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Automatic PCB Cutting Machine Using ESP32 and Arduino IoT Cloud with Enhanced Safety Features for TVET Education

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Abstract: The Fourth Industrial Revolution has accelerated the demand for automation and Internet of Things (IoT) systems, including in technical and vocational education. This study aims to design and develop a safer, more stable, and user-friendly automatic PCB cutting machine for use in TVET workshop environments. Key issues in manual methods and existing machines include unstable PCB holders, the absence of an emergency stop button and unstable control applications. Using the ADDIE model, the system was developed with an ESP32 microcontroller and the Arduino IoT Cloud platform. Continuity, voltage, and functionality tests showed the system operated successfully after tuning, was controllable both manually and remotely, and met safety and operational efficiency requirements. This study contributes to the development of compact automated systems suitable for experiential learning in technical education.

Keywords: Automatic PCB, Arduino IoT Cloud, workshop safety, TVET education, ADDIE design, experiential learning

1. Introduction

The Fourth Industrial Revolution has triggered a surge in demand for automation and Internet of Things (IoT)-based systems across various sectors, including technical and vocational education. In institutions such as Kolej Vokasional Sungai Buloh (KVSB), hands-on training involving printed circuit board (PCB) cutting is a crucial component in the Diploma in Electronic Technology program. However, manual PCB cutting methods are still widely practiced, utilizing tools such as handheld drills and cutters, which result in imprecise cuts, rough edges, and heightened injury risks as students are required to hold the PCB manually during the cutting process (Shan Li & Calderon, 2024; Zhang & Nie, 2020).

Moreover, existing automatic PCB cutting machines exhibit several critical weaknesses. These include the absence of a stable PCB holder, which causes movement during cutting, the lack of an emergency stop button which is essential during emergencies (Gutnichenko et al., 2016; Mladjenovic et al., 2025), and instability in the control application (Blynk), which frequently experiences connection issues, hindering students' daily operation. Physical design problems such as oversized machine dimensions also limit the available workspace in the workshop (Park et al., 2013).

In industrial settings, IoT applications have been leveraged for real-time machine monitoring and control. For instance, Mohsin et al. (2025) recommended the integration of edge computing with IoT in PCB separation processes to improve efficiency and reduce injury risks. Furthermore, Trong et al. (2022) demonstrated how computational theories can be applied to detect PCB defects more effectively within IoT-enabled environments. In the context of technical education, Farisi et al. (2023) successfully developed an ESP32-based automatic PCB screening system for early defect detection via IoT networks.

More relevantly, Beraún-Espíritu et al. (2023), in their project on an automatic potato cutting machine, emphasized the importance of automated safety systems to ensure safer and more efficient machine operations — a principle that can be adapted in the innovation of PCB cutting machines. Meanwhile, Mohanraj, Hari Chealvan, et al. (2023) and Mohanraj, Rajamani, et al. (2023) highlighted the necessity of real-time monitoring of CNC cutting machines via IoT for safety purposes and operational control enhancement.

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However, most previous innovations have focused on industrial applications or electronic waste disposal, rather than in the context of technical learning environments that require compact machine designs, user-friendly interfaces for students, and autonomous safety during operation.

Therefore, this study aims to address that gap by designing and developing a safer, more stable, and user-friendly automatic PCB cutting machine. The proposed system will utilize the more reliable Arduino IoT Cloud platform instead of previously used applications, and will incorporate a PCB holder and emergency stop button. The objectives of this study are: (1) to design a PCB cutting machine equipped with safety features; (2) to develop a control system using physical buttons and IoT connectivity; and (3) to evaluate the functionality of these components in real workshop settings.

2. Research Methodology

2.1 Research Design

This study employs the ADDIE design and development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected as it provides a systematic approach suitable for producing complex teaching and learning products such as IoT-based systems. The ADDIE model allows researchers to organize actions in a structured manner covering user needs, product structure, technical development, and functional testing of the final product.

