PROTOTYPE MONITORING AND CONTROL OF MINIATURE STEAM POWER PLANTS (PLTU) USING THE IOT-BASED FUZZY LOGIC METHOD

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ABSTRACT
This study develops a prototype monitoring and control system for a miniature Steam Power Plant (PLTU) using Fuzzy Logic based on the Internet of Things (IoT). The prototype manages operational variables such as voltage and current with a Fuzzy Logic algorithm, enabling adaptive control that enhances efficiency and stability. The integration of IoT via the Virtuino platform provides real-time supervision through mobile devices or computers, facilitating operators in monitoring and taking quick actions, and includes early notifications to detect anomalies. Test results demonstrate high accuracy in monitoring and control with automatic adjustments based on sensor data. Fuzzy Logic effectively addresses sensor data uncertainties, showing potential for application in full-scale PLTUs and industrial automation.

Keywords: *Fuzzy Logic, Internet of things, Pembangkit Listrik Tenaga Uap (PLTU) Miniatur, Monitoring, Control*

1. INTRODUCTION

The Steam Power Plant (PLTU) differs from other power plants due to its use of water as a primary resource, which is readily available and easily accessible. The Steam Power Plant generates electricity by harnessing the kinetic energy of steam. The generator and turbine are the main components of the plant, driven by the kinetic force of hot steam.. (Fuad Tohari Putra, 2022)

The Steam Power Plant (PLTU) plays a crucial role in meeting energy needs across various sectors. However, its utilization as an educational tool remains limited, particularly at Politeknik Penerbangan Surabaya. With the advancement of technology, there is a growing demand for interactive learning tools that can be monitored in real-time. An innovative approach that can be applied is the use of the Internet of Things (IoT) for monitoring and controlling a miniature PLTU.

This research aims to develop a prototype of a miniature PLTU equipped with an IoT-based monitoring and control system using the Fuzzy Logic Sugeno method. The study also explores the use of coconut shells as an alternative fuel, which is expected to improve the efficiency and performance of the developed prototype. With this system, it is hoped that students at Politeknik Penerbangan Surabaya will gain a better understanding of the working principles of PLTUs through a more representative learning tool.

This is a fourth level heading. You can replicate it where suitable.

2. METHOD

2.1 Research Design

This type of development research utilizes the Analysis, Design, Develop, Implement, and Evaluate (ADDIE) approach, which is a comprehensive framework widely used in instructional design and other development projects. The primary goal of this approach is to systematically identify and analyze problems, design effective solutions, develop and refine those solutions, implement them in a real-world setting, and evaluate the outcomes to ensure they meet the desired objectives. By following these structured phases, the research aims to create a well-organized and effective process that results in practical and reliable solutions to the identified problems. (Rusdiana, 2021)

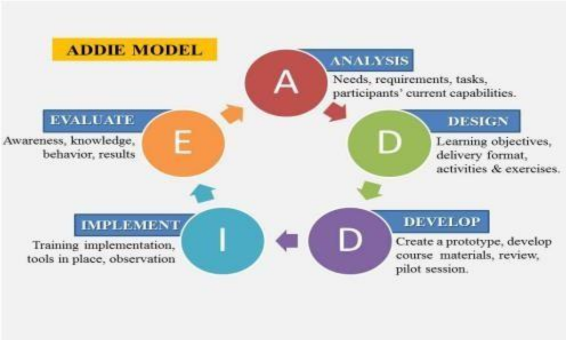

Figure 1 Method ADDIE

1. *Analysis: This phase involves evaluating the needs for instructional materials, including the assessment of competency standards (SK) and basic competencies (KD), as well as the evaluation of learning resources.*
2. *Design: In this phase, the instructional materials are designed by creating an outline that covers all the necessary components. During this process, the most recent and relevant references are gathered.*
3. *Develop: The development of instructional materials is carried out based on the design that has been created and validated by experts. Once validated, the instructional materials will be prepared for implementation.*
4. *Implement: The validated and developed instructional materials are implemented in the learning process to assess their effectiveness.*
5. *Evaluate: This phase involves evaluating the implemented instructional materials to determine their quality and effectiveness in the learning process.*

