IoT-Based 3D Printer Development for Student Competence Improvement

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Abstract. This study aims to develop an IoT-based 3D Printer as a CNC Maintenance and Repair Learning Media, identify competencies that can be supported by an IoT-based 3D Printer Learning Media, and find out the implementation of 3D Printers in learning to improve student competence in the Mechatronics Engineering Education Study Program. The method used in this research is Research and Development using the ADDIE model, namely Analyze, Design, Development, Implementation, and Evaluation. The results of this study obtained an IoT-based 3D Printer machine that has been tested both in terms of function and feasibility which can be used in learning to improve the competence of students of the Mechatronics Engineering Education study program and the competencies supported by the learning media.

1. Introduction

Various challenges are faced by the world is facing challenges in the era of the fourth Industrial Revolution (Industry 4.0). New technologies and approaches that combine the physical and digital worlds will fundamentally change human civilization today. Humans are on the threshold of a technological revolution that will fundamentally change the way of life, work, and relate to one another. In addition, entering the technological era as well as the fourth industrial revolution led to changes in various sectors, including in the world of work and industry.

Educational institutions have the role and responsibility to act as quickly as possible to design action plans to prepare future people to face new challenges. Educational institutions need planning for action in different directions and different fields, such as laboratories, teachers, and curriculum [1].

Education has the task of organizing an educational process to prepare experts for the Industry 4.0 paradigm. The Industry 4.0 paradigm means creating an industry with digital informative technology and functions automatically. To be able to work in the industry, education must prepare a supportive competency profile. The scientific content of educational programs must contain the nature of interoperability for all technologies used together in digital production [2].

Graduates must have the appropriate competencies in meeting the needs of the current Industrial Revolution 4.0 Era. Industry 4.0 is known as a term for digitizing the production process of goods and services where decisions are made without involving humans by making computers connected and communicating with each other. The application of industry 4.0 is currently carried out in the fields of: Internet of Things (IoT), robotics, smart factories, 3D printing, routers to innovations in goods and service production systems that are integrated with information and computer technology (ICT).
In adapting to the era of the industrial revolution 4.0, the world of education requires major changes. Curriculum, learning, environmental, social, and cultural changes in the school environment need to be made in adapting to this era. To support educational attainment in the era of industrial revolution 4.0, facilities and infrastructure are needed in learning, one of which is practicum equipment. One of the factors that have a strong influence on the output in education is the fulfillment of the needs of school facilities used in learning such as practicum equipment.

Practical learning must be reproduced to achieve appropriate graduate competencies in the Industrial Revolution 4.0 era. Several supporting factors must be met to achieve success in practical learning in the Mechatronics Engineering Education study program. One of these factors is the facilities and infrastructure, especially in the field of learning media or practical equipment. The practicum equipment used in learning must support and adapt to the needs in the era of industrial revolution 4.0 with the characteristics of working automatically, 3D printing, working based on the internet of things (IoT), and Data of Things. According to Shuning Li [3], IoT and 3D printers are two important new technologies, these technologies are increasingly impacting many fields of industry and daily life. Therefore, students need to be introduced to this technology and get ready for future career opportunities.

One of the practical pieces of equipment that works with the principle as mentioned above is a 3D Printer machine. According to Assante et al [4], currently, the use of 3D printers is increasingly widespread as a supporting tool in education, so it is necessary to have special skills and competencies in using this technology. Günther [5], stated that the obstacle in implementing the practical use of digital technology, in this case, 3D printers, for students is the lack of the necessary equipment and technical knowledge in many universities. The 3D Printer design that will be developed has been equipped with modern computing technology. This IoT-based 3D printer learning media aims to make students not only skilled in operating a tool but can design and program to make an object.

1.1. 3D Printer Technology
3D Printer is a medium that forms a component using layers of material to create objects in 3 dimensions. 3D Printers can create physical objects from geometric representations by sequentially adding materials.

