IOT BASED SMART GREENHOUSE MONITORING SYSTEM WITH FUZZY LOGIC

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ABSTRAK

Tesis ini membentangkan sistem pemantauan rumah hijau pintar berdasarkan logik kabur untuk kawalan suhu, pengairan dan keadaan pencahayaan yang berkesan. Amalan pemantauan rumah hijau tradisional selalunya memerlukan campur tangan manual dan pemantauan kelembapan tanah, suhu, kelembapan dan keamatan cahaya, yang membawa kepada cabaran dalam mengekalkan pertumbuhan tumbuhan yang optimum. Untuk mengatasi batasan ini, sistem pemantauan automatik dibangunkan menggunakan prinsip logik kabur. Sistem pemantauan rumah hijau pintar yang dicadangkan memantau keadaan tumbuhan secara autonomi. Ia menggunakan algoritma logik kabur untuk menilai dan melaraskan faktor persekitaran secara berterusan. Sebagai contoh, apabila suhu melebihi ambang yang telah ditetapkan, sistem mengaktifkan sistem pengudaraan untuk mengawal dan mengekalkan julat suhu yang diingini untuk pembangunan tumbuhan yang optimum. Sistem ini seterusnya menangani isu penyiraman manual dengan memantau tahap kelembapan tanah. Apabila kelembapan tanah jatuh di bawah ambang yang ditentukan, sistem secara automatik mengaktifkan pam air, menyediakan pengairan yang mencukupi untuk memastikan kelembapan tanah yang optimum untuk pertumbuhan tumbuhan. Selain itu, sistem ini menggabungkan sistem pencahayaan pintar untuk mengoptimumkan keamatan cahaya. Ia sentiasa memantau tahap cahaya dalam rumah hijau dan mengaktifkan lampu tumbuh tambahan apabila keamatan berkurangan di bawah julat yang dikehendaki, dengan itu menggalakkan pendedahan cahaya yang konsisten dan mencukupi untuk tumbuhan, walaupun pada waktu malam. Dengan menggunakan teknik kecerdasan buatan dan kawalan logik kabur, sistem pemantauan rumah hijau pintar menyediakan penyelesaian automatik untuk mengoptimumkan suhu, pengairan dan keadaan pencahayaan. Melalui pengaktifan autonomi pam air dan sistem pengudaraan, sistem ini mengurangkan campur tangan manual dan memastikan tumbuhan menerima keadaan pertumbuhan yang optimum. Keputusan kajian ini menunjukkan pertumbuhan tumbuhan yang bertambah baik, hasil tanaman yang dipertingkatkan, dan usaha buruh yang berkurangan untuk penanaman rumah hijau. Kesimpulannya, tesis ini menyumbang kepada bidang teknologi rumah hijau pintar dengan mempersembahkan sistem pemantauan menyeluruh yang menggunakan kawalan logik kabur. Sistem ini memantau dan mengawal suhu, pengairan dan keadaan pencahayaan dengan berkesan, mengurangkan keperluan untuk campur tangan manual, dan membolehkan pertumbuhan tumbuhan yang dioptimumkan.

Penemuan ini menyerlahkan keberkesanan sistem yang dicadangkan dalam menyediakan pemantauan yang cekap dan automatik untuk persekitaran rumah hijau, memupuk amalan penanaman yang lebih baik, dan memaksimumkan hasil tanaman.

ABSTRACT

This thesis presents a smart greenhouse monitoring system based on fuzzy logic for effective control of temperature, irrigation, and lighting conditions. Traditional greenhouse monitoring practices often require manual intervention and monitoring of soil moisture, temperature, humidity, and light intensity, leading to challenges in maintaining optimal plant growth. To overcome these limitations, an automated monitoring system is developed using fuzzy logic principles. The proposed smart greenhouse monitoring system autonomously monitors the plant's growing conditions. It employs fuzzy logic algorithms to continuously assess and adjust environmental factors. For example, when the temperature exceeds predefined thresholds, the system activates the ventilation system to regulate and maintain the desired temperature range for optimal plant development. The system further addresses the issue of manual watering by monitoring soil moisture levels. When the soil moisture falls below a specified threshold, the system automatically activates the water pump, providing adequate irrigation to ensure optimal soil moisture for plant growth. Additionally, the system incorporates an intelligent lighting system to optimize light intensity. It continuously monitors the light levels within the greenhouse and activates supplementary grow lights when the intensity decreases below the desired range, thereby promoting consistent and adequate light exposure for plants, even during nighttime hours. By employing artificial intelligence techniques and fuzzy logic control, the smart greenhouse monitoring system provides an automated solution to optimize temperature, irrigation, and lighting conditions. Through its autonomous actuation of the water pump and ventilation system, the system reduces manual intervention and ensures that plants receive optimal growing conditions. The results of this study indicate improved plant growth, enhanced crop yield, and reduced labor efforts for greenhouse cultivation. In conclusion, this thesis contributes to the field of smart greenhouse technology by presenting a comprehensive monitoring system that utilizes fuzzy logic control. The system effectively monitors and regulates temperature, irrigation, and lighting conditions, alleviating the need for manual intervention, and enabling optimized plant growth. The findings highlight the efficacy of the proposed system in providing efficient and automated monitoring for greenhouse environments, fostering improved cultivation practices, and maximizing crop yields.

