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Air Conditioner Control and Monitoring System based on Temperature Balance in Server Room using Fuzzy Logic and Internet of Things Methods

I Gusti Putu Rika Permana [1,2,a,*]; Supriadi Sahibu [3,b]; Abdul Jalil [4,c]; Munawirah [5,d]
[1] *Magister Sistem Komputer, Universitas Handayani Makassar, Makassar*
[2] *Manajemen Informatika, AMIK Luwuk Banggai, Banggai*
[3,4] *Sistem Komputer, Universitas Handayani Makassar, Makassar*
[5] *Sistem Informasi, Universitas Tomakaka, Mamuju*
[a] *gustypermanax@gmail.com;* [b] *supriadi@handayani.ac.id;* [c] *abdullatief@unhas.ac.id;* [d] *munawirahkadir@gmail.com*
* *gustypermanax@gmail.com*

Abstract

This research develops a temperature and humidity control system in the server room based on the Internet of Things and using fuzzy logic algorithms at AMIK Luwuk Banggai. The system is designed using NodeMCU ESP32, DHT11 sensor, Arduino IDE, and Blynk application, with objective of monitoring and controlling environmental conditions in real time. A series of quantitative experiments were conducted to evaluate the effectiveness of the sensor system. These experiments involved observations, measurements, and a comparison of the results with manual calculations. The results demonstrate that the DHT11 sensor exhibits a margin of error of 1.21% and a hardware accuracy rate of 98.79%. Furthermore, the integration of the Internet of Things (IoT) and the implementation of fuzzy logic in air conditioner control studies, as demonstrated in this study, has the potential to enhance the accuracy of temperature and humidity control within the room server to an accuracy rate of 90.91%. Furthermore, it can improve the responsiveness of the system in maintaining temperature stability. These findings were observed at AMIK Luwuk Banggai, where the application of IoT and fuzzy logic has been implemented. Fuzzy logic offers an effective and dependable approach to regulating temperature fluctuations in the server room, ensuring a stable environment that minimizes the likelihood of operational issues or hardware damage. The objective is to extend the lifespan of the hardware by preventing such complications.

Keywords*—Internet of Things, Air Conditioner, Temperature, Server, Fuzzy Logic*

1. Introduction

In the context of digital era and globalization, the necessity for sophisticated and efficient technology in various aspects of life is increasing (Annisa et al., 2024). A particular area of focus is the management and control of indoor temperature, particularly in facilities where precise temperature regulation is essential, such as data centers and server rooms. Proper temperature management is of critical importance for the maintenance of equipment performance and longevity, as well as for the prevention of damage that could result in significant financial losses. As an educational institution that operates a considerable number of servers and information technology devices, AMIK Luwuk Banggai campus faces significant challenges in maintaining a stable temperature within its server room. Uncontrolled temperature fluctuations have the potential to cause overheating, impair server performance, and even result in hardware failure. Consequently, a system capable of monitoring and controlling the temperature in real-time is essential to ensure optimal conditions for these devices.

The integration of Internet of Things (IoT) technology and fuzzy logic methodologies presents a novel approach to addressing the aforementioned challenge. Internet of Things (IoT) facilitates real-time aggregation of temperature data from a multitude of sensors situated within the server room and its surrounding environment. Subsequently, the data is processed using fuzzy algorithms, which facilitate data analysis through a more flexible and adaptive approach. The employment of fuzzy logic rules enables system to provide more intelligent and responsive decisions regarding temperature changes, thereby ensuring an optimal balance between server temperature and room temperature. The implementation of a temperature balance-based control and monitoring system using Internet of Things (IoT) and Fuzzy Logic at AMIK Luwu Banggai is intended to facilitate the creation of a more efficient and secure operational environment. The system's functionality extends beyond mere temperature maintenance to encompass the provision of timely alerts in the event of unfavorable conditions, thereby enabling prompt corrective action. It is anticipated that this technology will enhance the operational efficacy and security of server devices, while also facilitating the smooth functioning of academic and administrative activities across the entire campus (Akbar & Sugeng, 2021).

A number of studies have been conducted in this field, including a study by JB et al., (2020) who developed an Internet of Things (IoT)-based temperature monitoring system in a data center. The efficiency of the system remains uncertain due to the inability to conduct metric testing to accurately assess the system's accuracy. And as stated by Maulana et al., (2023) the research on design an IoT-based temperature and humidity monitoring system, server room case study, employs a single sensor and does not utilize fuzzy algorithms or other decision-making algorithms. A study by Al Hafid et al. (2024) examined the efficacy of the Fuzzy Logic algorithm in controlling devices based on the Internet of Things (IoT). The findings indicated that this method yielded optimal outcomes, surpassing the performance of conventional control systems. Specifically, the study noted that the IoT-based devices exhibited enhanced adaptability in their responses, contributing to an augmented efficiency in tool control operations. The research conducted by Medina-Santiago et al., 2020) utilising Internet of Things (IoT) for Air Conditioner temperature monitoring in data centres highlights the significance of predictive analysis for more proactive temperature management. The research conducted by Tampubolon et al. (2024) on the utilisation of fuzzy logic for temperature control in industrial and business settings demonstrates the considerable potential of this method for broader applications.

While the aforementioned studies have made notable contributions, there are still several areas where further development is needed. The integration of Internet of Things (IoT) and fuzzy logic in a unified system remains a relatively uncommon practice. There is a clear need to enhance the responsiveness of such systems when confronted with rapid and extreme temperature fluctuations. The employment of more sophisticated real-time data analysis for the prediction and prevention of temperature-related issues remains a relatively unexplored area of research. Despite the importance of energy efficiency for cost-effectiveness and environmental sustainability, many studies have not fully optimized energy use in cooling systems. Specific research regarding the implementation of these systems in educational environments, such as campuses, is still limited, thus providing an opportunity for further study in this area. Based on the aforementioned identification of the development gap, this research proposes the development and implementation of a temperature control and monitoring system that integrates IoT technology and fuzzy logic methods comprehensively on the AMIK Luwuk Banggai Campus. The objective of this research is to develop an integrated system that can collect, analyze, and control server room temperature in real time, thereby improving responsiveness of the system to rapid temperature changes and preventing overheating while maintaining temperature stability. Furthermore, real-time data analysis techniques will be implemented to facilitate more proactive temperature prediction and problem prevention, as well as energy use optimization in the cooling system for cost efficiency and sustainability. Customization of the system for the specific needs of educational environment will ensure that developed solution is relevant and beneficial to campus operations. Thus, this research is expected to make a significant contribution to more efficient and effective server room temperature management, especially within the AMIK Luwuk Banggai.

2. **Method**

2.1 Research Stages

The study employed a quantitative experimental method, which is one of several types of quantitative research methods. The objective of this quantitative study was to evaluate the efficacy of experimental variables pertaining to observation, measurement, and testing of Internet of Things (IoT) and Fuzzy Logic-based temperature control and monitoring systems (Rustamana et al., 2024). In this study, the integration of hardware, specifically DHT11 sensors for temperature and humidity and MQ-135 sensors for air quality, with the ESP32 microcontroller was conducted.