During the Analysis phase, the researchers identified issues related to safety, stability, and effectiveness in the use of existing PCB cutting machines. Based on these findings, the need for a safer, more stable, and user-friendly cutting system was established. Among the requirements identified were the addition of an emergency stop button, a stable PCB holder, and the replacement of the control system from the Blynk application to the more stable Arduino IoT Cloud platform. Additionally, the physical design of the machine needed improvement to become more compact and suitable for use in vocational workshop environments.

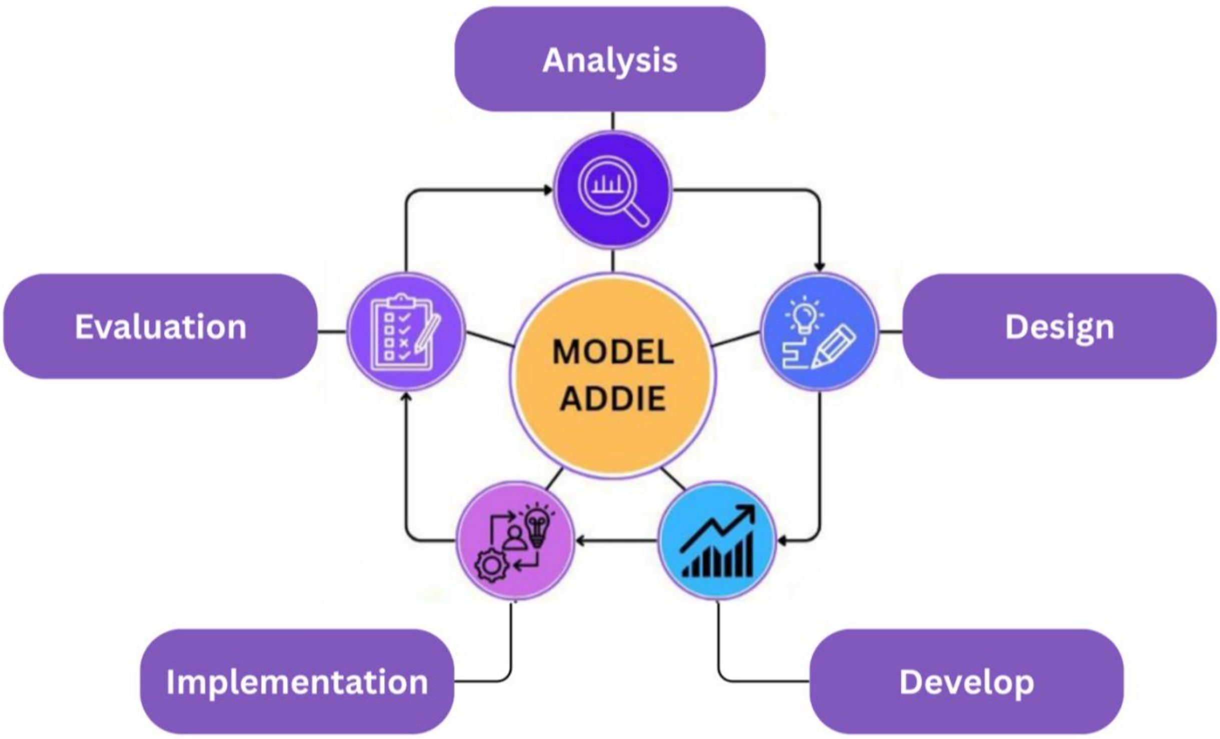

Fig. 1: ADDIE Design Model

2.2 Product Development

The Design phase involves producing a complete system plan covering both software and hardware aspects. On the hardware side, the researcher designed the electronic circuit using an ESP32 as the main controller, along with two MDD10A motor drivers and an emergency stop button. The machine casing was also redesigned using a lightweight yet sturdy aluminum structure and equipped with a 3D-printed PCB holder to ensure stability during cutting.

On the software side, the researcher developed a remote IoT control application via the Arduino IoT Cloud platform, allowing users to control the machine's operation online. The application interface was built with four functional buttons:

Move PCB Holder Forward, Move PCB Holder Backward, PCB Cutting Process, and Retract Cutting Motor. All software and interfaces were tested in a simulation environment before being deployed to the ESP32 module.

