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Monitoring and Control System for Temperature, Humidity, and Air Quality in LVMDP Panel Rooms to Improve the Reliability of LVMDP Panel Components Using Fuzzy Logic

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Abstract: Power Distribution System plays a crucial role in modern life. Low Voltage Distribution Panel (LVMDP) is a critical component within this system, responsible for distributing low-voltage electricity to various loads. Optimal reliability and performance of LVMDP are essential to ensure continuity and stability of power supply. Environmental factors such as temperature, humidity, and air quality can significantly impact the reliability and lifespan of electrical equipment in LVMDP. An Internet of Things (IoT) and Fuzzy Logic- based Monitoring and Control System offers an innovative solution to address these issues. The IoT Monitoring System enables real-time monitoring of temperature, humidity, and air quality, allowing for early detection of environmental changes that could potentially damage equipment. The Fuzzy Control System then responds to these changes automatically and adaptively, regulating cooling, heating, circulation, dehumidifier, or humidifier devices to maintain optimal environmental conditions. Implementing this Monitoring and Control System not only enhances equipment reliability and lifespan but also reduces the risk of power supply disruptions. Therefore, the development and implementation of this system serve as an innovative and essential solution in maintaining the reliability of the power system. Advancements in IoT and Fuzzy Logic technologies open up opportunities to improve the overall reliability and efficiency of the Power Distribution System. This Monitoring and Control System presents a strategic step that can yield significant positive impacts on the reliability and performance of the Power Distribution System as a whole.

Keywords: IoT, Fuzzy Logic, Monitoring System

Introduction

Aspects of life continue to evolve with advancements in information and communication technology, impacting various fields, including electrical power systems, especially distribution panels like MDP, MVMDP, and LVMDP. LVMDP panels play a crucial role in maintaining controlled voltage levels sent to loads. The reliability of the LVMDP panel room is essential to ensure the continuity of power supply, as system disruptions may stem from internal, external, or human factors. Temperature and humidity are external factors affecting the performance and lifespan of electrical equipment, making environmental control in LVMDP panel rooms very important (Feng, 2024).

An IoT-based monitoring system provides a solution for real-time temperature and humidity control using sensors or devices connected to computers or microcontrollers. Collected data can be analyzed to prevent equipment damage. Additionally, a control system based on Fuzzy Logic allows for adaptive responses to environmental changes by controlling devices such as coolers, dehumidifiers, or humidifiers based on current conditions to maintain system stability.

Previous studies have explored room monitoring and control systems. According to research by (Saepudin, 2022), IoT devices continuously connected to the internet facilitate efficient and effective warehouse monitoring, allowing analysis based on historical data from IoT-based temperature and humidity monitoring systems connected to MQTT. Research by Rosyid M. A. et al. (Mufti Abdurrohman et al., n.d.) reported that a real-time temperature and humidity thermometer prototype yielded highly satisfactory results, providing accurate environmental monitoring to ensure reliability. Similarly, a study by (Dilla Regita et al., n.d.) developed a system to monitor server room temperature and humidity every 30 seconds using Lattepanda devices and Thingspeak for data storage. Another study by (Putu et al., 2021) developed a system to monitor temperature and humidity in a chicken coop, using Arduino to collect data and send it to a server via an ESP module (Alika, 2024).

In contrast to previous studies, this research uses the ESP32 module connected to a DHT11 sensor for temperature and humidity and an MQ-135 gas sensor to collect real-time data, which is then sent to an InfluxDB server and processed in Grafana to display the data on a Grafana web server (Faiz, 2024).