A software program was developed to collect and process sensor data using the fuzzy logic algorithm and then transmit the results to Internet of Things (IoT) platform. The testing phase was conducted in the AMIK Luwuk Banggai Campus server room with the objective of evaluating the system's performance in a variety of environmental conditions. The data obtained were subjected to quantitative analysis in order to assess the accuracy, responsiveness, and efficiency of the system in controlling temperature and preventing overheating.

This study employs a quantitative experimental method with structured stages, in order to achieve the stated objectives. The following stages of the research were carried out:

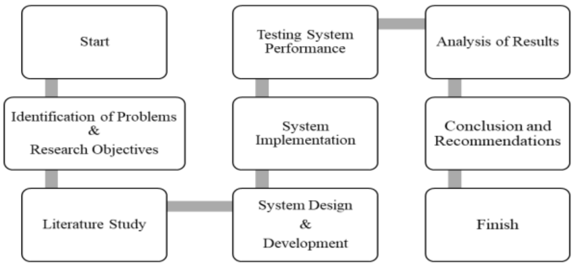


Figure 1. Research Stages

2.2 System Flowchart

Figure 2 illustrates the experimental flow using a flowchart of the air conditioning control and monitoring process system based on the balance between server and room temperature. This system utilizes fuzzy logic and the Internet of Things (IoT) at the AMIK Luwuk Banggai.

The flowchart begins with the initialization of the sensors, specifically the DHT11 for temperature and humidity readings, the PZEM-004T for power consumption measurements, and the MQ-135 for air quality monitoring. The data obtained from the sensors is transmitted to the ESP32, which is linked to the server via a WiFi connection and the Blynk platform for remote monitoring. The system employs the Fuzzy Logic method to categorize temperature into three classes by applying membership functions, which define the boundaries between the three temperature categories: hot, ideal, and cold. Additionally, it considers the time (day/night) based on the default system. This temperature and time data is then processed to determine the operational status of two AC units (AC1 and AC2) in order to maintain a balanced temperature within the server room. The system's decision-making process is contingent upon the temperature and time conditions that have been input. The process commences with an examination of the temperature and time conditions, such as a scenario wherein the temperature is elevated at night, AC1 is deactivated, and AC2 is activated. In the event that the temperature is optimal at night, the AC1 is activated while the AC2 is deactivated. During the daytime, when the temperature is elevated, both units are activated. Conversely, when the temperature is low, only AC1 is engaged. The IR signals are transmitted to the AC in order to execute the aforementioned decisions, while the AC status data is sent to the server for remote monitoring and control. Consequently, the system is capable of maintaining consistent temperatures, optimizing energy usage, and facilitating real-time monitoring via the Internet of Things (IoT) platform, illustrated in the following flowchart.

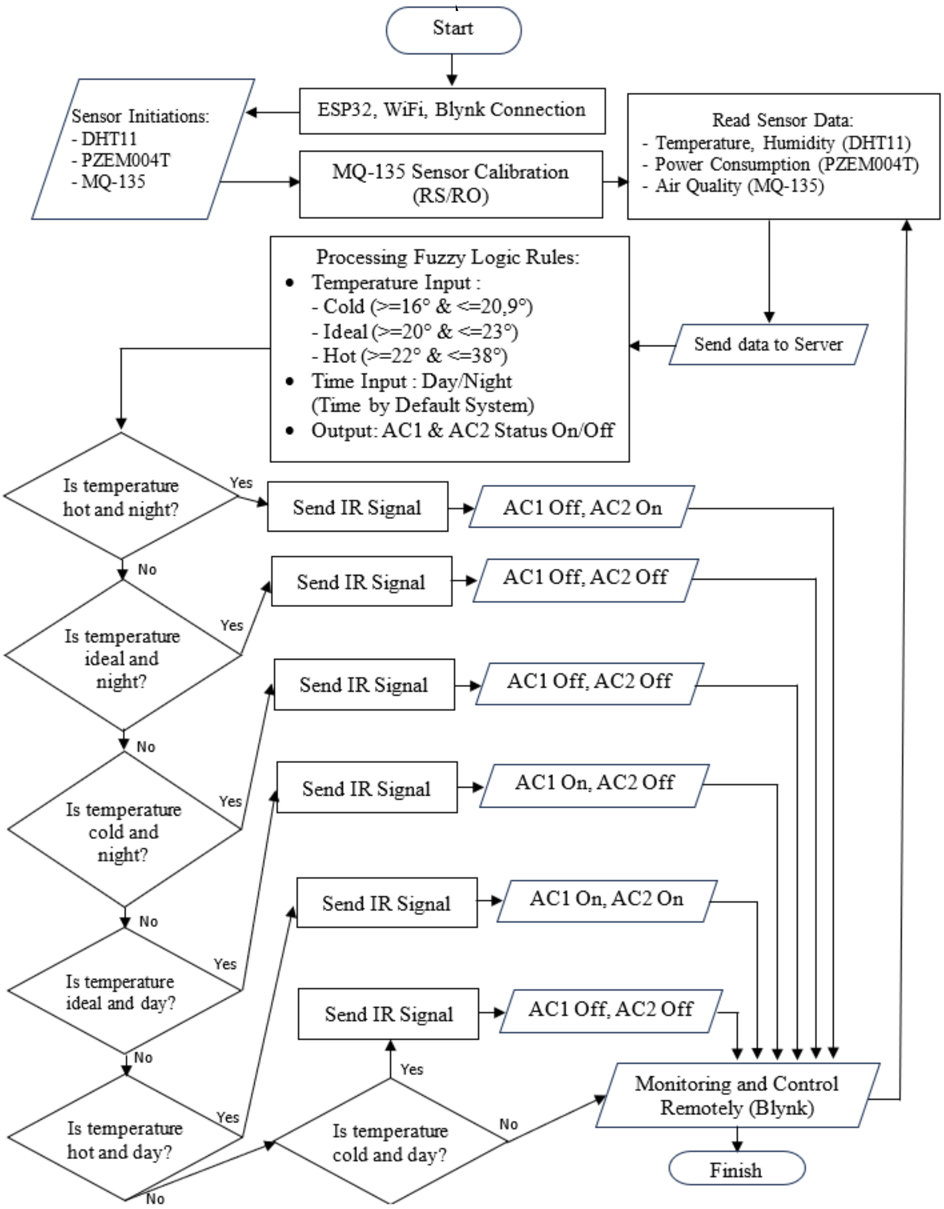


Figure 2. System Flowchart

2.3 System Architecture

As defined by Sawitri Dara (2023), Internet of Things (IoT) is a concept that encompasses the interconnection and interaction between diverse physical devices (including sensors, electronic devices, control devices, and other devices) through the internet. The fundamental concept of Internet of Things (IoT) is the ability of objects to communicate with one another and exchange data autonomously. In an IoT ecosystem, each device is assigned a unique identity and possesses the capacity to generate, transfer, and receive data without manual intervention. The collected data can encompass information about the surrounding environment, the operational conditions of the device, or user behavior. This data can then be subjected to analysis, processing, and utilization in the formulation of pertinent decisions or actions (Arief Deswar & Pradana, 2021). One illustrative example of an IoT application is in a server room, where devices such as lights, air conditioners, and thermostats can be connected to the internet and controlled remotely via a smartphone application. In the industrial sector, the Internet of Things is employed to monitor and control automated systems, enhance preventive maintenance, and augment operational efficiency. The application of the Internet of Things is not limited to a single field or industry. From health to transportation, agriculture to manufacturing, Internet of Things has the potential to alter the manner in which we interact with our surroundings and enhance efficiency, comfort, and safety in a multitude of aspects of life (Rachman et al., 2020). Prior to examining the architectural design, it is first necessary to gain an understanding of the configuration of the server room at AMIK Luwuk Banggai.