2.2 How The Tool Works

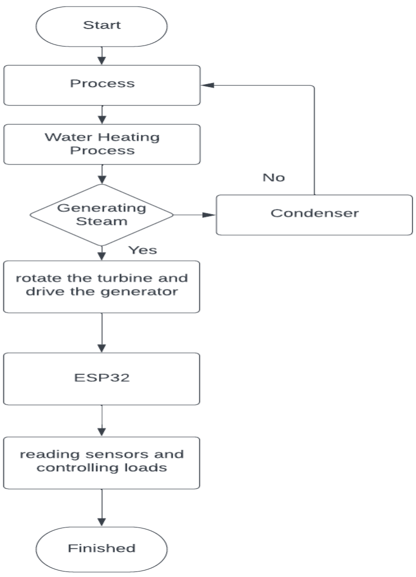

Figure 2 Flowchart How The Tool Work

The development of a prototype monitoring and control system for a steam power plant (PLTU) utilizing the Internet of Things (IoT) and coconut shells as a renewable energy source marks a significant innovation in energy conversion technology. The system is designed to effectively convert the thermal energy generated from the combustion of coconut shells into mechanical energy, which is then transformed into electrical power. The process begins with the burning of coconut shells, which produces the necessary heat to convert water into high-pressure steam. This steam is then directed to drive a steam engine, whichin turn rotates the generator to produce electricity.

The electricity generated by the system is versatile and can be used for various applications, or it can be displayed on an LCD screen integrated into the system. This display is connected to an ESP32 microcontroller, which plays a crucial role in processing data from sensors that measure both current and voltage. The ESP32 also manages the control of the load, ensuring that the electricity generation process is both efficient and reliable.

In addition to its technical advantages, this prototype serves an educational purpose by demonstrating the potential of renewable energy sources like coconut shells. It offers a practical and interactive way to understand the principles of energy conversion, control systems, and sustainable energy utilization. By integrating IoT andrenewable resources, this project not only contributes to advancements in green energy technology but also provides a valuable learning tool that highlights the importance of sustainabilityin modern energy production.

2.3 Tool Components

Components Used:
Hardware:

1. Boiler: Functions to generate hot steam by heating water through the combustion of coconut shells as an alternative fuel to coal. It contains pipes filled with demineralized water that is converted into steam.
2. Steam Engine: Used to convert steam from the boiler into kinetic energy, which drives the DC generator, subsequently generating electricity.
3. 12 Volt DC Generator: Converts kinetic energy from the steam engine into electrical energy. The generator used has a specification of 12 volts, 180 watts, with a rotation speed of 500-800 rpm.

4. INA219 Sensor: Measures the current, voltage, and power generated by the generator, then sends the data to the microcontroller for processing.

5. ESP32: Acts as the brain of the system, receiving data from the sensors and displaying information on the LCD.

6. LCD: Displays the monitoring results of the current and voltage generated by the DC generator

Software:

1. Arduino IDE: Used to program the ESP32 with the C language, controlling the entire IoT-based monitoring and control system.

2. Virtuino IoT: Facilitates local server management, database handling, and the implementation of Fuzzy Logic in the development and testing of the IoT-based monitoring and control system for the steam power plant (PLTU).

2.4 TESTING TECHNIQUE

Technical testing is conducted to evaluate the performance of the designed device and ensure that it operates according to its intended function. During this testing phase, the researcher will assess the development of the Steam Power Plant Prototype by considering each testing stage. This process aims to confirm that the generator can successfully produce electricity.

Once the Steam Power Plant Prototype functions properly, demonstrating that the generator is capable of generating electricity, voltage, and power sensors will be employed to measure the current, voltage, and power output from the generator. The ESP32 microcontroller will then read this data and display it on the LCD screen.

2.5 DATA ANALYSIS TECHNIQUE

Data Collection Methods Used in Writing the Final Project Proposal:

1. Literature Study Method: This process involves in-depth research on relevant theories to address the research problem.

2. Library Research Method: This approach utilizes reference books, advice from lecturers and peers, and online sources to build a solid theoretical foundation for the writing and to provide references related to the author's topic.

3. Observation Method: This method requires the researcher to directly visit the field to gather data and supporting information that is not available through library or laboratory sources.

4. Calculation Analysis Method: This technique involves the mathematical analysis of the designed component's construction.

5. Experimental Method: This approach uses practical testing to gather data from simulations of the created program, assisting in solving the research problem.

6. Discussion: This process includes consultation and guidance from lecturers and other parties contributing to the successful design**.**

2.5 TOOL COMPONENT

2.5.1 Hardware Manufacturing

In this subsection, the author will explain the essential components that will be assembled and tested.