![Figure 1. The work process in 3D Print technology](image)

3D Printer technology is derived from the technology of layer-by-layer structural formation of objects in three dimensions (3D) directly from computer-aided design (CAD) drawings. Conventional
thermoplastics, ceramics, graphene-based materials, and metals are materials that can now be printed using 3D Print technology. 3D Print technology has the potential to revolutionize the industry and transform production lines. Production speed will increase and costs will be reduced further with the adoption of 3D printing technology. So that further consumer demand will have a greater influence on production. The process in 3D Print can be seen in Figure 1.

At present, 3D printing technology is increasingly being used for mass customization, production of all kinds of open-source designs in the field of agriculture, health care, automotive industry, locomotive industry and aviation industries [20].

Shahrubudin [20] state that according to ASTM Standard F2792, ASTM categorizes 3D printing technology into seven groups, namely binding jetting, directed energy deposition, extrusion material, jetting material, powder bed fusion, sheet lamination, and vat photopolymerization. Currently, 3D printing technology is no longer limited to the use of prototypes but is increasingly being used to make various products. 3D Print technology is capable of producing components in a variety of materials, namely ceramics, metals, polymers, and their combinations in the form of hybrids, composites, or functionally graded materials (FGMs).

A 3D printer machine consists of components, namely Motherboard, Frame, Motion Controller, Power Supply Unit, Print Material, Feeder System, Extruder, Print Bed, Connectivity, Interface. The motherboard serves as the brain of the 3D printer which directs the motion components according to the instructions sent from the computer and at the same time, interprets the signals from the sensors. The frame serves to unite all the components of the 3D printer and maintain stability in its operation. Motion controller/motion controller will receive instructions from the motherboard about the movement to be done, this component consists of a belt, stepper motors, threaded rods, and end stops.
The Power Supply Unit serves to provide power for the smooth operation of the 3D printer components.

Print material in the form of filament is used for FDM 3D printers. Filaments are available in coils. The filament is heated to a certain temperature and melted for printing on the print bed. There are two feeder systems in the feeder system which are most commonly used in 3D printer components, namely the Bowden system and the direct system. An extruder or also known as a print head extrudes the filament and prints it on the print bed. The print bed is the place where the product/design will be made. In terms of 3D printer connectivity, some 3D Printers only provide an ethernet or USB port for connection. However, nowadays there are many 3D printers available with Wi-Fi settings. Most 3D printers come with an LCD user interface.

1.2. Internet of Thing
The era of the industrial revolution 4.0 has used Cyber-Physical Systems, in other words, the industry has used the internet and big data for all processes in the industry. With the Revolutionary Era 4.0, the industry produces a smart factory where everyone uses the Internet of Things (IoT). IoT is a concept such as industrial machines, electric generators, vehicles, household appliances, to wearable devices that are interconnected through networks to exchange in real-time [10]. There are four principles in Industry 4.0, namely: (1) the ability of machines, devices, sensors, and humans to connect and communicate with one another through IoT; (2) the ability of information systems to create a physical world into a virtual world; (3) the ability of information systems to assist humans by gathering and visualizing comprehensive information and performing a range of tasks that are too strenuous or unsafe for humans; and (4) the ability of cyber systems to make their own decisions and perform tasks independently [11].

According to Handayani [12], the Internet of Things is the next evolution of the Internet where it takes a big leap in its ability to collect, analyze, and distribute data that turns into information, knowledge, and wisdom. The purpose of the Internet of Things is to connect devices to one another via the internet in the hope that the system can help people in doing a task or work [13].

Internet of Things also allows users to manage and optimize electronic and electrical equipment connected to the Internet [12]. Meanwhile, according to Hidayatulloh [14], the Internet of Things is a concept that aims to expand the benefits of continuously connected internet connectivity. This means that the Internet of Thing utilizes a programming argument in which every command of an argument produces an interaction and communication between machines that are connected automatically through the internet.
2. Research Methodology

A design developed by Mohamad Hasan Bin Tasneem and Gamal Talal Amer [15]. 3D Printers use BLDC motors because the accuracy and efficiency are much higher than the current use of stepper motors. In addition, it uses a ball screw instead of the main screw as it provides smoother, quieter, and more efficient movement.