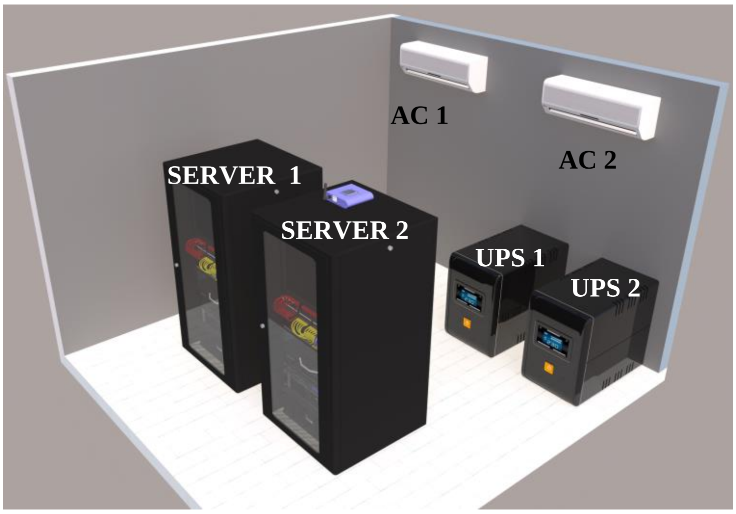


Figure 3. Illustration of AMIK Luwuk Banggai Server Room

The image above illustrated the AMIK Luwuk Banggai Server Room. The room has been designed with the objective of supporting optimal information technology operations, and has been equipped with the necessary infrastructure to facilitate this. The room is equipped with two server racks, which serve as a data storage and processing center. Two uninterruptible power supply (UPS) units are also present, which maintain a stable power supply even in the event of a power outage. Additionally, two wall air conditioners (ACs) are in operation, with the objective of maintaining a stable room temperature within the range of 20°C-22°C. AC 1 (1 Paard Kracht) and AC 2 (2 Paard Kracht) and. Furthermore, an Internet of Things (IoT)-based monitoring system has been implemented, comprising temperature and humidity sensors (DHT11), air quality sensors (MQ-135), and electrical power sensors (PZEM-004T). The data is then transmitted to the Blynk platform for real-time monitoring, thereby ensuring that the environmental conditions within the room remain within optimal limits and thus avoid any potential interference with the server devices.

Block diagram of the research on air conditioner control and monitoring based on temperature balance using fuzzy logic and Internet of Things (IoT) can be explained through several system layers, each of which has a specific function according to the IoT architecture concept (Gitakarma & Tjahyanti, 2022). The sensor layer serves the function of data acquisition (Khattak et al., 2019), utilizing devices such as the DHT11 to read temperature and humidity, the MQ-135 to detect air quality, and the PZEM-004T to monitor power consumption. The data obtained from the sensors is then transmitted to a microcontroller, such as the ESP32 or Arduino (Wangge et al., 2019), which is responsible for processing the data and implementing it in a fuzzy logic-based control system. The fuzzy system is employed to make decisions based on predefined rules, thereby facilitating more adaptive AC control in response to environmental changes. The system is designed to mitigate temperature spikes and maintain thermal equilibrium within the server room. Additionally, the microcontroller functions as a gateway for data transmission to a cloud-based IoT platform, such as Blynk (Hasanuddin & Herdianto, 2023), which offers data storage and analytical capabilities. The complete block diagram of the system is illustrated in the figure below.

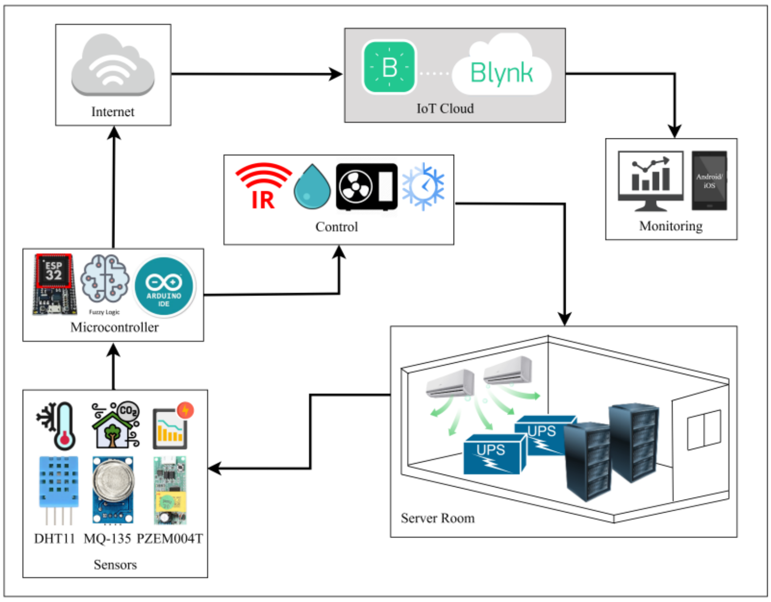


Figure 4. System Block Diagram

In the cloud layer, the data undergo further processing and are then made available for visualization in a web-based or mobile monitoring application (Kumar & Mallick, 2018). This enables users to monitor temperature, humidity, air quality, and power consumption in real time, as well as to control the AC remotely. The theoretical integration of fuzzy and IoT technologies within this architectural framework has the potential to yield a more efficient, automated, and responsive environmental control system capable of responding to the dynamic temperature fluctuations observed in server rooms. Furthermore, this integration could facilitate optimal energy management.

2.4 Control Scheme on Air Conditioner

Following an understanding of the tools and materials that will be used to complete the tool, the next step is to commence the initial design phase. This involves the creation of a schematic of the tool to be constructed.

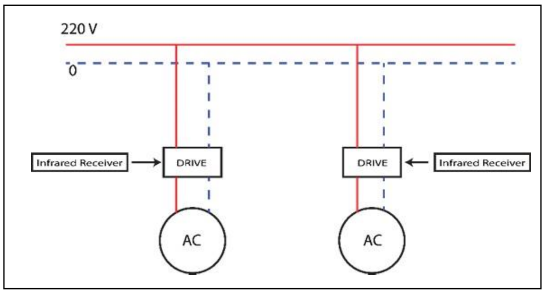


Figure 5. Control Scheme on Air Conditioner

A digital application that facilitates schematic design may be employed to create the schematic. In this instance, the software utilized is Fritzing, which is operated on a laptop or computer. Figure 5 illustrates the control circuitry of the air conditioning system. As illustrated in the figure, the air conditioner is equipped with an infrared receiver.

2.5 Control Scheme on Device

Figure 6 illustrated the control circuitry of the device under construction. The device will employ NodeMCU as a microcontroller and will be equipped with an infrared transmitter.