In the Development phase, the researcher carried out the assembly of actual components and the development of the circuit and casing. Each component was tested individually before being integrated into the complete system. Wiring was done based on references from previous projects and adapted to current design requirements. The researcher did not use simulation software like Proteus due to limited component libraries, thus the assembly was performed directly on the actual hardware.

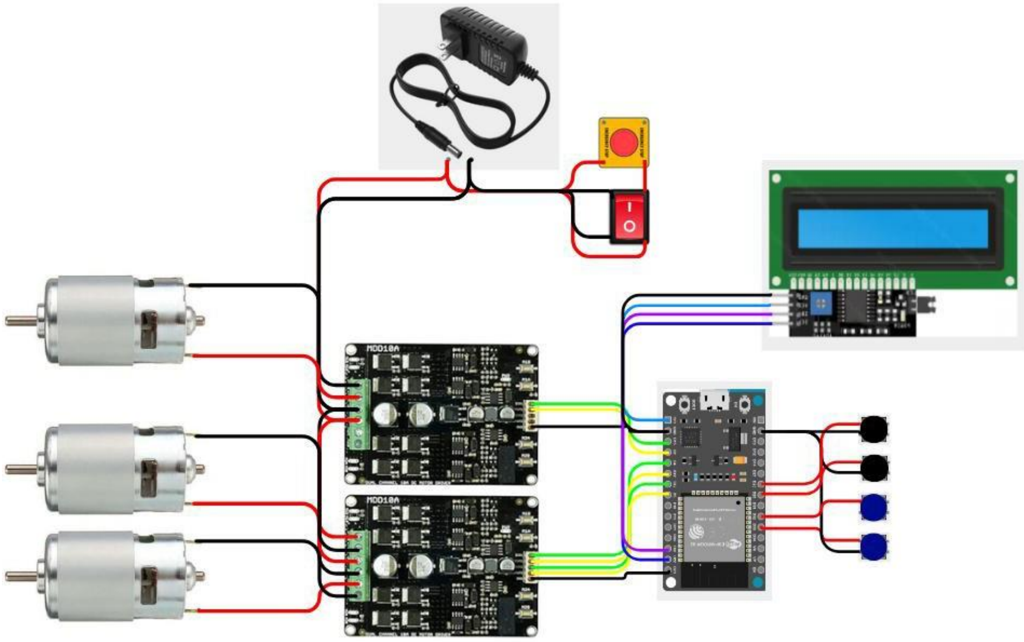

Fig. 2: Project Wiring Circuit

2.3 Product Testing

The testing or evaluation phase involved three types of tests: continuity testing of circuit connections, voltage testing at component inputs and outputs, and comprehensive system functionality testing. A digital multimeter was used to ensure all connections were correct and that there were no short circuits. Voltage tests were conducted to verify that the input and output voltages were within the operating range of the components.

For functionality testing, the system was tested using physical buttons as well as the IoT Remote application. Each button was tested individually to ensure it moved the motor as directed. The LCD display, LED indicators, and buzzer feedback were also tested to provide indications that the system was ready to operate or had successfully completed specific functions. Additionally, internet connection stability was tested by ensuring smooth two-way communication between the application and the ESP32.

Finally, the researchers identified any damages or inaccuracies occurring during the tests and performed repairs, including modifications to the programming, motor position adjustments, and replacement of incorrectly fitted casing parts.

3. Findings and Discussion

This section presents the findings from tests conducted on the developed PCB Cutter V2 machine, including continuity testing, voltage testing, and functionality testing. The results are analyzed to evaluate the performance and effectiveness of the product in meeting the design, development, and system improvement objectives. Discussions are also provided to correlate the findings with the research objectives and to support the validity of the machine's functionality through the ADDIE research approach.

3.1 Continuity Testing

Continuity testing aims to verify the connections between components and ensure that the circuit does not experience an open circuit. The test results showed that the majority of connections between the ESP32, MDD10A motor drivers, control switches, LCD display, and motors were successfully tested after several attempts.