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%	Percentage
C	Degree of Celcius

LIST OF ABBREVIATIONS

IoT	Internet of Things
DHT11	Digital Humidity and Temperature 11
Wi-Fi	Wireless Fidelity
LAN	Local Area Network
JSON	JavaScript Object Notation
MQTT	Message Queuing Telemetry Transport
AI	Artificial Intelligence
VSC	Visual Studio Code
GUI	Graphical User Interface
FLC	Fuzzy Logic Control

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A greenhouse is a manufactured environment that encourages all aspects of agricultural performance improvement. It is composed of four parts: surface cover, soil, plant, and internal air. The surface divides the outer environment from the internal environment. It shields the inside plants from poor weather and illness. It can be made of polyethylene or glass. The inside air is the most important aspect or components of the greenhouse. It is influenced by the outside temperature and relative humidity. The soil must be considered in this section due to its thermal heat absorption and diffusion properties. Plants play a significant part in the process's heat and water balances (Mostakim, N., Mahmud, S., & Jewel, K. H, 2020).

Malaysia's lowlands have a hot and humid climate all year (temperature range: 21-32 C, relative humidity (RH): 80-90%, solar radiation: 12-20 MJ/m2, wind speed: 2-22 m/s, and substantial rainfall: 2032-2540 mm). High temperature and humidity are two key obstacles in this place; so, the primary objective of employing a greenhouse in Malaysia's lowlands is to protect plants from excessive temperatures, rain, wind, insects, and diseases. A well-designed and managed greenhouse environment minimises production costs, increases yield, and preserves crop quality (Shamshiri, R., & Ismail, W. W, 2012).

As a result, there are several chances for IoT technology to be brought into the agriculture industry. This project will primarily focus on monitoring and controlling the measurements of the parameters (temperature, humidity, soil moisture, and light intensity) within the greenhouse into appropriate levels to promote plant development. To address these difficulties, an 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic', or SGMS for short, is proposed. This system will merge IoT technology with the existing greenhouse system.

By implementing automation actuators such as a water pump and the activation of a ventilation fan and light, this system will be able to monitor and regulate the reading of the parameters to the suitable readings. These actuators are controlled by fuzzy logic control decisions based on predefined rules. Eventually, all collected data will be visualised into understandable data visualisations such as graphs and present values and displayed within a web-based interactive dashboard along with data analytics to allow users to monitor the data and even alert them to take relative action to maintain ideal storage conditions based on the results displayed.

1.2 PROBLEM STATEMENT

The problem statement of ‘IoT based Smart Greenhouse Monitoring System with Fuzzy Logic’ are as follow: -

I. Existing system is relied on manual intervention and lack-time data analysis.

The traditional approach of greenhouse monitoring depends largely on human intervention, with farmers physically observing and assessing environmental conditions. This manual approach is time-consuming, prone to human mistake, and does not allow for real-time data processing. It has become clear that a more efficient and precise monitoring system that delivers real-time insights on greenhouse conditions is required. Data may be captured and communicated wirelessly by incorporating IoT technology, enabling for real-time monitoring and analysis of the greenhouse environment.

II. Controlling temperature regulation, irrigation management and light optimization.

Temperature control, irrigation management, and light optimisation are all important aspects of greenhouse gardening. Because various plants have varying temperature requirements, maintaining ideal temperature levels is critical for plant growth. Similarly, good irrigation management ensures that plants get enough water without being overwatered or suffering from water stress. Additionally, optimising light intensity is critical for photosynthesis, which is necessary for plant energy generation. These parameters can be properly monitored and regulated using sensors, actuators, and cognitive algorithms in the IoT-based smart greenhouse monitoring system. Based on established thresholds and desired plant conditions, the system can automatically change temperature, watering, and lighting factors, assuring optimal development, and eliminating user involvement.

III. Assessing the performance of a IoT Smart Greenhouse Monitoring System.

The performance of the IoT-based smart greenhouse monitoring system must be evaluated to prove its usefulness in enhancing greenhouse production. The system's dependability, precision, responsiveness, and energy efficiency may all be assessed using rigorous examinations. To examine total system performance, performance criteria such as data accuracy, system responsiveness, power consumption, and user satisfaction may be evaluated. The evaluation results will give significant insights for future system modifications and will be used to compare with traditional greenhouse monitoring methodologies.

1.3 OBJECTIVE

The objective of the development 'IOT based Smart Greenhouse Monitoring System with Fuzzy Logic' are as follows: -

1. To study the requirements of monitoring a greenhouse.

2. To develop an IoT based system that is capable of monitoring and determining greenhouse's condition using fuzzy logic.

3. To evaluate the effectiveness of the greenhouse monitoring system in monitoring the greenhouse's condition.

1.4 SCOPE

The scope of the 'IOT based Smart Greenhouse Monitoring System with Fuzzy Logic' are as follows:

User scope:

I. Greenhouse owners.

System scope:

I. Sensors that have been used in this system are DHT11 sensors, photocell sensor and soil moisture sensor.

II. Actuators that have been used in this system are water pump and ventilation fan while for output device, there is a bulb.