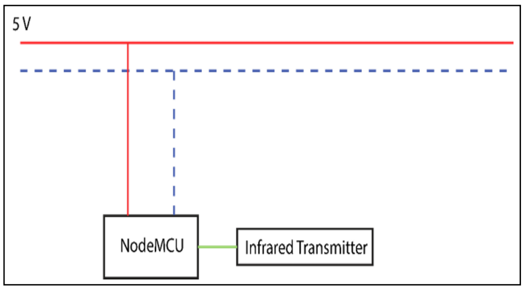


Figure 6. Control Scheme on Device

2.6 Circuit Design

In addition to system architecture, IoT circuit design is illustrated through the use of a Fritzing diagram. Fritzing is an open-source initiative that aims to develop software for designing electronic hardware (Haidar, 2023). Figure 7 illustrated the design of the tool as an integrated system for the real-time monitoring and management of environmental conditions within the server room.

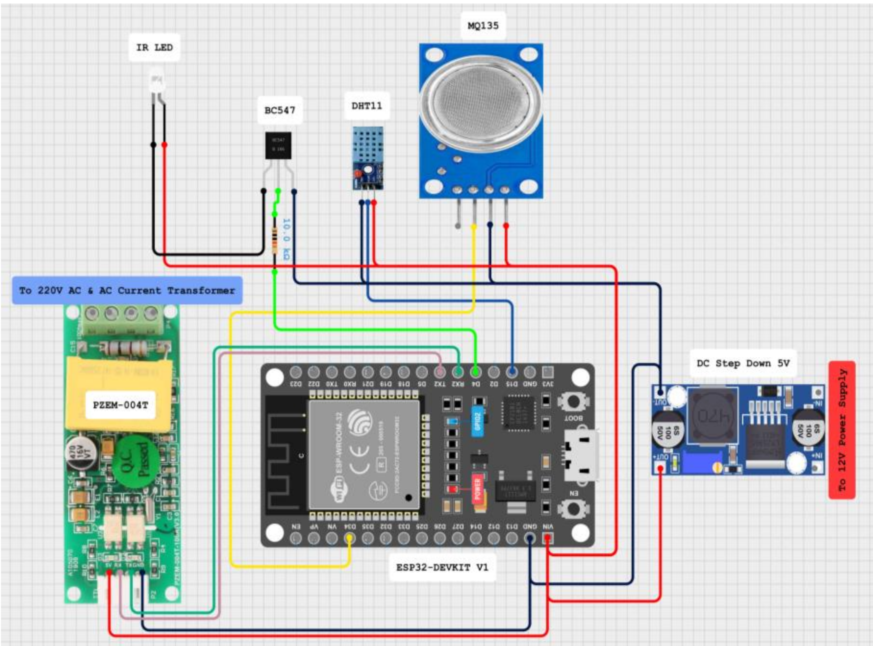


Figure 7. Circuit Design

The NodeMCU ESP32 serves as the control center, aggregating data from diverse sensors, including the DHT11 for monitoring temperature and humidity (Ginting & Nuraini, 2020) and the MQ-135 for detecting air quality (Rosa et al., 2020). The data obtained from these sensors is crucial for maintaining environmental stability in the server room, preventing overheating, and ensuring that the air quality remains within safe limits. Furthermore, the PZEM-004T monitors electricity consumption by measuring voltage, current, and active power (Nirwan & MS, 2020) utilized by devices such as servers and air conditioners. The aforementioned information enables more efficient energy management, while simultaneously providing an early warning of potential power surges that could otherwise damage the device. All data collected by the sensors are transmitted by the NodeMCU via a Wi-Fi connection to the Blynk application, which enables remote monitoring via a smartphone. This enables users to monitor the condition of the server room in real time and receive notifications if environmental parameters deviate from predetermined limits. The step-down converter ensures that all devices receive a stable power supply, while the BC547 transistor and IR LED in this study act as infrared signal transmitters for communication and remote control of the air conditioner.

2.7 Fuzzy Logic

The application of fuzzy logic is of significant importance in this study. Fuzzy logic is a logic system that employs true and false values to facilitate the decision-making process (Nurjanah et al., 2023). Penelitian ini menggunakan algoritma Fuzzy Tahani, yang merupakan pendekatan untuk menangani logika fuzzy berbasis basis aturan (rule-based system) dan memanfaatkan representasi data dalam bentuk nilai derajat keanggotaan (*membership degree*) untuk employed to regulate the AC system in accordance with temperature and humidity data obtained from the DHT11 sensor. Input temperature and humidity data from the DHT11 sensor will be classified into several temperature conditions, namely "ideal," "cold," and "hot," based on the temperature category indicated in the table. In accordance with this classification, fuzzy logic will ascertain the optimal action, such as automatically activating the cooler in the event that the room temperature is identified as "hot," or automatically turning off the cooler if the room temperature is identified as "cold" and maintaining the room temperature within the "ideal" range. Accordingly, the condition of the server room remains stable in accordance with the predetermined threshold.

The implementation of fuzzy logic Tahani is a multi-stage process, which can be delineated as follows:

2.7.1 Data Acquisition

The initial stage of employing fuzzy logic in this study, the sensor is utilized to collect temperature and humidity data in real-time via the DHT11 sensor. Furthermore, time data (day/night) is employed as an additional parameter in the decision-making process. Subsequently, the data is transmitted to the NodeMCU for further processing.

2.7.2 Fuzzification

At this stage, the numerical data obtained from the temperature sensor is converted into membership values within fuzzy categories. The temperature data is divided into three categories, desinagted "cold," encompassing a temperature range of 16°C–20.9°C; "ideal," which includes temperatures between 20°C–23°C; and "hot," which covers temperatures between 22°C–38°C.

1. The membership degree value is determined by calculating the temperature position within the given category. Overlap management is achieved through the overlapping of the cold, ideal, and hot categories at the boundary area, such as temperatures between 20°C and 22°C. This permits a specific temperature to simultaneously be associated with two categories to a limited extent.
2. The advantages of overlap Management include the ability to respond flexibly to temperatures at category limits, such as 20°C, 21°C, and 22°C, due to their membership in multiple categories simultaneously. Furthermore, the system becomes more precise in handling temperature limits, reducing the frequency of AC status changes and providing more stable temperature control.

2.7.3 Fuzzy Rule Application

Fuzzy rules (rule base) are designed to determine the appropriate course of action based on a combination of temperature conditions, time (day/night), and the status of the air conditioning system. The fuzzy rules utilized in this study are presented in Table 1 below. Each of these rules is formulated using the "IF-THEN" conditional statement, with the input being the fuzzy membership value of temperature and time, and the output being the control status of AC1 and AC2.