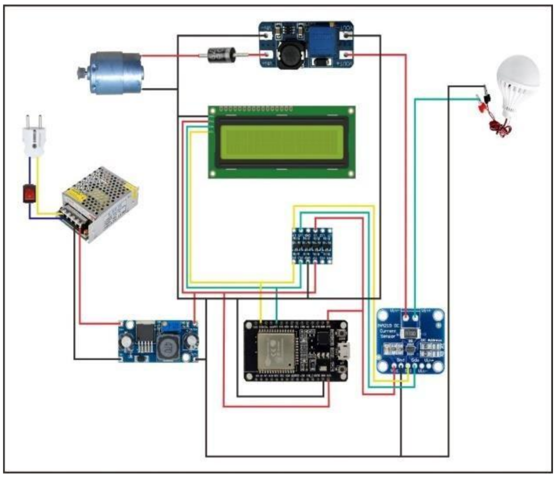

Figure 3 Hardware Manufacturing

1. ESP32
2. 12V Adaptor
3. INA 219 Sensor
4. MT3608 Step-Up Module
5. 16x2 LCD
6. LM2596 Step-Down Module

2.5.2 Software Manufacturing

1. Arduino IDE

Figure 4 Arduino IDE

The Arduino IDE is the tool that is usually used to create programs or apps that are intended to control microcontroller devices using C/C++. We can use Arduino to translate commands from sensors or other parts of the intended gadget. In this last project, directives for device components such as the INA219 sensor are generated using the Arduino IDE. To develop a simulation of programming using the Arduino IDE, a few steps must be taken.

2. Virtuino IoT

Figure 5 Virtuino IoT

Virtuino IoT is helpful for developing and overseeing Internet of Things (IoT) projects, and it may be accessible via an app or web browser. As long as it is linked to the internet, Virtuino IoT may be used to remotely adjust loads and monitor the generated current and voltage over the web or a mobile app in this final project.

3. *Matrix Laboratory* (MATLAB)

Figure 6 *Matrix Laboratory* (MATLAB)

A numerical programming language used for data analysis, visualization, and method creation is called MATLAB, short for Matrix Laboratory. In this final project, real-time data visualization dashboards are created to monitor system conditions, and control algorithms are developed and optimized using MATLAB. Sensor data from the ESP32 is processed. The creation of this control system becomes more organized, effective, and adaptive when MATLAB is used.

3. RESULT AND DISCUSSION

1. ESP32 Testing

The ESP32 functions as a microcontroller with built-in Wi-Fi and Bluetooth components, which can be accessed via the Internet of Things (IoT) through a smartphone. The ESP32 also serves as a bridge to synchronize hardware and software, using C and C++ languages.

Figure 7 ESP32

Analysis Result:

After measuring the voltage on the ESP32, the measured voltage corresponds to the required voltage needed to power the ESP32.

2. Adaptor 12V Testing

A 12V adapter is an essential component used to convert 220 VAC to 12 VDC and provide a stable voltage, which is used to power various electronic components.

Table 1 adaptor 12V Testing

Testing	Input	Output
1	224 VAC	12,3 VDC
2	223,1 VAC	12,3 VDC
3	223,2 VAC	12,2 VDC

Figure 8 Adaptor 12V Testing

Analysis Result:

After measurement using a clamp meter, the 220 VAC input voltage is converted to a 12 VDC output voltage, which will be used to power other electronic components.

3. MT3608 Step-Up Testing

The MT3608 Step-Up Module is typically used to increase DC voltage, converting a lower input voltage into a higher output voltage.

Table 2 MT3608 Step-Up Testing

Testing	Input	Output
1	6,8 VDC	10,7 VDC
2	7 VDC	11,2 VDC
3	6,9 VDC	10,9 VDC

Figure 9 MT3608 Step-Up Testing

Analysis Result:

Based on the measurement shown in the image above, the voltage measured using a clamp meter before entering the MT3608 step-up module was 6.8 VDC, and after passing through the MT3608, the voltage increased to 10.7 VDC.

4. Testing a 16x2 Liquid Crystal Display (LCD)

The LCD is used in various applications for transmitting and receiving information. Additionally, it simplifies the process for users to display sensor readings, such as voltage and current sensors.