III. Protocols that have been implemented in this system are MQTT and WebSocket.

IV. Components of Artificial Intelligence (AI) that has been implemented in this system is Fuzzy Logic which generates the control signals to the actuators.

V. Dashboard of this system are displayed the real-time data for graphs and current value displayed for each sensors readings, table of alert, fuzzy logic information and control button for actuators. Aside from that, this system offers alarm notification via Telegram to warn the system's user.

Development scope:

I. Servers that have been used by this system are MQTT server, Web server, WebSocket server and AI server.

II. Database that has been selected to store all the data is MySQL database which is local database.

III. The sources of development system that has been used is Laravel framework through Visual Studio Code (VSC).

IV. Programming languages that have been used in this system are Python and C++.

1.5 SIGNIFICANCE OF PROJECT

The significance of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' project is primarily to monitor the parameters within the greenhouse to maintain stable and suitable readings that support the growth of plants. Temperature, humidity, soil moisture, and light intensity are the parameters that have been the focus of this project.

The automated system irrigation, which includes a water pump, ventilation fan, and bulb activation, has been integrated in this system to obtain appropriate readings of parameters within the greenhouse. The greenhouse owner basically needs to watch and monitor the state of their plants via the dashboard and does not need to control the greenhouse manually.

This system is also capable of reacting immediately when the parameters within the greenhouse approach the danger level specified in this system using Telegram. It will alert the user about the state of their greenhouse, allowing them to take immediate action to resolve any issues. For example, the system will activate and warn the user if the temperature inside the greenhouse exceeds 31 degrees Celsius, the humidity falls below 40%, and the soil moisture and light intensity readings fall below 30%.

1.6 THESIS ORGANIZATION

This thesis will be divided into five chapters: INTRODUCTION, LITERATURE REVIEW, METHODOLOGY, IMPLEMENTATION & RESULT, and CONCLUSION.

The first chapter, INTRODUCTION, focuses on general information about the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' projects, such as the project's introduction, further explanation of the problem statement, objectives and scope of this project, and project's significance once implemented in real-life situations.

The second chapter, LITERATURE REVIEW, analyses the details of current existent systems on the market that are relevant to this project. Comparing those systems to understand the strengths and weaknesses that should be taken consideration when developing this project.

The third chapter, METHODOLOGY, concentrates on the technique selected for developing this project, as well as additional elaboration on the system's flow by providing flowcharts and diagrams, and illustrates the featured software and hardware that will be implemented to develop the system.

The fourth chapter, IMPLEMENTATION AND RESULT, focuses on demonstrating the system's implementation in real-life scenarios, as well as testing results from various active users of the system.

Finally, the fifth chapter, CONCLUSION, focuses on a summary of the developed project, including whether it has made any significant changes to the process of maintaining the readings of parameters inside the greenhouse in order to support plant growth, as well as a discussion of the constraints encountered during the project and the likely future expansions of the work produced.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In develop a system, comparison must be made between the existing system that are like the proposed system to understand each of their capabilities as well as other distinguishing features such as methodologies and technologies that may be applied to the system. The concrete advantages and shortcomings of each system may then be examined for the consideration while develop the ‘IoT based Smart Greenhouse Monitoring System with Fuzzy Logic’.

2.2 EXISTING SYSTEMS/WORKS

The following discussion is an assessment of three existing systems on the market, all of which are relevant to smart greenhouse monitoring system. The following are the reviews of these systems:

2.2.1 SYSTEM A: IOT BASED SMART GREENHOUSE DESIGN WITH AN INTELLIGENT SUPERVISORY FUZZY OPTIMIZED CONTROLLER.

The major goal of this system is to demonstrate an intelligent supervisory fuzzy controller (ISFC) that uses IoT to manage the temperature, soil moisture, and humidity in the smart greenhouse. The newly launched ISFC validates data, avoids plant damage, and provides an alarm system to alert users. The Jaya algorithm is used to optimise the proposed controller's membership functions. It has been developed to be user-friendly so that the user may remotely monitor and alter the desired value of the greenhouse's settings as well as be warned of the occurrence of any incident such as a fire. The proposed controller successfully controls greenhouse parameters in practise, according to the results.

Figure 2:1 Smart Greenhouse of System A

The sensing layer for this system is made up of sensors (LM35 sensors, DHT12 sensor, Y1-69 sensor, and Co -LPG sensor), actuators (fan-heater, piezoelectric, pump), and microcontroller devices (Mega 2560 Arduino board and ESP8266) to collect system data.

Figure 2:2 Block diagram of System A

By utilized the Mega 2560 Arduino board in this system, there are covered the network and data processing layer parts. There are using wired connection between sensing layer to the network layer and store the data into the cloud database. For the Artificial Intelligence that has been implemented in this system are Fuzzy Logic Control.