Table 1. Fuzzy Rules in AC Control and Monitoring System based on Temperature Balance

Rule-	Temperature (°C)	Time (by Default)	AC1 Control	AC2 Control	Status
1	Hot (≥22° & ≤38°)	Night	Off	On	AC1 Off, AC2 On
2	Ideal (≥20° & ≤23°)	Night	Off	Off	AC1 Off, AC2 Off
3	Cold (≥16° & ≤20.9°)	Night	Off	Off	AC1 Off, AC2 Off
4	Hot (≥22° & ≤38°)	Day	On	On	AC1 On, AC2 On
5	Ideal (≥20° & ≤23°)	Day	On	Off	AC1 On, AC2 Off
6	Cold (≥16° & ≤20.9°)	Day	Off	Off	AC1 Off, AC2 Off

1. [R1] IF the temperature is in the Hot category (≥22°C & ≤38°C) AND the time is Night, THEN AC1 is turned off and AC2 is turned on. This is due to the fact that only AC2 is required to maintain a stable temperature without excessive power consumption during night-time hours.
2. [R2] IF the temperature is in the Ideal category (≥20°C & ≤23°C) AND the time is Night, THEN AC1 is turned off and AC2 is turned off. In this condition, the necessity for cooling is negated by the fact that the temperature is already within the optimal range.
3. [R3] IF the temperature is in the Cold category (≥16°C & ≤20.9°C) AND the time is Night, THEN AC1 is turned off and AC2 is turned off. The cold condition does not require air conditioning, maintaining the current state conserves energy.
4. [R5] IF the temperature is in the Hot category (≥22°C & ≤38°C) AND the time is Day, THEN AC1 is turned on and AC2 is turned on. Both air conditioning units are operational to mitigate the elevated temperatures resulting from external conditions and internal heat from devices during the daytime.
5. [R4] IF the temperature is in the Ideal category (≥20°C & ≤23°C) AND the time is Day, THEN AC1 is turned on and AC2 is turned off. AC1 is sufficient to maintain the ideal temperature while compensating for daytime heat and ensuring air circulation
6. [R6] IF the temperature is in the Cold category (≥16°C & ≤20.9°C) AND the time is Day, THEN AC1 is turned off and AC2 is turned off. The cold condition during the day does not necessitate air conditioning, both units remain off to conserve energy.

2.7.4 Decision Making

In the Fuzzy Tahani algorithm, a pre-determined rule table is employed for the purpose of matching the input degree of membership with the control output of the AC. This process is conducted directly, obviating the necessity for additional steps. The ultimate outcome of the rule table is a determination of whether the AC1 and AC2 status control is ON or OFF.

2.7.5 Translation of Results to Control Signals

The result of the fuzzy process, which represents the operational decision regarding the operation of the Air Conditioner, is translated into a signal that is sent via NodeMCU. The IR (infrared) module transmits a signal to activate or deactivate the AC in accordance with the established fuzzy rules.

The system is linked to an Internet of Things (IoT) platform via Blynk, which enables the real-time monitoring of the temperature, humidity, and operational status of the AC. The data is then displayed on a mobile or web application, thereby allowing the user to monitor and control the system at any given moment.

2.7.6 Fuzzy Implementation

The following section illustrates the application of fuzzy logic to this research project. If the temperature is observed to be 21°C at night, then the following fuzzy logic operation is applicable:

1. The temperature of 21°C exhibits partial membership in both the cold (0.4) and ideal (0.6) categories.
2. In accordance with the fuzzy rule, if the temperature is classified as "cold" and the time is identified as "night," then the optimal action is to deactivate AC1 and AC2. However, as the membership is also in the "Ideal" category, the system considers the optimal action in a more flexible manner.
3. NodeMCU transmits a signal to the control system, which then initiates the deactivation of AC1 and AC2.
4. The system status is conveyed to the Blynk application, thereby ensuring that the user is apprised of the actions undertaken by the system.

The processes described above are executed in a sequential manner within an AC control system that employs a microcontroller platform, such as the Arduino or NodeMCU. The temperature data obtained from the DHT11 sensor is then received as input, processed through a fuzzy logic algorithm, and subsequently produces a control signal that determines whether or not to turn the AC on or off.

3. **Results And Discussion**

3.1 Result of System Design

In this section, a prototype design model is presented, with the Internet of Things circuit subsequently implemented. The result is illustrated in the following figure

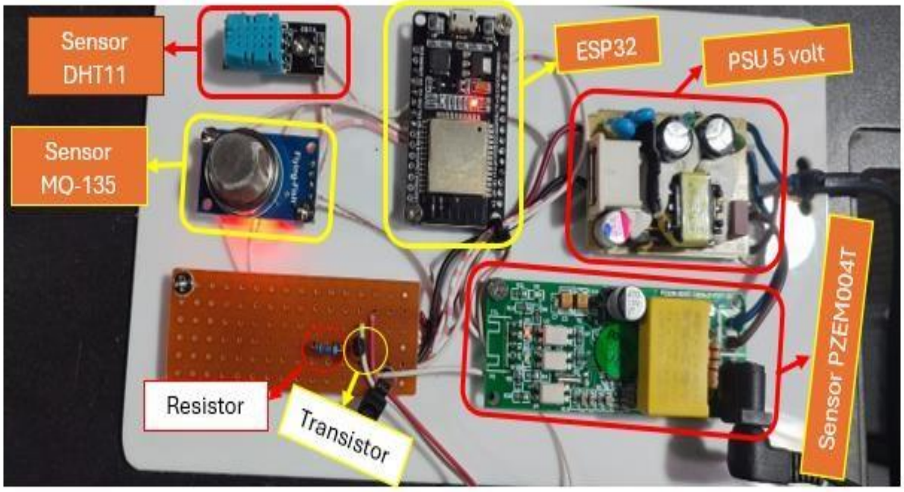


Figure 8. Result of System Design

As illustrated in the figure, the result of the IoT-based monitoring system design implemented is a control center comprised of the NodeMCU ESP32, which serves as the main component. The DHT11 sensor is employed to quantify room temperature and humidity, whereas the MQ-135 is utilized to assess air quality. The PZEM-004T is responsible for monitoring the voltage, current, and electrical power consumed by devices within the server room. The system is equipped with a 5-volt power supply unit (PSU) to provide the necessary power, as well as resistors and transistors to support the operation of the circuit. The data from all sensors is transmitted in real-time to the Blynk application, which is used to control and monitor AC 1 (1 PK) and AC 2 (2 PK) in the server room. This design ensures that the server environment remains stable and efficient.

3.2 Application and Codes

3.2.1 Arduino IDE

In terms of software, Arduino IDE is employed as a platform for the creation and transmission of program commands to NodeMCU ESP32. The programming language utilized by Arduino IDE is C++, a sophisticated derivative of C that necessitates a comprehensive reacquaintance with the intricacies of its syntax, which differs from that of Java and Delphi (Nasruddin & Kusmanto, 2023).

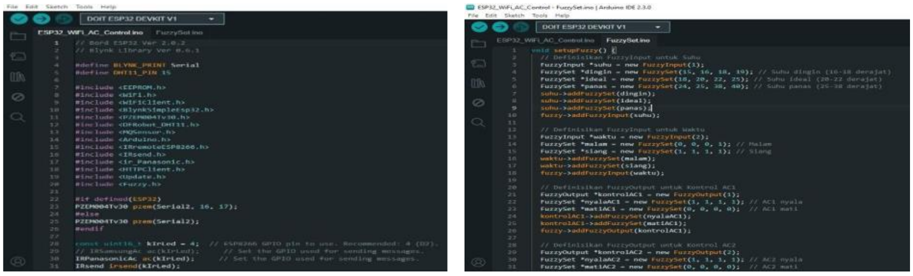


Figure 9. Application Program

The program created in Arduino IDE oversees the collection, processing, and transmission of data from sensors to the monitoring application. In order to guarantee that the device is capable of providing an appropriate response to environmental conditions, a fuzzy logic algorithm is employed as a foundation for decision-making processes within the software.