Methodology

Research Flow Diagram

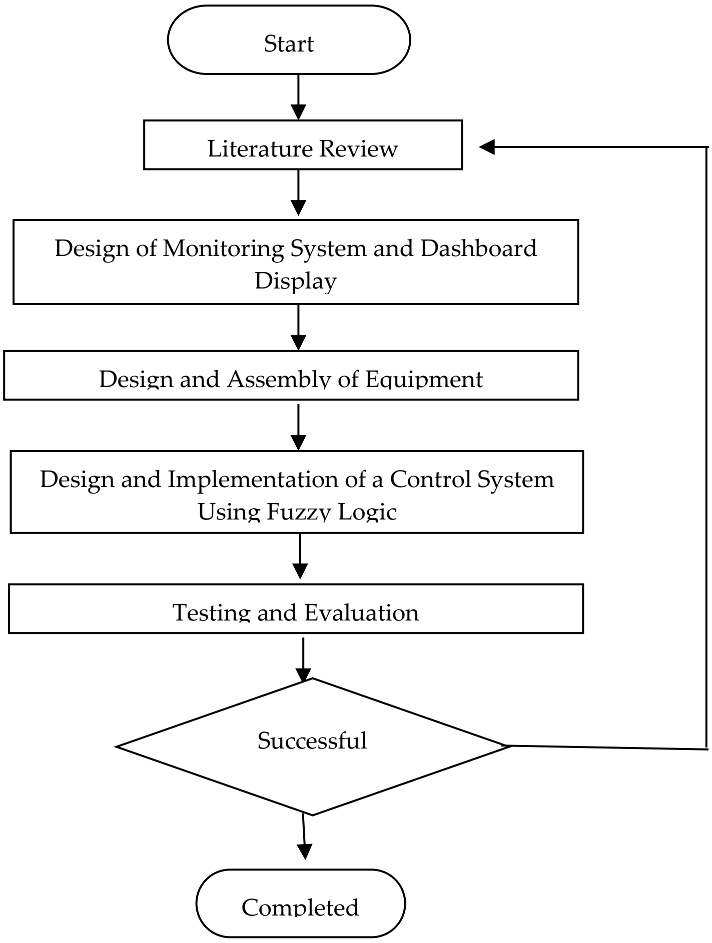

Figure 1. Research Methodology Flowchart

The system design for monitoring and dashboard display will be created based on the indicators or parameters to be monitored: temperature, gas, and air humidity. The design and assembly of the tools used in this study will utilize both software and hardware as the medium for a temperature and humidity monitoring system accessible through a website. Following this, the design and application of a fuzzy logic control system will be integrated into the monitoring system (Castillo, 2024). Then, the system will undergo testing and evaluation by examining real-time data to ensure it aligns with the conditions in the panel room. If the monitoring system is successful, it will facilitate determining actions or steps for controlling the panel room conditions.

Electrical Prototype Diagram of the Device

The stages of designing and assembling the device's electrical system begin with creating a Wiring Diagram for the system to be developed. The ESP-32 microcontroller, serving as the central data processing unit, will receive input from the SHT-20 sensor to obtain temperature and humidity data and from the MQ-135 gas sensor to gather air quality data (Luo, 2024).

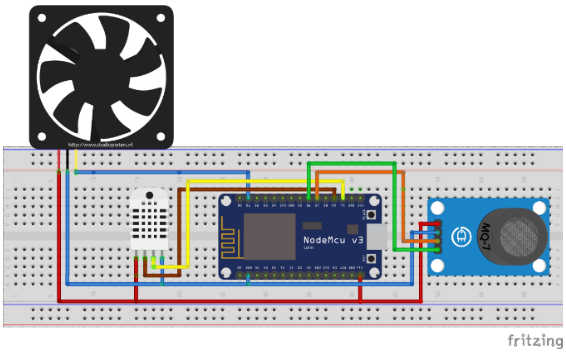

Figure 2. Prototype Wiring Diagram of the Device

A 5V power supply is used to power the ESP-32 microcontroller and the connected sensors. The SHT-20 sensor utilizes the I2C communication protocol, using the SDA and SCL pins on the microcontroller. Meanwhile, the MQ-135 gas sensor uses either analog or digital pins on the microcontroller to send reading data. Below are the components and modules used:
- 5V Power Supply
- ESP-32 Microcontroller
- SHT-20 Temperature and Humidity Sensor
- MQ-135 Gas Sensor
- Relay
- Exhaust Fan / Fan
- Cable Terminal
- Power Cable
- I2C Jumper Cable

Monitoring System and Dashboard

The data received by the microcontroller will then be stored in variables within the program in the microcontroller. The data from the sensors that have been stored in the variables will then be converted into actual reading data by calling the sensor library or adding formulas. For the SHT-20 sensor, the electrical readings will be converted into temperature values (Fahrenheit/Celsius/Kelvin) and air humidity percentage (%). Meanwhile, for the MQ-135 gas sensor, the electrical readings will be converted into gas/particle concentration levels (PPM) (Sajadinia, 2024).

The converted data will be sent to the database via the internet. The ESP-32 microcontroller also functions as a gateway because it has WiFi capabilities to connect to the internet. The data transmission from the microcontroller to the database is done through a Web Server using the Hypertext Transfer Protocol (HTTP).