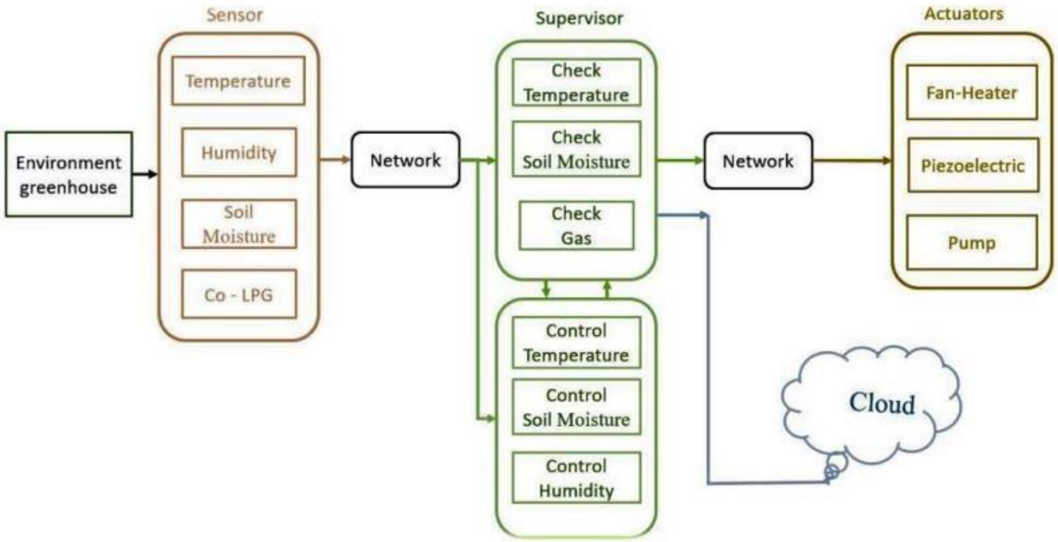


Figure 2:3 The control structure of the greenhouse parameters in System A

For the last layer, which is application layer, the system is showing the graph of real-time data and status of that data either in the normal or danger readings. The system also shows the current value of that data for the user easy to know the exact value of that data.

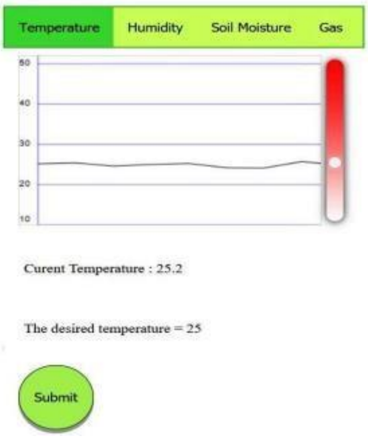


Figure 2:4 Screenshot of System A dashboard

2.2.2 SYSTEM B: A SIMULATION BASED STUDY OF A GREENHOUSE SYSTEM WITH INTELLIGENT FUZZY LOGIC

In this system, the main objective is to build a greenhouse system to control climate, soil moisture, lighting using fuzzy logic. The proposed model consists fuzzy logic to control GHS parameter such as temperature, Humidity, light, soil moisture and watering system to the plant. In this proposed system temperature controlling controller is used to take current temperature as input by using temperature sensor and its deviation from user set data. The temperature is controlled by the speed of fan. This algorithm is same for all other parameters. In this research the set value of different sensors is selected by the owner of the greenhouse according to the basis of growing plant condition. This system will enhance the capability of fuzzy logic control systems in case of process automation and potentiality. Simulation using MATLAB is used to achieve the designed goal.

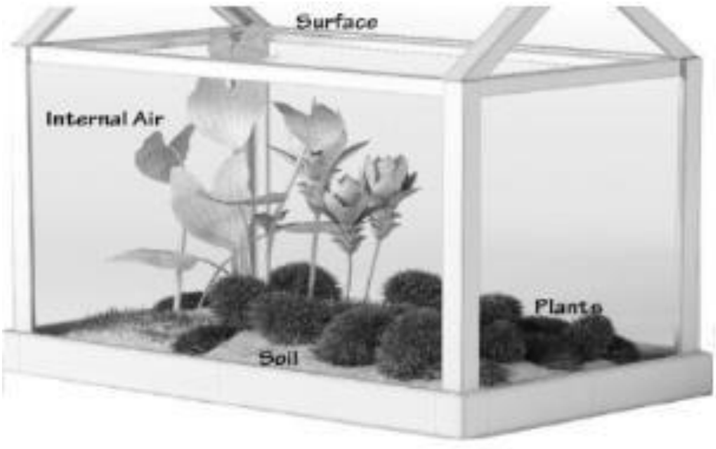


Figure 2:5 Basic view of Greenhouse System B

In terms of IoT architecture, the sensing layer for this system is comprised of sensors (Temperature sensor, humidity sensor, rain sensor, moisture sensor and light sensor), actuators (Heater, lamp, cooler, vapour, roof motor and water pump), and microcontroller devices (Arduino Uno) to gather system data.