3.2.2 Blynk Application

The Blynk application is employed as the user interface for real-time monitoring of data due to its user-friendly operation and compatibility with cloud services that are compatible with NodeMCU ESP32 (Saputra, 2023). Blynk provides an intuitive interface through which users can monitor the temperature, humidity, and air quality parameters of the server room via Android and iOS smartphones or via the web. The Blynk application provides users with comprehensive access to real-time data and alerts them in the event of any deviations from the optimal parameters.

Figure 10. Dashboard Monitoring System

Fuzzy logic will determine the optimal course of action, such as activating an alarm or initiating the cooler's automatic operation if the room temperature is deemed "hot." The integration of hardware and software, coupled with the application of fuzzy logic algorithms, enables the system to adapt and make autonomous decisions to manage the environmental conditions of the server room. The algorithmic approach enables the device to maintain a stable environment within the server room, adhering to the predefined threshold.

3.3 Testing Results

A testing procedure was conducted to evaluate the efficacy of the DHT11 module utilized in the air conditioner control and monitoring system. The objective of system testing is to prove that the software and hardware are capable of functioning in accordance with the established standards. System testing is conducted with the objective of identifying any potential errors or deficiencies that may exist within the system. This encompasses both the functionality of the system and its accuracy in carrying out monitoring tasks and decision-making based on data obtained from sensors. The system testing comprises several sub-points, as detailed below:

3.3.1 System Hardware Testing

The integration testing is conducted to evaluate the functionality of the hardware components (NodeMCU, DHT11 sensor) and software (Arduino IDE, fuzzy logic algorithm, and Blynk) in a synchronous manner. The objective of data testing is to ascertain whether the hardware and software are capable of responding to changes in an automated and manner that is consistent with the system design. This is achieved through the simulation of a variety of environmental scenarios.

Table 2. Hardware Testing

Testing-	Date	DHT11 Sensor	Manually (Thermometer)
1	8/11/2024.09:12:04	22°	22,2°
2	8/11/2024.13:33:36	24°	24,5°
3	8/11/2024.16:50:37	22°	22,1°
4	8/11/2024.20:08:36	23°	23,2°
5	9/11/2024.10:03:37	23°	23,5°

3.3.2 System Software Testing

Figure 11 illustrates the system testing process, which was implemented with the objective of guaranteeing that the software developed with the Arduino IDE and Blynk could operate in accordance with the planned scenario.

Figure 11. Software Testing

The functionality of the command and program flow is evaluated to confirm that the NodeMCU ESP32 receives the input data accurately from the sensor and processes it using the specified fuzzy logic algorithm. Additionally, it is ascertained that the resulting test data is transmitted in a real-time basis to both the Blynk application and a dedicated Google spreadsheet.

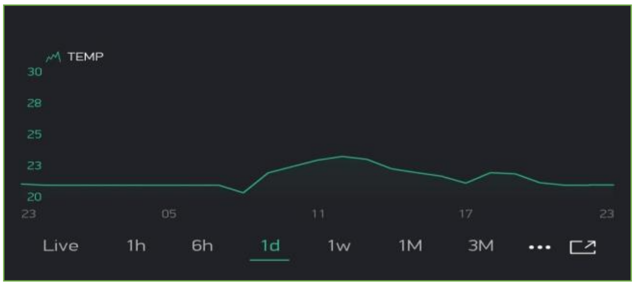


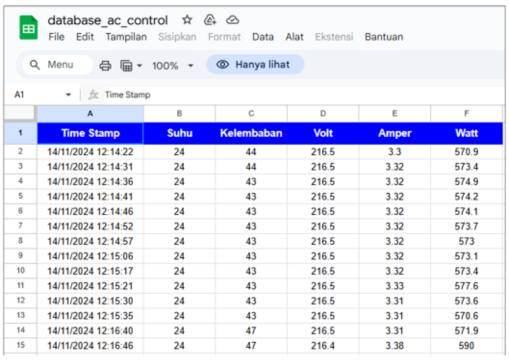
Figure 12. Temperature Graph

In the table 3 below the system testing using Fuzzy Logic is to ensure that the system can operate according to the logic that has been designed using the Fuzzy logic method. This method is applied to process input data from the DHT11 sensor and control output that is accurate and according to needs.

Table 3. Software System Testing

Testing	Date	Temperature	AC1 (1 PK)	AC2 (2 PK)
1	14/11/2024.11:14:22	26°	On	On
2	14/11/2024.18:00:06	22°	Off	On
3	15/11/2024.15:20:40	24°	On	On
4	15/11/2024.21:19:52	22°	Off	Off
5	16/11/2024.00:07:49	22°	On	Off

The fuzzy logic algorithm is executed by entering a series of input values within a specified time interval to evaluate the system's output response.


database_ac_control
File Edit Tampilan Sisipkan Format Data Alat Ekstensi Bantuan
Menu 100% Hanya lihat
A1 Time Stamp

	A	B	C	D	E	F
1	Time Stamp	Suhu	Kelembaban	Volt	Amper	Watt
2	14/11/2024 12:14:22	24	44	216.5	3.3	570.9
3	14/11/2024 12:14:31	24	44	216.5	3.32	573.4
4	14/11/2024 12:14:36	24	43	216.5	3.32	574.9
5	14/11/2024 12:14:41	24	43	216.5	3.32	574.2
6	14/11/2024 12:14:46	24	43	216.5	3.32	574.1
7	14/11/2024 12:14:52	24	43	216.5	3.32	573.7
8	14/11/2024 12:14:57	24	43	216.5	3.32	573
9	14/11/2024 12:15:06	24	43	216.5	3.32	573.1
10	14/11/2024 12:15:17	24	43	216.5	3.32	573.4
11	14/11/2024 12:15:21	24	43	216.5	3.33	577.6
12	14/11/2024 12:15:30	24	43	216.5	3.31	573.6
13	14/11/2024 12:15:35	24	43	216.5	3.31	570.6
14	14/11/2024 12:16:40	24	47	216.5	3.31	571.9
15	14/11/2024 12:16:46	24	47	216.4	3.38	590

Figure 13. Data Monitoring Results in Google Spreadsheet

The output value of the sensor data, in conjunction with the results of the fuzzy logic method calculation, is processed using the Blynk application and Google Spreadsheet as a reference data set for subsequent analysis. The data in the table demonstrate that, following a series of trials, the software is capable of functioning in accordance with its intended functionality. The figure 13 above illustrates the monitoring results of data read by the system and automatically inputted into a Google Spreadsheet.