For example, the connections from the MDD10A to the ESP32 for both motor drivers recorded successful outcomes in all three trials. Although there were some initial failures (such as connections to the LCD and relay module), adjustments and repairs were successfully made before the final test. These findings demonstrate that the designed circuit layout and connection configuration are reliable and can be consistently verified.

3.2 Voltage Readings

Voltage testing was conducted to ensure that each component in the system received a stable and accurate voltage supply according to specifications. Voltage readings on the ESP32, MDDA10, and LCD display showed values within the allowable tolerance range. For example, the ESP32 received an input of 5V, while the MDDA10 received inputs of +12.40V and -12.40V, consistent with the operational requirements of a 12V DC motor.

The accuracy and stability of these voltages indicate that the circuit power system functions properly, thereby supporting the overall effectiveness of the system. Voltage testing also helped the researcher identify critical connection points and correct any inaccuracies in the power supply connections during the initial installation.

3.3 Functionality Testing

This test was conducted to evaluate the extent to which the system can operate properly both physically and through control via the IoT Remote application. The test results showed that, after initial tuning and repair, the system functioned as intended. The machine was able to be activated with text displayed on the LCD, followed by the ESP32 successfully connecting to WiFi, and operations being executed through the four application buttons:

- **Move PCB Holder Forward**: moves the PCB holder forward,
- **Move PCB Holder Backward:** retracts the PCB holder,
- **PCB Cutting Process**: activates the cutting motor and cuts the PCB,
- **Retract Cutting Motor**: returns the cutting motor to its original position.

The successful operation of the system across all three testing methods demonstrates that the research objectives were achieved: the system functions correctly, can be controlled both manually and remotely, and features a cutting mechanism that is both safe and accurate.

Table 1: Functionality Test Results – Manual Control (Control Box Buttons)

Component / Function Tested	Testing Method	Test Result	Remarks
Powering On the Machine	Pressing the main power button. Observing LCD display and LED lights.	Successful (3/3 trials)	LCD turns on and displays text. LED lights blink in sequence (Red 3x, then Green).
Button 1 (Move PCB Holder Forward)	Pressing Button 1. Observing motor movement and PCB holder motion.	Successful (2/3 trials)	First attempt failed. Second and third attempts successful.
Button 2 (Move PCB Holder Backward)	Pressing Button 2. Observing motor movement and PCB holder motion.	Successful (2/3 trials)	First attempt failed. Second and third attempts successful.
Button 3 (Start PCB Cutting Process)	Pressing Button 3. Observing cutting process initiation and cutter motor action.	Successful (2/3 trials)	First attempt failed. Second and third attempts successful.
Button 4 (Return Cutter Motor to Home)	Pressing Button 4. Observing cutter motor returning to initial position.	Successful (2/3 trials)	First attempt failed. Second and third attempts successful.

Table 2: Functionality Test Results – IoT Remote Control (Mobile Application)

Component / Function Tested	Testing Method	Test Result	Remarks
Powering on the Machine	Same method as manual control.	Successful (3/3 trials)	LCD lit up and displayed text.
Wi-Fi Connection to ESP32	Checking Wi-Fi connection between ESP32 and the programmed network.	Successful (2/3 trials)	First attempt failed, possibly due to network/configuration issue.
'Move PCB Holder Forward' Button	Pressing button on the app. Observing movement of the PCB holder motor.	Successful (2/3 trials)	First attempt failed, code or app review required.
'Move PCB Holder Backward' Button	Pressing button on the app. Observing movement of the PCB holder motor.	Successful (2/3 trials)	First attempt failed, code or app review required.
'PCB Cutting Process' Button	Pressing button on the app. Observing the start of the cutting process and motor.	Successful (2/3 trials)	First attempt failed, code or app review required.
'Retract Cutting Motor' Button	Pressing button on the app. Observing motor returning to original position.	Successful (2/3 trials)	First attempt failed, code or app review required.