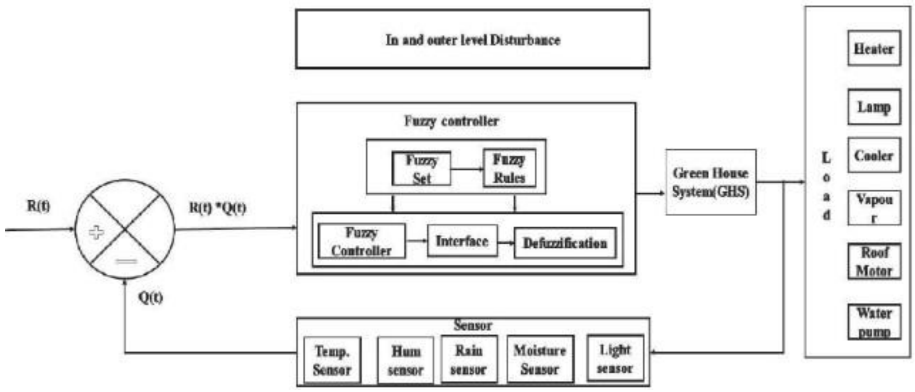


Figure 2:6 Block diagram of Greenhouse System B

For the Fuzzy Logic Control (FLC) in this system, there are four controlling of parameters such as temperature, humidity, light, and moisture. These parameters readings will trigger that activation of actuators based on decision making by FLC.

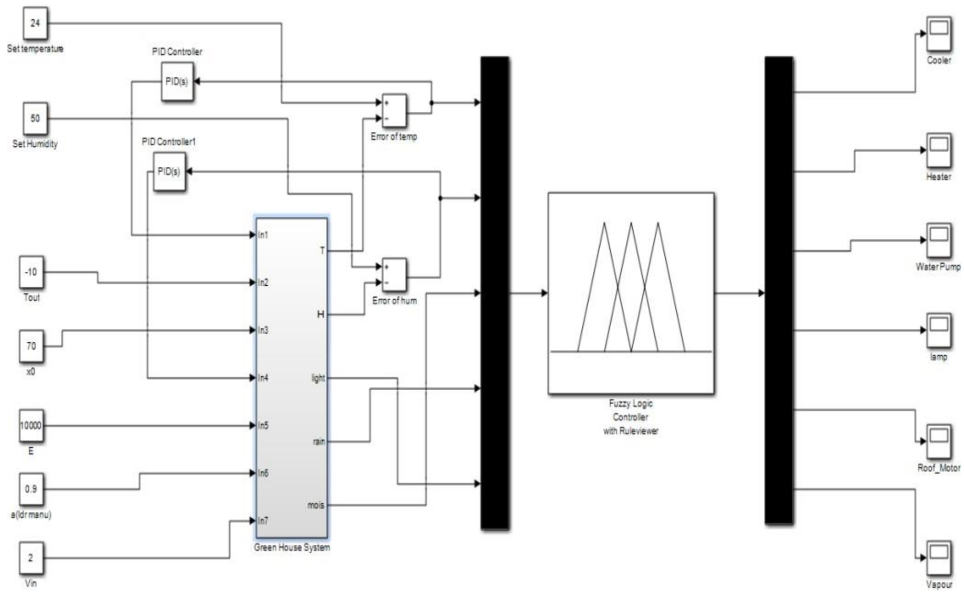


Figure 2:7 Model of greenhouse system using Fuzzy Logic (System B)

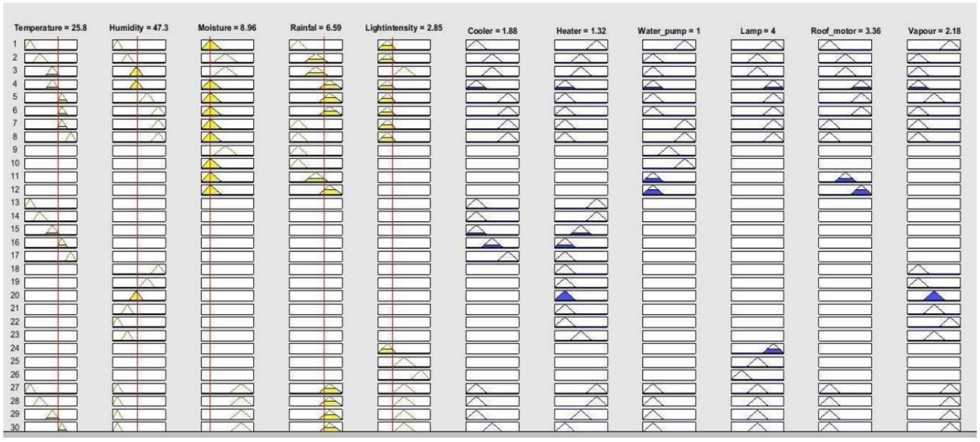


Figure 2:8 MATLAB Rules View

2.2.3 SYSTEM C: THE CONTROL OF GREENHOUSE BASED ON FUZZY LOGIC USING WIRELESS SENSOR NETWORKS.

The major goal of this system is to improve greenhouse quality and production by conserving time, energy, light, and water consumption by measuring and managing climate parameters that are useful in producing climatic variables in greenhouses. A realistic sensor application assessed greenhouse environment factors such as temperature, relative humidity, soil moisture, and light intensity. Several sensor nodes from the nodal packages were thus disseminated to a wireless sensor network (WSN) built in a similar manner. The study of star topology. Furthermore, the data acquired from the nodes was managed and monitored using the fuzzy logic-based control approach suggested as a dynamic, smart, and remotely accessible Android-based interface. The suggested solution has been examined in terms of the advantages to both the user and the greenhouse (Alpay, Ö., & Erdem, E., (2018).