Based on research conducted by Ishtiaq Ahmed, et al [16], 3D Printer is an additive manufacturing technique in which 3D objects are printed with the help of CAD (Computer-Aided Design) software. The process adopted is FDM technology, in which different materials such as PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), HIPS (high impact polystyrene), etc. By heating one of the filament materials to its melting point and carried out layer by layer.

The results of research conducted by Jun Zhao [17], new technology in the design of 3D Printers use nozzles of different diameters in different stratification heights respectively on the printing pressure surface, internal support, and auxiliary support of the workpiece, and effectively improves printing speed and precision molding of the workpiece surface, with different wire materials, at a suitable temperature range to ensure the extrusion mechanism on the stability of the filament, and improve the shaping precision of the workpiece.

The research was conducted using the Research and Development method. This research was carried out based on the ADDIE model, namely Analysis, Design, Development, Implementation, and Evaluation. At the Analysis stage, the identification of what competencies are needed by students in terms of the design and operation of IoT-based 3D Printers. This is intended to see the extent of the specifications of the 3D Printer that will be made to support these competencies. The Design stage is carried out by designing an IoT-based 3D Printer according to the needs at the analysis stage. This design is carried out in the form of hardware and software. The results of the 3D Printer design that will be used are expected to be close to industry standards.

![Figure 5. Initial design of an IoT-based 3D Printer system](image)

The development stage is carried out by making the 3D Printer starting from assembling the hardware, then installing and connecting the software to the assembled hardware. Settings are also made on the software so that it can communicate with the hardware that has been prepared and can be controlled via the internet network. At this stage, validation of the media that has been made is carried out. The validation is carried out by experts and lecturers who teach courses that are following the objectives of this research. At the implementation stage, the implementation of the CNC maintenance and repair practice course is carried out using a 3D Printer. The selection of classes as respondents, step-by-step implementation of learning, and getting feedback from students and lecturers are carried out in this process. The evaluation stage is carried out to obtain improvements from the implementation that has been carried out. Improvements in hardware, software, lesson plans, and user manuals are carried out in this stage.

This study has the ultimate goal of designing a learning media in the form of an IoT-based 3D Printer to improve student competence in the Mechatronics Engineering Education study program. It is
expected that the results of this study can be used by the study program and develop competencies of students, especially in terms of design, installation, programming, and control of a 3D Printer.

Data collection was carried out in two ways, namely literature studies related to the competencies needed by students in terms of design, installation, programming, and control of IoT-based 3D Printers and questionnaires to validate the results of the designs that had been implemented. Performance testing of the tools that have been made is also carried out in the data collection process by taking tool parameters that will produce specifications and tool manuals.

3. Discussion on the Results of the Redesign
The analysis stage is carried out by identifying what competencies are needed by students of the Mechatronics Engineering Education study program related to the operation and maintenance of 3D printers as one of the parts studied in the CNC maintenance and repair course. This analysis phase is carried out by studying literature obtained from various sources related to the operation of 3D printers for learning. The curriculum compiled by Erasmus+ supported by the European Commission [18] presents learning outcomes and a sequence of activities designed to learn 3D Printers which consist of; 1) Technical Basic, 2) Introduction to 3D Printing, 3) 3D Printing in education, 4) Design and/or print 3D objects, 5) Overview of CAM Processes, and 5) Set up a 3D Printer. In the curriculum of the UNY mechatronic engineering education study program, it has been studied regarding the introduction of 2D and 3D designs in the Engineering Drawing and CAD Practice course so that the operation of 3D Printers in the CNC maintenance and repair course prioritizes the CAM process and prepares 3D Printers to print objects. In the discussion related to the CAM process, we will briefly discuss the CAM process, CAD and CAM processes, and 3D Printer materials. Materials related to preparing a 3D Printer to print objects consist of an introduction to the parts of an IoT-based 3D Printer, how to build an IoT-based 3D Printer, Setting up an IoT-based 3D Printer, and Maintenance and troubleshooting related to an IoT-based 3D Printer. The hardware and software produced at the design stage are presented in Figure 6.