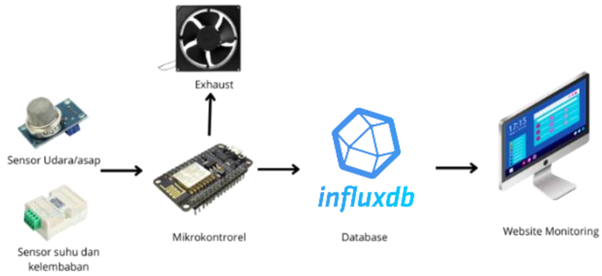

Figure 3. System Architecture

The database platform and dashboard display that will be used is Grafana. The stored reading data in the database will then be displayed on the dashboard in Grafana. This data will be continuously sent to the database to obtain accurate readings of the LVMDP Panel Room conditions. The dashboard can be accessed through both PCs and smartphones by accessing the IP address created in Grafana.

Figure 4. Grafana Monitoring Dashboard

Design and Implementation of the Fuzzy Logic Control System

The basis of the control system to be used is the Closed-Loop Control System. This is because, fundamentally, the sensors on the microcontroller act as feedback signals that are necessary to regulate the output according to the desired conditions. The implementation of Fuzzy Logic is incorporated into the program inside the microcontroller. The fuzzy logic will classify the sensor readings from the SHT-29 sensor (temperature and humidity) and the MQ-135 sensor (air quality) to assess the condition of the LVMDP panel room. There are three status categories that represent the condition of the LVMDP room: Bad, Moderate, and Good. Prior to classification, temperature, humidity, and air quality values must undergo a process called Fuzzification (Begum, 2024). Fuzzification serves to convert crisp (precise) values into fuzzy values.

Table 1. Fuzzification Test "Temperature"

Temperature (°C)	CoolMembership (μCool)	Warm Membership (μWarm)	Hot Membership (μHot)
10	1.00	0.00	0.00
15	1.00	0.00	0.00
20	1.00	0.00	0.00

25	0.18	0.82	0.00
30	0.00	1.00	0.00
35	0.00	0.60	0.40
40	0.00	0.00	1.00

In the fuzzification test for temperature, the indicators obtained are **Cool**, **Warm**, and **Hot**. These indicators will later be displayed automatically according to the sensor readings.

Table 2. Fuzzification Testing of "Humidity"

Humidity (%)	µDry	µSlightly Humid	µHumid
0	1.00	0.00	0.00
10	1.00	0.00	0.00
20	1.00	0.00	0.00
30	1.00	0.00	0.00
40	0.50	0.50	0.00
50	0.00	1.00	0.00
60	0.00	1.00	0.00
70	0.00	1.00	0.00
80	0.00	0.67	0.33
90	0.00	0.33	0.67
100	0.00	0.00	1.00

In Table 2, the indicators are Dry, Slightly Humid, and Humid. Excessive humidity can affect the lifespan of the equipment in the electrical panel, as high humidity can cause condensation on the panel's components, reducing performance and increasing the potential for electrical leakage.

Table 3. Fuzzification Test "Air Quality"

Air Quality (ppm)	Good	Normal	Dirty
0	1.00	0.00	0.00
25	1.00	0.00	0.00
50	1.00	0.00	0.00
75	1.00	0.00	0.00
100	1.00	0.00	0.00
110	0.80	0.20	0.00
120	0.60	0.40	0.00
130	0.40	0.60	0.00
140	0.20	0.80	0.00

150	0.00	1.00	0.00
160	0.00	0.80	0.20
170	0.00	0.60	0.40
180	0.00	0.40	0.60
190	0.00	0.20	0.80
200	0.00	0.00	1.00

Air quality in the panel room should also be carefully monitored. Poor air quality can cause corrosion on metal parts and terminals. This corrosion can lead to unstable connections between cables and reduce component performance.

Result and Discussion

In this chapter, the author will discuss the testing of the prototype for the monitoring and control system of temperature, humidity, and air quality in the LVMDP panel room using the DHT11 sensor, SHT20, and ESP32 Module. The development of a prototype capable of measuring and displaying temperature and humidity in real-time and accurately is the main objective of this research. Afterward, the prototype will be compared with manual measurements (Munadi, 2024).

Prototype Testing

Pengujian prototype ini penulis lakukan di ruang panel LVMDP yang bertujuan untuk memantau suhu ruang panel secara real time, Dashboard yang digunakan yaitu menggunakan platform grafana serta influxdb sebagai pengolah data dari sensor-sensor yang terhubung dengan ESP32.

