted by a student and approved by an instructor, an assignment's status is sorted as "Waiting queue for transferring to the CNC machine" (See mark No. 1 in the Figure). If an assignment is not submitted by the deadline, the status is sorted as "Overdue" (See mark No. 2 in the Figure) and the status can be canceled or swapped by an instructor. If an assignment is completed as assigned, the status is changed to "Completed." After that, the platform shows a notification of the next queue. Then, the QR code is generated to be used with other relevant platforms and can be downloaded only when it is the turn for that queue.

A Setting CNC Monitoring platform is developed for monitoring workpieces and cutting tools. This procedure is essential for students to perform before using a CNC machine to inspect the setup and tools as illustrated in Fig. 11.

A Safety Control platform is developed as a system to control safety during students' CNC operations. An operation is conducted under a digital door system. To use a machine, students can download a QR code available on a platform and scan it to get access. Besides this safety control procedure, there is also a CCTV system for an instructor to monitor students when they set up their workpiece before starting a CNC operation set in their program, as shown in Fig. 12.

A Camera and IoT Monitoring platform are developed for monitoring a working environment as shown in Fig. 13 and any CNC machine error can be checked through an IoT system as shown in Fig. 14.

According to Fig. 13, an instructor can monitor a working environment during a student's operation in a CNC lab through a video surveillance system only.

According to Fig. 14, an IoT system is utilized for monitoring the malfunction of a CNC milling machine. It is installed on a Z-axis motor spindle. A platform consists of temperature, current power, and vibration sensors. An IoT sensor will record data and generate a report that can be used in monitoring a machine's condition. This will help manage potential risks before there are machine damages and predictive maintenance.

Results of Assessment of Platform Performance

The findings of the study regarding the framework, techniques, and devices are in line with the findings of the studies conducted by Kim *et al.* (2019); Jáuregui *et al.* (2017), and Hilliker and Loranc *et al*. (2022) as follows.

In sending data through the Wi-Fi DNC G-code platform, the data of a G-code program could be sent to a CNC machine at a faster speed rate. It reduced the risk of data distribution errors that occurred in the old system. Table 2 illustrates the comparison of rates of data transfer.

According to Table 2, data transfer done through a Raspberry Pi board is the fastest one when compared to data transfer through Post RS-232 and USB. Furthermore, a disconnection problem that occurred before remains when DNC is performed for a long period because the machine did have a memory card.

The Queueing G-code Monitoring platform is developed for queue configuration for students. A platform is developed based on the first-in, first-out principle. This helps optimize a machine's efficiency and reduce the cycle time in a CNC process.

The Setting CNC Monitoring platform is developed based on a check-sheet principle. Students are always reminded to follow the steps in preparing a workpiece and cutting tools and check for machine readiness. These steps help students reduce the risks of errors that may cause damage to a machine.

The Safety Control platform has an identity authentication system using QR codes to protect unauthorized individuals from accessing it.

The Camera and IoT Monitoring is based on real-time monitoring with the use of sensor technologies for error detection (Rizal *et al.*, 2014; Plaza *et al.*, 2019; Mareš *et al.*, 2020). Figure 15(A) - 15(C) illustrate the records of CNC working conditions.

The results of temperature and acceleration measurement tests were presented in 180 min. According to Fig. 15(A), temperatures were between 35 to 50 °C. The maximum temperature was set at 55 °C. If higher than that, the system is set to make a notification of a malfunction warning to related persons. Figure 15(B) illustrates the records of acceleration monitoring of a CNC machine, with the frequency range at ±1. If higher than that, the system is set to make a notification of a malfunction warning to related persons.

The graph in Fig. 15(C) illustrates the records of power measurement tested at a rotation at a speed range of 0-4000 rpm. The peak load is 0-2.4 kw. If higher than that, the system is set to make a notification of a malfunction warning to related persons.