Table 1. Topics and explanations of CNC maintenance and repair course related to 3D Printers.

| Meetings and Topics | Learning Materials |
|---------------------|--------------------|
| Meeting 1: CAM Process | Overview of CAM processes, CAD and CAM processes, and 3D Printer materials. |
| Meeting 2: Setting up the 3D Printer | Introduction of IoT-based 3D Printer parts, building an IoT-based 3D Printer machine. |
| Meeting 3: The process of printing objects | IoT-based 3D Printer setup and Maintenance and troubleshooting related to IoT-based 3D Printers. |

The 3D printer performs the Additive Process from the Gcode 3D design that has been made using Filament material as the construction medium. Raspberry Pi is used as a 3D printing bridge with users over the internet. As well as controlling and retrieving data needed for IoT from 3D printing such as working temperature data, camera monitoring, percentage of running processes, as well as cloud storage so that Gcode design data can be stored and used at any time. Octoprint is an agent providing 3D printing connectivity services to be able to connect to the internet. Gujar [19] explains, IoT-based Octoprint provides a web interface to control 3D printers, enabling users to start printing jobs by sending Gcode to a 3D printer connected via a USB port. Octoprint is free, open-source software that allows to remotely perform and monitor all aspects of a 3D printer using a Raspberry Pi.

This Octoprint has its own Operating System called Octopi which is installed into the Raspberry Pi so that IoT can work. In addition, Octoprint is also tasked with retrieving the required data from 3D printing via a USB cable. The internet router/modem serves to connect the Raspberry Pi device to the internet so that the IoT system can work properly. Local devices consisting of Smartphones, PCs, or laptops connected to a local network, the function is to access Octoprint so that it can function as a controller of the IoT 3D printing system. A local network is a local internet network (LAN) emitted by
a router/modem connected to the IoT system on Octoprint. Cloud or the Internet serves to store data so that it can be used in the IoT 3D printing system, usually containing the Gcode of the design to be printed. The Spaghetti Detective (TSD) is third-party software that can be integrated with Octoprint so that users can access the IoT 3D printing system from anywhere without having to connect to a local network. External devices are devices used by users who are outside the local network so that users can access IoT 3D printing anytime and anywhere as long as the device they have is connected to the TSD.

![Diagram](image)

**Figure 6. IoT-based 3D Printer hardware and software design**

When the user is outside the local network and will operate the 3D printing machine, the user can use TSD as an intermediary. The TSD will later operate Octoprint through the existing internet network. Users simply enter the Gcode design that will be printed to the cloud that has been provided by TSD. Then after that, the user can start printing the design by pressing the start printing button and then selecting the Gcode file to be printed. At that time, TSD will send the Gcode file into the Octoprint system. In the Octoprint system, the Gcode file will be translated and later will be entered into the 3D machine via a USB cable. 3D printing that has received the Gcode file from Octoprint will then work on the file into a 3D form that is following what was designed by the user. Due to the model of accessing via the internet, the quality of the internet network connected to both local and external devices greatly affects the 3D print response in executing commands.
Figure 7. TSD display on the Smart phone screen

Figure 7a is an initial view of The Spaghetti Detective which is accessed using a smartphone. In this initial view, several parts are seen, namely the monitoring section and the control section. The monitoring section shows images in real-time that are connected to the camera on 3D Printing. While the control section has a start printing button to start the printing process.

In Figure 7b, showing the process when it has started the print process, here it is possible to monitor the temperature of the Hot End (left) and Hot Bed (Right) where this monitoring is based on the temperature setting that is set when carrying out the slicing design process. The temperature monitoring display is divided into two parts, namely monitoring the running temperature on the top side, and monitoring the target temperature on the bottom side.

As for the main display, monitoring of the 3D printing process can be carried out, such as estimated time, estimated completion, and the 3D printing process is declared good, as shown in Figure 7c. In addition, the Pause and cancellation process can also be carried out if needed. While the name of the file that is printed will be displayed on this menu to minimize errors in selecting the file to be processed.