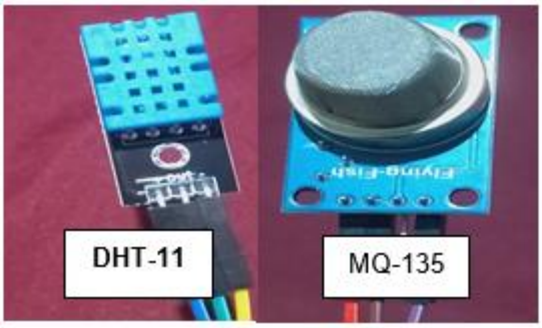

Figure 5. IoT Device for Temperature, Humidity, and Air Quality Sensors

The image above shows the device or sensor used in this study, where the sensor readings will be displayed in real-time on the Grafana platform.

Figure 6. Manual Temperature and Humidity Sensor Device

The image above shows a manual measuring device that cannot be connected to IoT. This measuring device will later be compared with the sensor that can be connected to IoT, allowing us to evaluate the reliability of the IoT system in monitoring the room's condition.

Figure 7. Manual Air Quality Measurement Device

The image above shows a device used for measuring the air quality around the area. This device cannot be connected to IoT. Once all sensors and devices are gathered, a comparison test of the measurements must be conducted to evaluate the reliability of the IoT sensors, as shown in the following table.

Table 4. Comparison of Measurement Results from the Prototype and Manual Measurements

Time	Temperature	Humidity	Air Quality
	Manual Sensor	IoT Sensor	Manual Sensor
9:00	25.5°	25.5°	63%
9:10	25.4°	25.4°	62%
9:20	25°	25.1°	62%
9:30	25.1°	25.1°	62%
9:40	25°	25°	63%
9:50	24.9°	24.9°	61%
10:00	24.9°	24.9°	63%
10:10	24.7°	24.7°	60%
10:20	24.6°	24.6°	62%
10:30	24.6°	24.6°	60%
10:40	24.5°	24.5°	62%
10:50	24.3°	24.2°	63%
11:00	24°	24.2°	61%

The data obtained from monitoring temperature, humidity, and air quality were compared with manual measuring instruments to evaluate the accuracy of the data and the reliability of the prototype. As shown in Table 3.1, there are some differences in the data, but these differences are not significant and still fall within acceptable tolerance limits. This indicates that the readings from the IoT sensors are accurate and consistent with the manual measuring instruments (Ali, 2024).

Upload Data to InfluxDB Server

Uploading this data aims to ensure that the data received by the sensors is neatly organized, making it easier to process. The data will eventually be integrated into the Grafana server to create the dashboard display. By consistently uploading the data according to the required intervals, users will find it easier to make decisions based on real-time data. InfluxDB also simplifies the synchronization of data automatically, making it accessible on multiple devices that need to access the same data (Genc, 2024).

After successfully creating the program in the Arduino software, the program will then be uploaded to the ESP32 microcontroller (Diantoro et al., n.d.), as shown in Figure 5

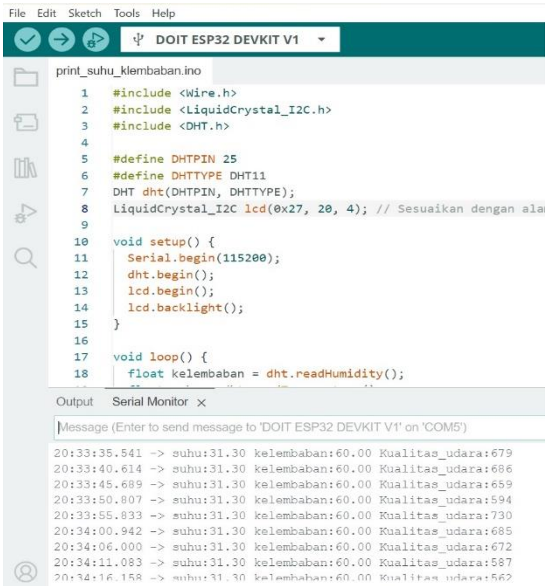

Figure 8. Program Testing and Sensor Reading

The program that has been uploaded to the ESP32 needs to be tested first in the serial monitor to ensure that the program works correctly so that when the data is sent to InfluxDB, there are no errors in real-time monitoring data (Triviño, 2024). After the sensor successfully detects the values, the next step is to send the data from the sensor to InfluxDB by entering the token we created in InfluxDB into the ESP32. The sensor readings will then appear on the InfluxDB page as shown in the image below.