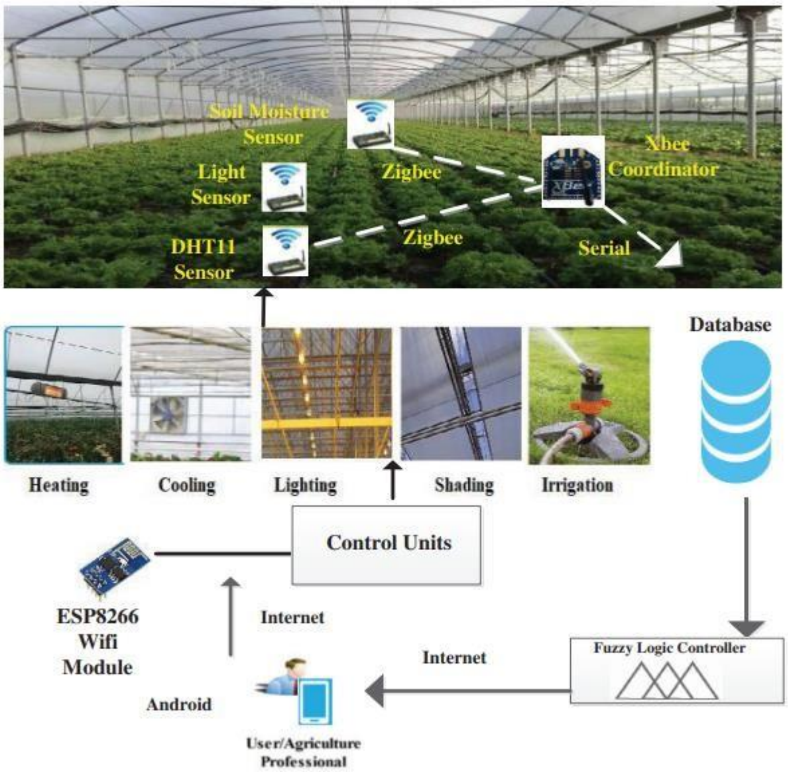


Figure 2:9 Block diagram of System C

In terms of IoT architecture, the sensing layer for this system is comprised of sensors (soil moisture sensor (YL69), light sensor(A2A7Y) and DHT11 sensor), actuators (water pump, ventilation fan and roof), output devices (heater and bulb) and microcontroller devices (Arduino Uno) to gather system data (Alpay, Ö., & Erdem, E.,2018).

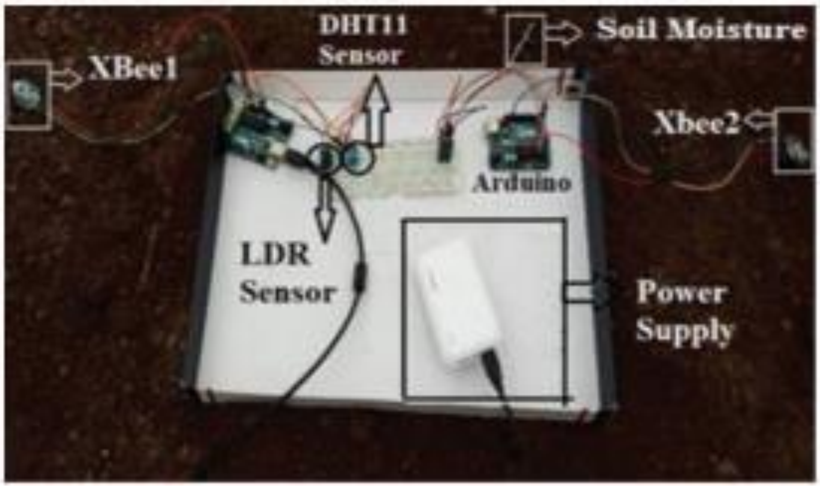


Figure 2:10 Content of nodal package System C

Following that, for the network layers, Xbee S2C sensor nodes that operate as routers will link to the Arduino Uno cards. This router will send all data to the coordinator Xbee node, which is serially connected to the computer through Zigbee protocols (Alpay, Ö., & Erdem, E.,2018).

For the data processing layers, all data will be stored in a database, and the system will be able to construct the fuzzy logic system utilising this data (Alpay, Ö., & Erdem, E.,2018).