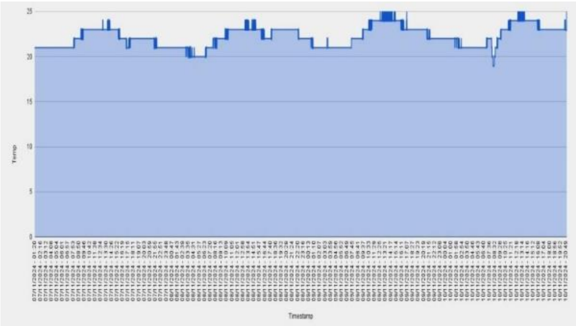


Figure 14. Server Room Temperature Output Graph

The graph illustrates the temperature fluctuations of the server room over a specified time period. The vertical (Y) axis represents the temperature in degrees Celsius, while the horizontal (X) axis represents the time of data collection in the format of a timestamp. The temperature fluctuations are relatively minor, indicating that the cooling system (such as an air conditioner) is functioning effectively in maintaining a consistent temperature. However, there are several instances of elevated temperatures and abrupt decreases. Such fluctuations may be attributed to transient disturbances, such as the opening of the server room door or an increase in server workload, which can impact the room temperature. The occurrence of sharp drops at specific points in time suggests the intervention of the cooling system or a sudden decrease in workload. The data indicates that the IoT-based monitoring system is functioning as intended, with the ability to monitor temperature in real-time and record any changes, including minor fluctuations. From this graph, it can be concluded that the server room has a temperature control system with reasonable stability. However, the presence of spikes and drops in temperature indicates the need for further attention to ensure the absence of significant technical or operational issues.

3.4 System Analysis

3.4.1 System Hardware Analysis

The testing of the DHT11 sensor is conducted with the objective of verifying that the sensor is capable of accurately measuring air temperature in accordance with the specified parameters. The DHT11 sensor is a digital sensor that is capable of reading temperature data within the range of 0–40°C with an accuracy of ±0.25°C in the range of 20–90% with an accuracy of ±98.79%. In order to evaluate the response of the DHT11 sensor, it is placed in an environment with varying temperatures during the testing phase. The data produced by the sensor is documented and evaluated in comparison with data obtained from conventional measuring instruments, thus ensuring the accuracy of the sensor.

In this test, theoretical comparisons are made with actual values. In this test, the actual temperature, as measured by a thermometer with a DHT11 sensor, is compared with the theoretical temperature.

Table 4. DHT11 sensor testing and analysis

Testing	Date	DHT11 Sensor	Manually (Thermometer)	*Margin of Error*
1	8/11/2024.09:12:04	22°	22,2°	**0,90%**
2	8/11/2024.13:33:36	24°	24,5°	2,04%
3	8/11/2024.16:50:37	22°	22,1°	0,45%
4	8/11/2024.20:08:36	23°	23,2°	0,86%
5	9/11/2024.10:03:37	23°	23,5°	2,12%
6	9/11/2024.14:27:11	24°	24,3°	1,23%

7	9/11/2024.18:01:36	23°	24,3°	1,23%
8	9/11/2024.19:51:36	23°	23,2°	0,86%
			Margin of Error	1,21%
			System Accuracy Average	98,79%

The margin of error represents the deviation between the actual measurement obtained by the DHT11 sensor and the reference measurement (manual thermometer). In this experiment, the margin of error value for all data was calculated using the following formula:

$$Error = \frac{|\,Measurement\ Value - Reference\ Value\,|}{Reference\ Value} \times 100\ \% \quad (1)$$

$$= \frac{22{,}2 - 22}{22{,}2} \times 100\ \%$$

$$= 0{,}90\%$$

The margin of error for each measurement was calculated and subsequently averaged based on the results of the test table conducted on 8-9 November 2024.

$$Average\ of\ Error = \frac{|\,Amount\ of\ Margin\ of\ Error\,|}{Amount\ of\ Data} \times 100\ \%$$

$$= \frac{0{,}90\% + 2{,}04\% + 0{,}45\% + 0{,}86\% + 2{,}12\% + 1{,}23\% + 1{,}23\% + 0{,}86\%}{8} \times 100\ \%$$

$$= 1{,}21\%$$

The mean margin of error demonstrates a markedly low degree of deviation between the sensor value and the reference value. Once the errors have been obtained and averaged, the subsequent step is to ascertain the system accuracy. The system accuracy is calculated based on the margin of error value, according to the following formula:

$$Accuracy = 100\% - Average\ of\ Margin\ of\ Error$$

$$= 100\% - 1{,}21\%$$

$$= 98{,}79\%$$

The margin of error obtained from the test results was 1,21% percent, indicating that the DHT11 demonstrated an accuracy level of 98,79% percent in this study.

3.4.2 System Software Analysis

In this study, the test was conducted for three days on AC 1 (1 PK) and AC 2 (2 PK). Figure 15 illustrates the relationship between temperature and AC status (AC 1 and AC 2) within a specified time frame. The temperature is represented by an orange line with dot markers, while the status of AC 1 (1 PK) and AC 2 (2 PK) are depicted as blue and green dashed lines, respectively. The position of the AC line is adjusted above the temperature scale for the purpose of visual distinction.

The hysteresis phenomenon is observable in the graph below, wherein the AC exhibits delayed response in turning off or on when the temperature approaches the pre-established threshold. This is done to prevent the AC from frequently turning on and off, which would otherwise result in accelerated wear on the system. Upon a subsequent increase in temperature above the upper threshold, the AC will resume operation.

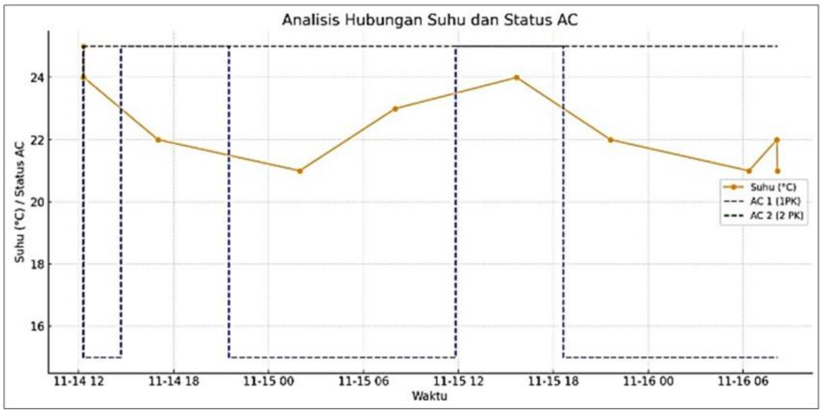


Figure 15. AC Temperature and Status Analysis Graph

At the initiation of the observation period on November 14, 2024 at 12:00 PM, the temperature was recorded at a high level, in the range of 24°-25°C. Throughout the observation period, AC 2 was consistently operating to maintain the desired temperature, while AC 1 was activated periodically to provide additional cooling. This pattern persisted until the evening temperature reached 22°C, at which point the temperature was between the hot and ideal membership functions. At this point, AC 1 began to be deactivated as the temperature approached the ideal range, while AC 2 remained operational. On November 15, 2024 at 00:00 AM, when the temperature reached an ideal range of 21°-22°C, AC 2 was largely inactive, while AC 1 remained operational. On November 15, 2024 at 06:00 AM, the temperature was recorded at an optimal level of 22°-23°C. During this period, AC 2 was not operational, while AC 1 remained active. On November 15, 2024 at 12:00 PM, the temperature was within the range of 23°-24°C, which is categorized as "hot" criteria. Both AC 1 and AC 2 demonstrated consistent operation until 6:00 PM. On November 16, 2024, between 00:00 and 06:00 AM, the temperature was monitored and found to be within the range of 21°-22°C. This temperature range was also observed when only AC 1 was operating, while AC 2 remained inactive.