Figure 8. TSD display on Smartphone screen for 3D Printer axis control
Figure 8 shows the 3D printing axis control display where this menu can be accessed by double-tapping on the monitoring section of the home menu. In this view, you can control or adjust the position of the nozzle on the X, Y, and Z axes in 3D printing by clicking the arrows on the buttons. If you want to adjust the X, Y-axis then use the right-side button, then if you want to adjust the Z-axis use the left side button. If you want to do home coordinates or do machine zero points, then you can click the button with the symbol of the house and the axis in it. The button that says 10mm is a one-click movement distance setting, so when you click the arrow button once, the axis will move 10mm in the selected direction. Then to clean the button so that it doesn’t interfere while monitoring, you can do it by clicking the eye button on the top right side of the screen. The process of operating the 3D printer carried out in the test is shown in figure 9.

An IoT-based 3D Printer machine has been tested for accuracy by providing input commands via gadgets (SmartPhone, Laptop) then measuring and comparing the command and the results of the machine movement. The measured movement is the movement in the direction of the X, Y, and Z axes with the command of 1 click movement or multiples thereof which results in a shift of the nozzle towards the selected axis. The results of the movement are then measured using a ruler, then compared between the measurement results (output) and the command (input).

| X-Axis Direction in (mm) | Y-Axis Direction in (mm) | Z-Axis Direction in (mm) |
|--------------------------|--------------------------|--------------------------|
| Input | Measured Value | Input | Measured Value | Input | Measured Value |
| 0-10 | 10 | 0-10 | 10 | 0-10 | 10 |
| 10-20 | 10 | 10-20 | 10 | 10-20 | 10 |
| 20-30 | 10 | 20-30 | 10 | 20-30 | 10 |
| 30-40 | 10 | 30-40 | 10 | 30-40 | 10 |
| 40-50 | 10 | 40-50 | 10 | 40-50 | 10 |
| 50-60 | 10 | 50-60 | 10 | 50-60 | 10 |
| 60-70 | 10 | 60-70 | 10 | 60-70 | 10 |
| 70-80 | 10 | 70-80 | 10 | 70-80 | 10 |
| 80-90 | 10 | 80-90 | 10 | 80-90 | 10 |
| 90-100 | 10 | 90-100 | 10 | 90-100 | 10 |
Figure 10. The process of measuring the results of the movement on the 3D Printer nozzle

From the results of testing the accuracy of the movement of the 3D Printer in table 2, it can be seen that there is no significant difference between the input value and the measured value on the movement of the nozzle towards the X-axis, Y-axis, and Z-axis. Testing the accuracy of tool movement is carried out for the setting value of 1 click (10 mm) to 10 clicks (100 mm) for the X, Y, and Z axes. The amount of this input value can be set via the device using the TSD application. Based on the measurement results, it can be concluded that the IoT-based 3D Printer that has been developed can be controlled and serve design processing via the internet with printer results that match the design input. The materials used in the implementation trials were filaments made from Polylactic Acid (PLA).

4. Conclusion
Based on the description above, IoT-based 3D Printers can support learning CNC maintenance and repair courses with relevant topics related to the CAM process, setting up a 3D Printer and the process of printing objects using a 3D Printer. This tool can be used by being operated or controlled via the internet so that the learning process can be done online.

The stages of research and development, namely analysis, design, development, implementation, and evaluation, have been carried out and resulted in IoT-based 3D Printer learning media, identification of student competencies in terms of the design and operation of 3D Printers, and learning modules that can be applied in learning. The design and manufacture of IoT-based 3D Printers as Learning Media consists of designing hardware and software where the hardware used consists of 3D Printers as processors. Raspberry Pi is used as a 3D printing bridge with users over the internet. Octoprint as software installed on the Raspberry Pi, is an agent providing 3D printing connectivity services so that you can connect to the internet. Local devices consisting of Smartphones, PCs, and laptops connected to a local network, which function to access Octoprint so that they can function as controllers of the IoT 3D printing system. The Spaghetti Detective (TSD) is third-party software that can be integrated with Octoprint so that users can access the IoT 3D printing system from anywhere without having to connect to a local network.

The performance of IoT-based 3D printers can be seen from the results of the movement accuracy test where there is no significant difference between the input value and the measured value from the test results of the tool and can carry out the process of forming objects using PLA materials by being controlled via the internet so that it is suitable for use as a practical learning medium.

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