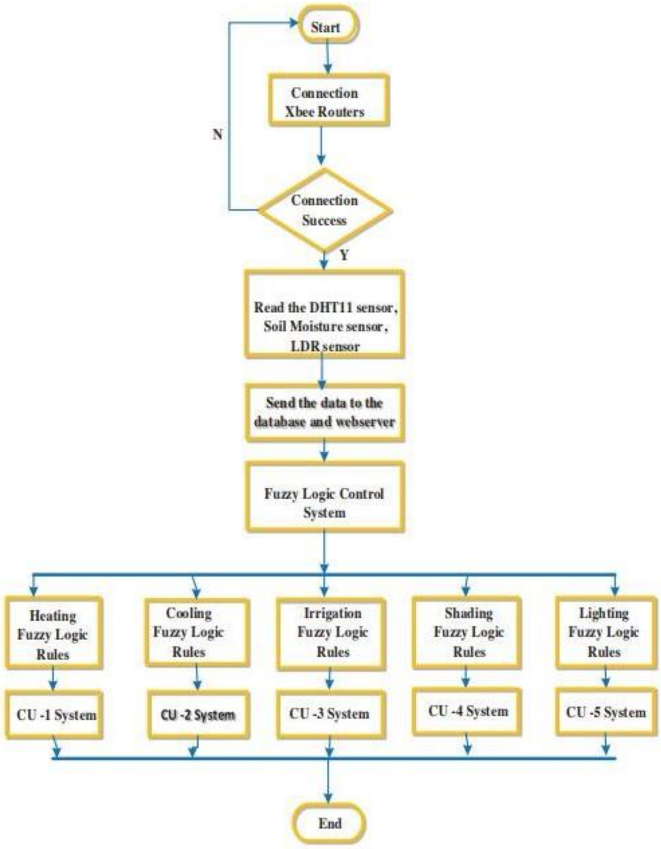


Figure 2:11Flowchart of system C

The application layer is the last layer in IoT architecture. This system makes use of Android-based mobile applications in this layer. The user must know the IP address of the ESP8266 Wi-Fi module used in the greenhouse to use this application. The computed average values are received from the system using that IP, and the output values created from the fuzzy logic unit based on these values are manually supplied (Alpay, Ö., & Erdem, E.,2018).

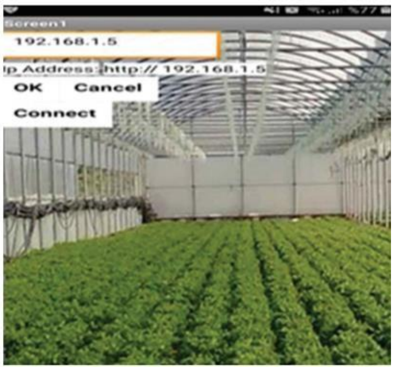


Figure 2:12 Interface for Mobile Application (Connect to the greenhouse)

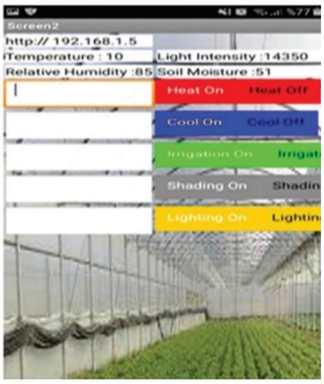


Figure 2:13 Interface for Mobile Application (Monitor the greenhouse)

2.3 ANALYSIS / COMPARISON OF EXISTING SYSTEM

Once the reviews on the three existing systems have been completed, comparisons based on their fuzzy logic control implementation may be made. From this, there will be differentiations among various systems based and may be profited from if applied into the design of 'IoT based Smart Greenhouse Monitoring System with Fuzzy Logic'.

2.3.1 ANALYSIS OF COMPARISON ON EXISTING SYSTEMS

Table 2-1Table of comparison between 3 existing system

Systems name **Components**	**System A**	**System B**	**System C**
Input attributes	**FLC 1** -Error (Difference between greenhouse temperature and optimal temperature) -Rate of Error **FLC 2** -Error (Difference between the greenhouse soil moisture and optimal soil moisture)	**FLC 1** -Temperature, C -Humidity, % -Light, lux -Rainfall, (in/h) -Soil moisture, %	**FLC 1** -Temperature, C -Relative Humidity, % **FLC 2** -Temperature, C -Relative Humidity, % **FLC 3** -Soil Moisture, % -Relative Humidity, 5

	FLC 3 -Error (Difference between the greenhouse humidity and optimal humidity) -Rate of error		**FLC 4** -Temperature, C -Light Intensity, lux **FLC 5** -Light Intensity, lux
Output attributes	**FLC 1** -Fan (ON/OFF) -Heater (ON/OFF) **FLC 2** -Water Pump (ON/OFF) **FLC 3** -Piezoelectric (ON/OFF)	**FLC 1** -Heater, W (OFF/LOW/HIGH) -Vapour, V (OFF/LOW/HIGH) -Lamp, V (LIGHTOFF/ LIGHTDIMMER/ LIGHTFULL) -Cooler, W (OFF/LOW/HIGH) -Roof motor, V (OFF/OPEN) -Motor, V (OFF/LOW/HIGH)	**FLC 1**: Heating, W **FLC 2**: Cooling, Micron **FLC 3**: Irrigation, Lt **FLC 4**: Shading **FLC 5**: Lighting *All output attributes in system C are classify into 5 terms: - very low -low -medium -high -very high

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The METHODOLOGY component of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' development is addressed in this chapter. The project's chosen development process is detailed in full here, including the Software Development Life Cycle (SDLC) employed and the system's flow, which is expounded on using necessary flowcharts for the overall system flow and diagrams such as context diagrams. Any specifics of specialised software and hardware that would be used in the system's development would also be thoroughly described.