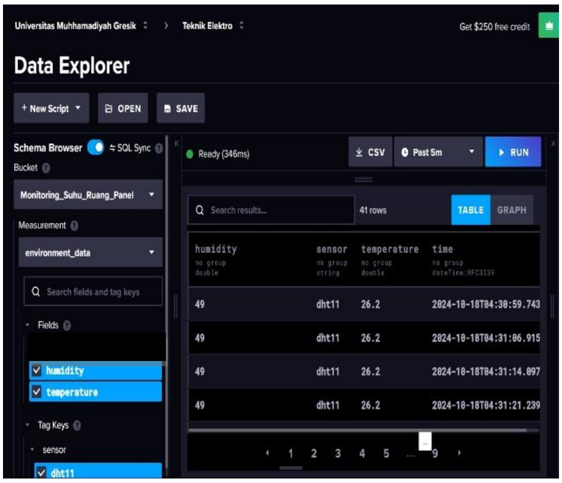

Figure 9. Influxdb Dashboard

The sensor readings will be recorded by InfluxDB as basic data, which will then be sent to the Grafana server.

Integration of Data to the Grafana Server

Grafana functions for the visualization and analysis of data that has been stored in InfluxDB. The process is similar to sending data to InfluxDB, which is done by using the token created in InfluxDB. The appearance of the Grafana dashboard is shown in the following image**:**

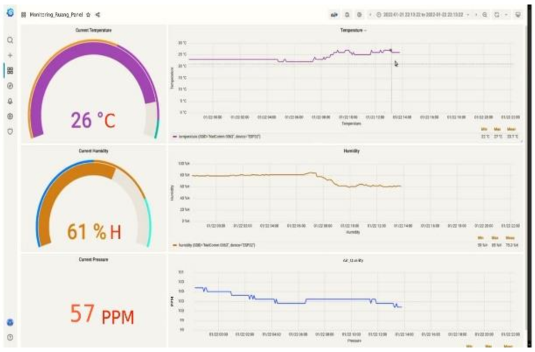

Figure 10. Grafana Dashboard

The image above displays the room temperature, humidity, and air quality conditions, along with graphs of the data read by the sensors (Thenmozhi, 2024).

Fuzzy rules on the ESP32

The fuzzy rules on the ESP32 are used to regulate the temperature, humidity, and air quality in the panel room. These rules are created to simplify decision-making when adjusting the conditions of temperature, humidity, and air quality in the panel room. Below are the fuzzy rules implemented on the ESP32:

```
if (suhuFuzzy == "Hot" && kelembabanFuzzy == "Low" && kualitasUdaraFuzzy == "Bad")
{ Serial.println("Fan: High, Dehumidifier: High");
} else if (suhuFuzzy == "Moderate" && kelembabanFuzzy == "High" &&
kualitasUdaraFuzzy == "Good") {Serial.println("Fan: Low, Dehumidifier: Off");
} else if (suhuFuzzy == "Cold" && kelembabanFuzzy == "Moderate" && kualitasUdaraFuzzy
== "Moderate")
{   Serial.println("Fan: Low, Dehumidifier: Low");
} else if (suhuFuzzy == "Hot" && kelembabanFuzzy == "High" && kualitasUdaraFuzzy ==
"Bad") {Serial.println("Fan: High, Dehumidifier: High");
} else if (suhuFuzzy == "Cold" && kelembabanFuzzy == "Moderate" && kualitasUdaraFuzzy
== "Moderate") {Serial.println("Fan: Low, Dehumidifier: Medium");
} else if (suhuFuzzy == "Moderate" && kelembabanFuzzy == "Low" && kualitasUdaraFuzzy
== "Good") {Serial.println("Fan: Medium, Dehumidifier: High");
```

This program contains 6 rules, and more rules can be added as needed for the research. These rules will control the devices based on sensor input, providing high flexibility in designing systems or other automation needs.

Conclusion

The temperature, humidity, and air quality monitoring system in the panel room, based on the Internet of Things (IoT), using the DHT11 sensor to measure temperature and humidity and the MQ135 sensor to measure air quality in the panel room, can be concluded to work well (Pakhira, 2024). The measurement results are accurate and can be sent to the InfluxDB page via a wireless internet connection, making real-time monitoring easier. The monitoring system with fuzzy logic also helps improve the reliability of components in the LVMDP panel, as it simplifies the control of humidity, temperature, and air quality inside the panel room according to the rules inputted into the ESP32 module (Li, 2024).

Suggestions for future researchers include the addition of IoT-based ampere and voltage sensors to enable real-time monitoring of amperage and voltage, which can then be monitored from data visualization platforms such as Grafana, Prometheus, ThingsBoard, and others (Siddula, 2024).

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