Figure 3: PCB Cutting Machine

3.4 Discussion

Research findings indicate that the developed PCB Cutting Machine V2 has been successfully upgraded in terms of safety, stability, and user-friendliness. Among the most significant improvements are the integration of an emergency stop button, a stable PCB holder, the use of an ESP32 microcontroller, and the development of an IoT Remote interface via the Arduino IoT Cloud platform. The more compact and ergonomic casing design also positively impacted machine handling, making it safer and more suitable for student use in vocational workshop settings. These findings support the original research objective of producing an automated, user-friendly system capable of enhancing hands-on training efficiency.

Both control methods—manual and IoT—demonstrated comparable performance in activating key functions, but the IoT control stood out due to its automation and remote operation capabilities. Despite initial failures in the first attempt for most functions—such as Wi-Fi connectivity, PCB holder movement, and cutting process—the system showed stable performance on the second and third attempts. This suggests the system requires a stabilization or initialization period before achieving consistent operation. Bhavya & Sudharshan (2025) noted that initial connection delays and system jitter are common issues in ESP32-based IoT applications and should be addressed with a structured stabilization delay.

Furthermore, the use of visual status indicators such as LCD text displays and colored LEDs helps users identify system status in real time. Li et al. (2013) support this by emphasizing that clear visual feedback reduces user errors and improves performance in smart control systems.

In terms of usability, the IoT functions tested via the mobile control application demonstrated flexibility and accessibility; however, reliance on network stability makes the system vulnerable to initial disruptions. Therefore, incorporating fail-safe mechanisms, a watchdog timer, and system status indicators could improve operational reliability. Almashhadani et al. (2023); Jebamani & Winster (2022) and Kristiani et al. (2019) recommend integrating edge computing into IoT control systems to enhance response time and reduce dependence on cloud servers, thereby making the system more resilient to external interruptions.

The use of the ADDIE model in research design provided a structured yet flexible framework, allowing for iterative evaluation and refinement throughout the product development process. Ciolacu et al. (2017) demonstrated the effectiveness of this model in the development of complex digital and interactive learning systems. This approach is particularly suitable for IoT-based projects that require ongoing testing, calibration, and improvement.

From an engineering perspective, the stable voltage test results within the ±12.40V range confirmed the effectiveness of the power supply system. Voltage stability is a critical foundation for ensuring the performance and safety of electronic components, as discussed by (Baleboina & Mageshvaran, 2023). Furthermore, physical verification of components such as relays and LCD displays is a crucial step, in line with the practical approach highlighted by Qurat-Ul-Ain et al. (2018) in IoT-based systems.

The interface design approach was based on User-Centered Design (UCD) principles, which prioritize user comprehension and ease of use. de Morais et al. (2019) explained that the use of visual elements such as text, color-coded symbols, and logical layouts helps users—especially students—operate the system more effectively and confidently. As such, the machine functions not only as a cutting tool but also as a responsive technical learning aid.

From a pedagogical standpoint, students' experiences in dealing with a system that did not function perfectly on the first try provided significant learning value. Sinha et al. (2019) noted that initial failures in technical learning environments can encourage students to develop problem-solving skills, technical reflection, and systematic thinking. Therefore, this system supports experiential learning approaches, which are essential in TVET (Technical and Vocational Education and Training).

Ultimately, this machine serves as a reference model for the development of automated systems in technical education. The combination of physical and digital (IoT-based) control makes the project hybrid in nature, easily adaptable, and well-suited for development into a learning module in TVET workshops or basic industrial training.

4. Conclusion

In conclusion, this project successfully developed a new version (V2) of an automatic PCB cutting machine that emphasizes safety, stability, and usability within the context of TVET education. The integration of an emergency stop button, a stable PCB holder, and control via ESP32 and the Arduino IoT Cloud platform has made the system more effective and accessible. Functionality tests demonstrated that the system can be controlled both physically and remotely, although it requires some initial stabilization time at startup. This machine also has strong potential to serve as a practical learning module, encouraging students to engage in problem-solving, systematic thinking, and experiential learning. It can serve as a model for small-scale automated system development in vocational education and basic industrial training.

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Conflict of Interest

The authors declare no conflicts of interest.

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