Figure 10 Testing a 16x2 Liquid Crystal Display (LCD)

Analysis Results:

During testing, the LCD received a voltage of 3.3 VDC, enabling it to function properly and display information, such as current and voltage sensor readings.

5. Testing the LM2596 Step-Down Module

The LM2596 step-down module efficiently reduces input voltage to output voltage. The purpose of testing this module is to ensure that it functions correctly.

Table 3 *LM2596 Step-Down Module Testing*

Testing	Input	Output
1	12 ,3VDC	4.9 VDC
2	12VDC	5 VDC
3	12 VDC	5 VDC

Figure 11 *Testing the LM2596 Step-Down Module*

Analysis Results:

After measuring the input and output of the LM2596 step-down module, it was determined from the table and image above that the module is functioning properly, successfully reducing the voltage from 12 VDC to 5 VDC.

6. INA219 Sensor Testing

In this test, several different load variations were applied to determine the ampere rating of the tested loads. This is useful for comparing the Direct Current (DC) current values displayed on a Liquid Crystal Display (LCD) and those shown on a multimeter.

Table 4 INA219 Sensor Testing

Load using 3.4V Led Lamp	Multimeter		Liquid Crystal Display (LCD)	
	Voltage (VDC)	Current (mA)	Voltage (VDC)	Current (mA)
1	7,5	22,37	7,2	20,52
2	7	22,80	6,6	20.88
3	6,9	20,03	6,4	18,90

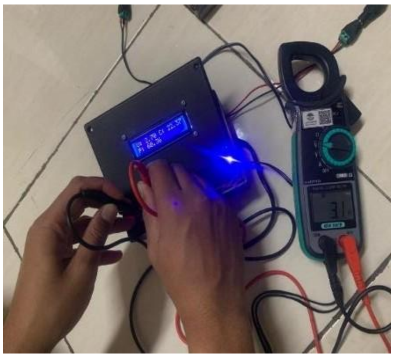

Figure 12 INA219 Sensor Testing

Analysis Results:

The test results indicate that the measurements between the multimeter and the Liquid Crystal Display (LCD) are not identical. This discrepancy is due to the measurement tolerance differences between the multimeter and the LCD, which can vary depending on the brand and model of the devices used.

7. Comprehensive Equipment Testing Table

Table 5 Comprehensive Equipment Testing Table

Testing	Liquid Crystal Display (LCD)		Fuel Using Coconut Shell	Testing Time	Virtuino Application		Avometer		Tacho meter
	Voltage (V)	Current (mA)			Voltage (V)	Current (Ma)	Voltage (V)	Current (mA)	Rpm
1	7,7	21,10	2 Kg	20 Minutes	7,7	20.90	7,5	20,90	158,2
2	4,6	13,70	1 Kg	20 Minutes	7,5	20.85	7,3	20,94	100,8
3	3,3	8,90	0,5 Kg	20 Minutes	7,3	20,80	7,2	20,91	63,3

In the first test with 2 kg of coconut shells, the voltage on the LCD was recorded at 7.7 V with a current of 21.10 mA, while the Virtuino application showed 7.7 V and 20.90 mA, and the Avometer recorded 7.5 V and 20.90 mA. The resulting RPM was 158.2.

In the second test with 1 kg of coconut shells, the voltage on the LCD dropped to 4.6 V with a current of 13.70 mA, while Virtuino recorded 7.5 V and 20.85 mA, and the Avometer recorded 7.4 V and 20.94 mA. The RPM also decreased to 100.8.

In the final test with 0.5 kg of coconut shells, the voltage on the LCD further decreased to 3.3 V with a current of 8.90 mA. Virtuino recorded 7.3 V and 20.80 mA, while the Avometer showed 7.2 V and 20.91 mA. The RPM dropped significantly to 63.3.

Analysis Results:

The Analysis show that the amount of coconut shell fuel directly affects electrical and mechanical performance. Voltage, current, and RPM all decrease as the amount of fuel decreases, indicating that the more fuel used, the higher these values. Conversely, reducing the fuel significantly diminishes performance, affecting the system's efficiency. This study provides important insights into the relationship between the amount of coconut shell fuel and energy output. The variation in fuel quantity directly influences system performance, which can serve as a basis for optimizing coconut shell fuel usage in applications requiring stability and energy efficiency.