Table 5 below presents a comparative analysis of the facts occurring in the air control system and the accuracy of the system developed. The conclusions drawn from Figure 15 above are also included in this table:

Table 5. Air Conditioner Control Testing and Analysis

Testing	Date	Temperature	AC1 (1 PK)	AC2 (2 PK)	Fuzzy Rule	
					Categories	Correct
1	14/11/2024.11:14:22	26°	On	On	Hot/Day	✓
2	14/11/2024.12:18:05	25°	On	On	Hot/Day	✓
3	14/11/2024.12:19:14	24°	On	On	Hot/Day	✓
4	14/11/2024.18:00:06	22°	Off	On	Hot/Night	✓
5	15/11/2024.01:57:35	21°	On	Off	Ideal/Night	x
6	15/11/2024.08:00:01	23°	On	Off	Ideal/Day	✓
7	15/11/2024.15:20:40	24°	On	On	Hot/Day	✓
8	15/11/2024.17:58:53	23°	On	On	Hot/Day	✓
9	15/11/2024.21:19:52	22°	Off	Off	Ideal/Night	✓
10	16/11/2024.00:07:49	22°	On	Off	Ideal/Day	✓
11	16/11/2024.06:10:06	21°	On	Off	Ideal/Day	✓

In this test, a theoretical comparison is conducted with actual values. In this test, the actual event of the air conditioner control system, as illustrated in Table 5, is evaluated in comparison with the fuzzy logic rules that have been implemented throughout the system.

The mean accuracy derived from the outcomes of the comprehensive system examination indicates that the implementation of Fuzzy Logic in conjunction with the Internet of Things methodology to ensure the stability of the temperature-based server room exhibits an accuracy level of 90.91% in this study. The accuracy of the comparison between the measurements of actual events and the application of fuzzy logic to the entire system can be calculated using the following formula:

$$Accuracy = \frac{|\,Correct\ Amount\,|}{Total\ Amount} \times 100\,\%$$
$$= \frac{10}{11} \times 100\,\%$$
$$= 90{,}91\%$$

3.5 Test Results Discussion and Analysis

A number of comparative analyses have been conducted, beginning with temperature readings obtained from two distinct measurement techniques: the DHT11 sensor (Internet of Things) and a manual thermometer. The temperature data generated by both methods exhibited a high level of correlation, with discrepancies represented by the margin of error at each measurement point. Specifically, the maximum margin of error was observed to be 0,4-2%. This result is further corroborated by the average margin of error of 1,21%, as many references writed that the acceptable margin of error usually falls between 4% and 8% at the 95% confidence level which indicates a minimal discrepancy from the reference value (manual thermometer) and serves to confirm the accuracy of the DHT11 sensor. The system accuracy of 98.79% indicates that the DHT11 sensor is a reliable method for measuring temperature under experimental conditions. A comparative analysis was also conducted to evaluate the overall system. This involved a comparison between actual events and the application of fuzzy rules. Following several experiments, the accuracy of the entire system was determined to be 90.91%. This was achieved through the use of the DHT11, the application of fuzzy rules, and the control of the air conditioner.

In the context of Internet of Things (IoT) applications, the significance of high accuracy cannot be overstated. The efficacy of such systems is contingent upon the capacity to gather and process precise, real-time data. The discrepancies observed in some measurements, though slight, can be attributed to external variables such as humidity fluctuations or the physical orientation of the device during the measurement. Nevertheless, these discrepancies fall within the tolerable limits for a DHT11-type sensor. The results of this study demonstrate that an Internet of Things (IoT) system employing the DHT11 sensor is an appropriate means of temperature control in a variety of applications. The low margin of error indicates that the device is sufficiently reliable to be used in real-time environmental monitoring applications. This example demonstrates the advantages of the fuzzy logic approach in processing dynamic data from the sensor. The system demonstrated an accuracy of 90%. Although this value is lower than that observed in other studies, it is nevertheless satisfactory, given that this system is designed for practical use with limited resources.

Nevertheless, the research is constrained by certain limitations, as are the practical implications of the research. The results of the analysis of these limitations and implications, based on a comprehensive study, are as follows:

3.5.1 Research Limitations

1 The testing was conducted in a limited capacity: The system was tested in a specific campus server room (AMIK Luwuk Banggai) under conditions that may not be fully representative

of other, larger or more complex server rooms. As a result, the findings may not be applicable in other contexts.
2 The impact of humidity was not considered in this analysis: Although humidity can impact hardware, the system exclusively considers temperature and time parameters.
3 The system is dependent on an internet connection: The system is dependent on the Internet of Things (IoT), which requires a stable internet connection. In environments with constrained internet access, the efficacy of the system may be diminished.
4 The financial implications of implementation: The deployment of Internet of Things (IoT) devices and fuzzy logic algorithms may result in an initial cost increase, which could be a deterrent for institutions with limited budgets.
5 The system exhibits a lack of comprehensive energy control capabilities: Notwithstanding the system's optimization of energy usage, it lacks the capacity to implement comprehensive energy-saving strategies, such as the dynamic control of cooling power levels.

3.5.2 Practical Implications

1 Enhanced temperature stability and device security: The implementation of an Internet of Things (IoT)-based control system, coupled with fuzzy logic, ensures temperature stability within the server room, thereby preventing overheating that can damage the hardware. This is pertinent to the maintenance of the device's operational lifespan and the sustenance of seamless operations, particularly within the context of academic institutions, such as campuses.
2 Energy Efficiency: The implementation of fuzzy-based control rules enables the system to operate the requisite number of air conditioners, contingent upon the prevailing temperature and time conditions. This approach optimizes energy usage, reduces operational costs, and supports environmental sustainability.
3 Real-time Monitoring and Response: Integration with the Blynk application enables real-time monitoring of temperature, humidity, and air quality via mobile devices. Furthermore, automatic notifications facilitate prompt corrective action in the event of anomalies, thereby enhancing responsiveness to critical situations.
4 Adaptation to the Educational Environment: The system is designed to meet the specific needs of University, such as ensuring the continuity of server operations to support academic and administrative activities.
5 Mitigation of Financial Loss: By preventing damage to devices due to uncontrolled temperatures, institutions can avoid the costs associated with repairs or replacements, which may be significant.
6 Potential for Industrial-Scale Development: The system can be adapted for application in temperature management in data centers or other work environments, thus providing commercial added value.

The implications of this study demonstrate that its findings have practical applications in diverse contexts, particularly in the efficient and effective management of server room environments.

4. **Conclusions**

The aim of this research project is to integrate Internet of Things (IoT) technology and Fuzzy Logic (FL) methods into a comprehensive system for the control of temperature within data centre environments. A margin of error of 1,21% was identified through testing and analysis, which indicates that the Fuzzy Logic system on this hardware is capable of providing consistent performance. The system is capable of meeting the requirements for temperature and humidity monitoring with an accuracy of 98,79%. This indicates that the implemented Fuzzy Logic algorithm is in accordance with the design objectives.

The system demonstrates an increased responsiveness in the face of rapid temperature changes, preventing overheating of server devices. It is evident that the system is able to operate effectively in a dynamic environment, providing relevant and adequate data for users to maintain the controlled room.

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