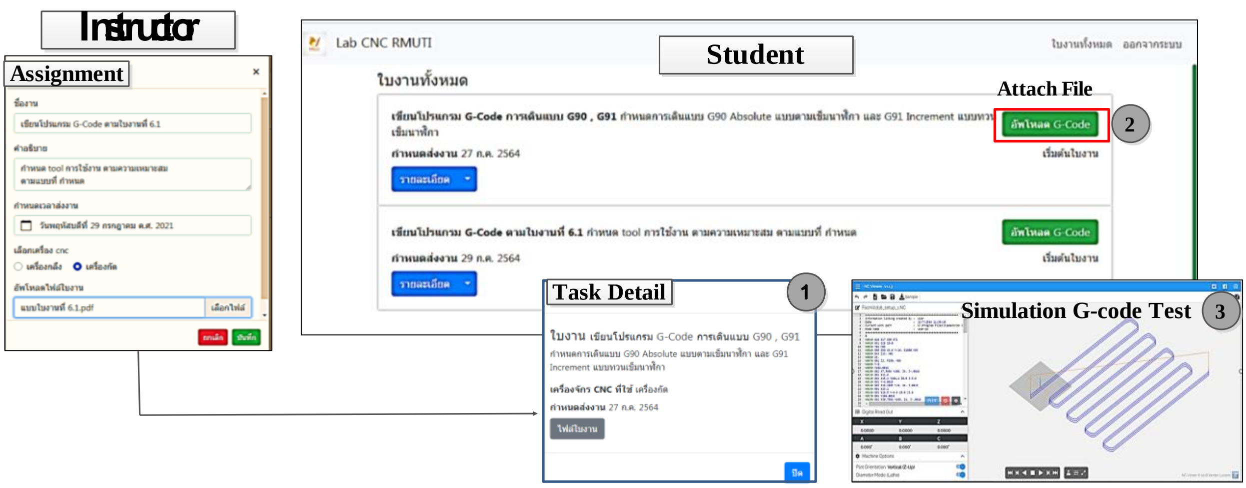

Fig. 7: An illustration of a screen display of a platform for instructors to assign a task and for students to check and submit their assigned task

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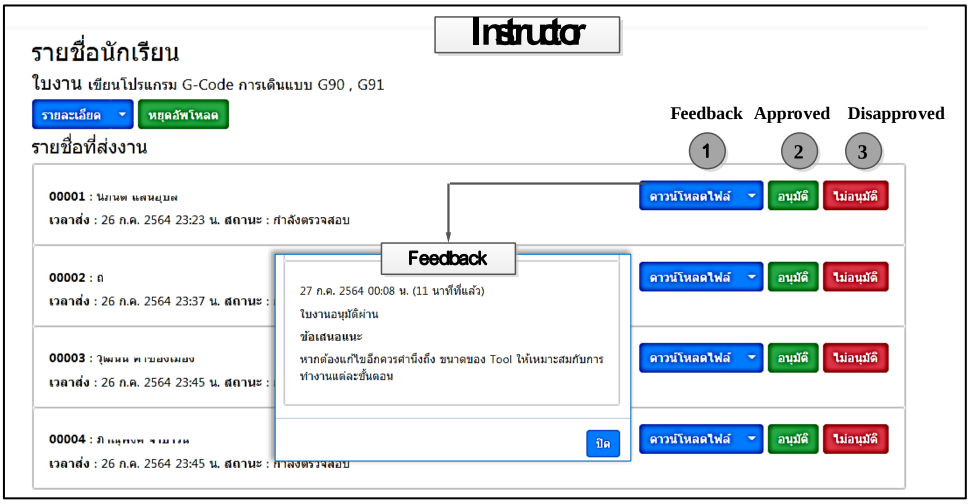


Fig. 8: An illustration of a screen display of a platform for instructors to mark assignments

Fig. 9: An illustration of the installation of a DND Wi-Fi device on a CNC machine