8. Testing Virtuino IoT Monitoring Application

Figure 13 Testing Virtuino IoT Monitoring Application

Virtuino IoT is used for controlling loads and remotely monitoring current and voltage via the web or a mobile application, as long as the device is connected to the internet. When testing Virtuino IoT, ensure that both the microcontroller and the smartphone are connected to the same Wi-Fi network. Check the connection status in Virtuino IoT; if connected, the widgets and gauges added to the interface will read data from the sensors installed.

9. Testing Fuzzy Logic in MATLAB Application

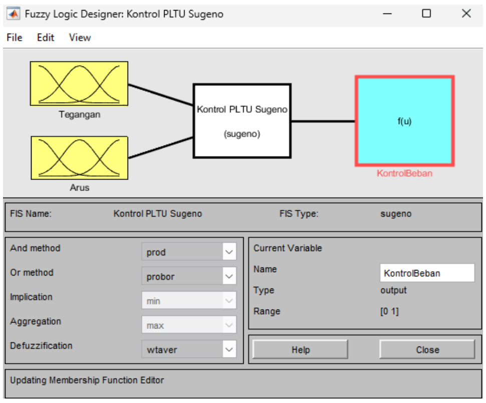

Figure 14 Sugeno Fuzzy Logic Interface in MATLAB

In this study, the author used MATLAB version R2023b to implement fuzzy logic, utilizing a Fuzzy Inference System (FIS) of the Sugeno type. The author employed an INA219 sensor with two variables, voltage and current. The fuzzification process was then carried out to determine the defuzzification value, or output, in order to achieve smarter and more adaptive load control.

Table 6 Input membership function

Variable Sensor INA219	Range	Params	Membership Function
Voltage	[0 12]	[-1 0 4 8]	Low
		[4 8 12]	Medium
		[8 12 14 16]	High
Current	[0 25]	[-1 0 5 15]	Low
		[5 15 25]	Medium
		[15 25 30 35]	High

The image above displays the membership function table for two INA219 sensor variables, Voltage (0–12) and Current (0–25), each categorized into Low, Medium, and High based on specific parameters. These membership functions are used in the fuzzy logic system to interpret the measured voltage and current values, enabling the system to determine appropriate control actions in the "Prototype Monitoring and Control of a Miniature Steam Power Plant (PLTU) Using IoT-Based Fuzzy Logic Method" project. By classifying voltage and current values as low, medium, or high, the Sugeno fuzzy inference system can efficiently control the PLTU load based on sensor inputs, supporting real-time monitoring and control through IoT technology.

Table 7 Output Membership Function

Range	Membership Function	Params
[0 1]	LowLow	0,2
	LowMedium	0,5
	LowHigh	0,8
	MediumLow	0,5
	MediumMedium	0,7
	MediumHigh	0,9
	HighLow	0,7
	HighMedium	0,9
	HighHigh	1

The image above is used to categorize the rules created in this Sugeno fuzzy logic system. For example, if the generator produces a current of 25mA and a voltage of 12V, the load control output will follow the "HighHigh" rule, causing the light, acting as the load, to turn on. These rules are created based on the received inputs, and the Sugeno logic will subsequently control the load more intelligently and efficiently according to the input variables used.

4. CONCLUSIONS AND RECOMMENDATION

Conclusion

A prototype for Monitoring and Control of a Miniature Steam Power Plant (PLTU) using Fuzzy Logic based on IoT has been designed and tested. This system utilizes the INA219 sensor to collect operational data, which is then processed by an ESP32 microcontroller and analyzed using the Sugeno Fuzzy Logic method in MATLAB. Through the integration of IoT via the Virtuino platform, the system is capable of real-time monitoring and control, providing intelligent and adaptive responses to changes in operational conditions. Test results show that this system is effective in optimizing operational parameters such as temperature, pressure, and turbine speed, making it suitable as a learning and simulation tool in the field of steam power plants.

Recommendations

1. It is recommended to further develop this system by adding emission monitoring features to reduce the environmental impact of using coconut shell fuel.

2. For future development, it is advisable to use sensors with better environmental resistance to enhance the accuracy and reliability of data, especially in high-temperature conditions.

3. Further research is encouraged to explore the use of alternative fuels that are more environmentally friendly and have higher combustion efficiency than coconut shells

These recommendations are expected to assist in the further development of this prototype and enhance the implementation of IoT and Fuzzy Logic technologies in the field of steam power generation**.**

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