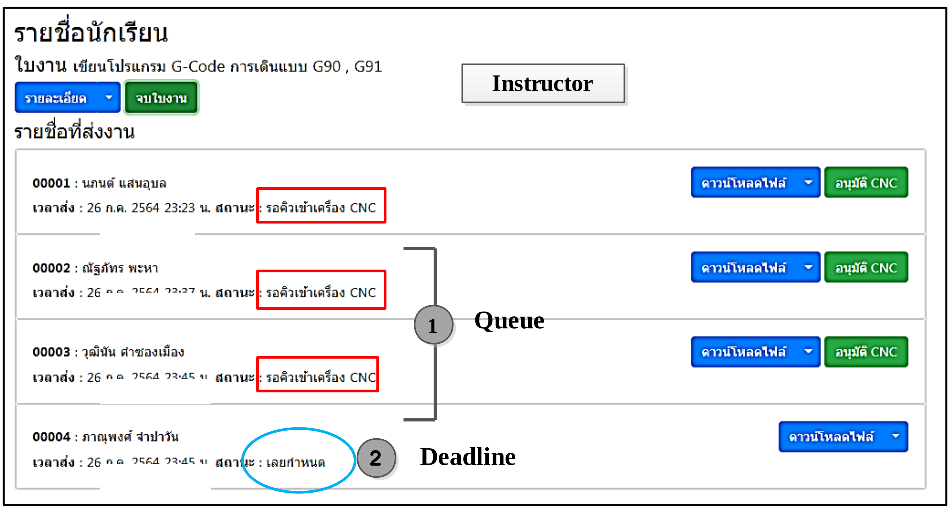


Fig. 10: An illustration of a screen display of a Queueing G-Code Monitoring platform used in transferring students' programs

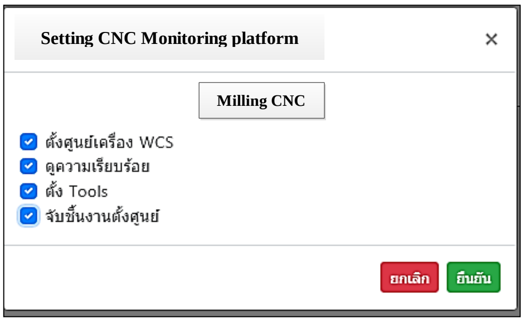


Fig. 11: An illustration of a screen display of a Setting CNC Monitoring platform

Fig. 12: A Safety control platform to control safety during a CNC operation

Fig. 13: The camera and IoT monitoring platform

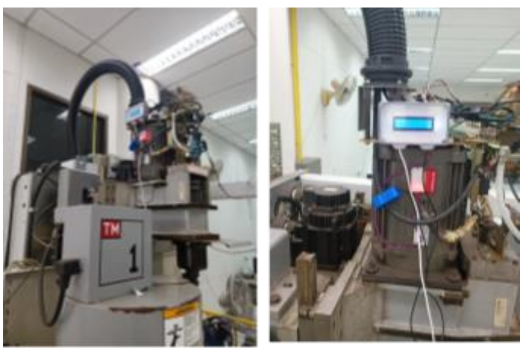
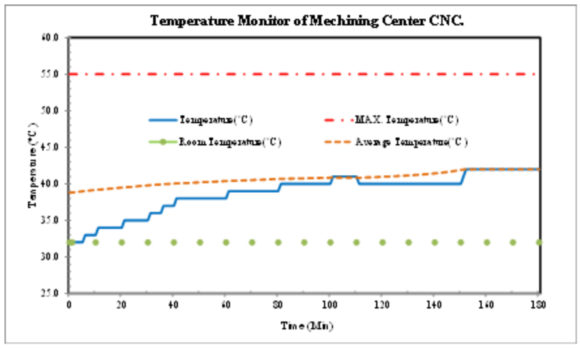
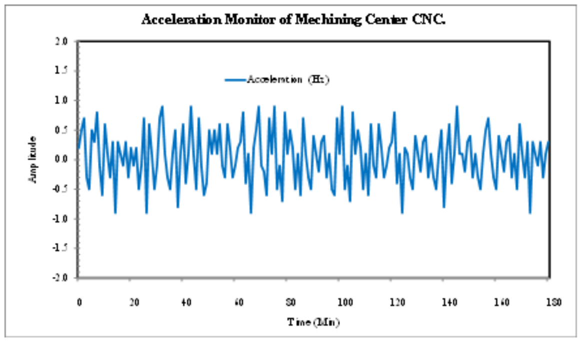


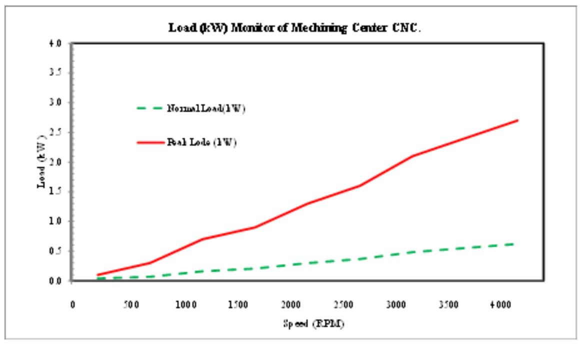
Fig. 14: A camera and IoT monitoring platform to monitor CNC errors through an IoT system



(a)



(b)



(c)

Fig. 15: (A). A graph of temperature monitoring records; (B). A graph of acceleration monitoring records; (C). Graph of power current monitoring

Table 2: Comparisons of data transfer rates

Tools used for data transfer	Data transfer rates
Port RS-232	9,600 b/s
USB	14.4 kb/s
Raspberry PI	Maximum transfer rate at 256 kb/s

The satisfaction assessment of the development of CNC management platforms for teaching and learning consisted of 20 people in the research sample; 3 experts and 17 students who were enrolled in Automatic Machine Tool Engineering in the third Semester of the academic year 2021. The purpose of the assessment was to evaluate the development of the platforms in (1) the qualities of the developed platforms (2) the content qualities of the developed platforms and (3) the user satisfaction. The assessment results show that the overall level of satisfaction is at a very good level (Mean = 4.52, S.D. = 0.69). The level of satisfaction with the qualities of the platforms is at a good level (Mean = 4.44, S.D. = 0.71) while the level of satisfaction with the content qualities is at a Very Good level (Mean = 4.52, S.D. = 0.64). The level of user satisfaction is at the Very Good level (Mean = 4.60, S.D. = 0.53).

Conclusion

The study aimed to develop the platforms of CNC management for old-model CNC machines to be used in practical teaching and learning with more efficiency. The existing CNC machines currently used at the University are old with outdated DNC technologies, resulting in low capacity and speed performance. However, the efficiency of the machines can be improved. The developed platforms are designed to improve CNC machine management when integrated into teaching and learning. For example, the platforms enable data transmission over Wi-Fi and also allow 24-h monitoring of students' operations and machine working status. This study can be used as a classroom model, for teaching and learning integration, at both higher education and vocational levels, for courses that use CNC machines. The study is beneficial to the development of CNC machine management in small and medium-sized industrial factories. It can also be employed as a model for the development of a 21st Century classroom that helps foster graduates who have competencies built in line with Thailand's 4.0 Policy and obtain desirable qualities that are needed in an Industry 4.0 job market. According to the aforementioned review, researchers who are interested in this area of research can integrate or apply the framework from this study in their research in finding solutions for similar problems and maximizing machinery efficiency. The researchers are interested in developing technology integration that can improve the efficiency of an old-model CNC machine and finding more techniques and approaches that can be used with modern IoT devices to reduce the workload of teachers.

Acknowledgment

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Author's Contributions

Charinee Chaichana: Platform designing, analysis, development, testing, and research writing.

Seetala Wongkalasin: Platform analysis and testing.

Apichat Sanrutsadakorn: Platform analysis on issues related to CNC machines, platform testing, and installation of necessary devices.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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