3.2 PROJECT MANAGEMENT FRAMEWORK: RAPID APPLICATION DEVELOPMENT

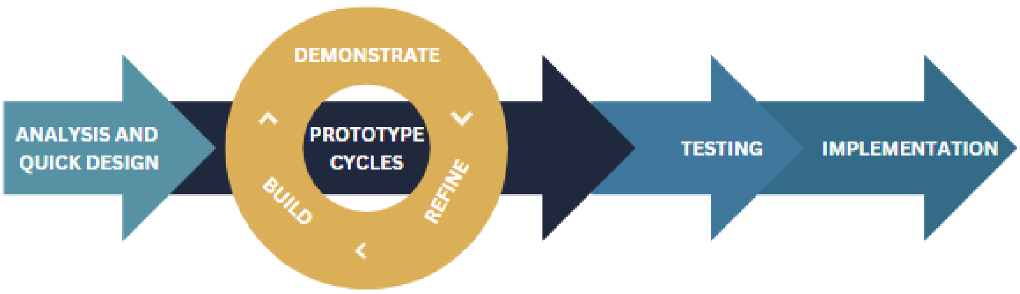


Figure 3:1 Rapid Application Development SDLC

Figure 3:1 depicts the stages involved in the RAPID APPLICATION DEVELOPMENT (RAD) process. This method was specially selected as the best Software Development Life Cycle (SDLC) approach for the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic.' The RAD technique has various advantages, including increased productivity and the capacity to provide a higher-quality output. This is especially advantageous for this system since it demands adaptation and flexibility to accept frequent changes and specialised requirements within a short timeframe. Furthermore, the RAD technique is iterative, allowing refining, constructing, and demonstration phases to be examined and improved upon throughout the development process, ultimately resulting to a successful project completion.

3.2.1 PHASE 1: ANALYSIS AND QUICK DESIGN

During the ANALYSIS AND QUICK DESIGN phase of designing the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic,' a complete gathering and analysis of all critical features of the system is carried out. This comprises obtaining information regarding the project's functional and non-functional needs, as well as the software and hardware specs that are required. Based on this research, a system design is created that is precisely tuned to fulfil the project's intended objectives and unique demands.

As previously stated in previous chapters, we have already set feasible goals and defined the scope of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' Furthermore, a review of existing market systems revealed significant differences in their application of fuzzy logic control, which must be considered throughout the project's development.

Furthermore, this phase allows for the identification and specification of other needs, such as functional and non-functional features, as well as the essential software and hardware specifics, all of which are expounded on in PROJECT needs Chapter 3.3.

3.2.2 PHASE 2: PROTOTYPE CYCLING

During this phase, the additional components, such as the suggested system and data design, as well as a well-defined IoT architecture, are polished to successfully show the inner workings of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic.' These improvements will be described in depth in the future PROPOSED DESIGN Chapter 3.4.

Following that, the build process begins, signalling the start of system development. This phase requires significant effort, including the installation of sensors, the establishment of network connections between hardware components, and the construction of the entire database system.

After the development phase is done, the demonstration phase begins. Before moving on to final product testing, a produced prototype of the system is reviewed here. This phase allows for the introduction of new modules that may be required because of future changes to system requirements. It is an iterative method that aims to improve the system by observing the prototype and preparing for more quick development until a functioning model is obtained that is ready for testing in real-world circumstances.

3.2.3 PHASE 3: TESTING

The testing phase's goal is to thoroughly analyse the overall operation of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' and resolve any found problems or malfunctions. This step can be repeated as needed to accommodate additional components and alterations. End customers' valuable comments on the interface and functioning will be gathered in order to improve all elements of the product. By actively integrating users throughout this stage, they may give thorough input, recommending revisions, changes, or new ideas to tackle problems as they emerge. This input serves as the foundation for either repeating the prototype cycle process or, if the feedback is overwhelmingly good, moving to the final phase.

3.2.4 PHASE 4: IMPLEMENTATION

The last stage of the RAD technique focuses on overcoming any technological issues that occurred during early prototyping. The purpose is to optimise the implementation for increased stability and maintainability, ultimately leading to the product's completion and formal launch. All critical components of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' have been moved to a live production environment, allowing for large-scale testing to uncover any lingering product defects. Furthermore, detailed documentation and other necessary maintenance chores are completed to ensure that the client receives a fully finished product.

3.3 PROJECT REQUIREMENTS

This section goes into further detail on the project requirements for the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic.' It provides comprehensive explanations of both functional and non-functional requirements, as well as the requisite software and hardware. These standards provide critical direction during the system's design phase.

3.3.1 FUNCTIONAL & NON-FUNCTIONAL REQUIREMENTS

It is critical to create different functional and non-functional requirements for the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' from the start of the development process. This guarantees that the system works as it should. It is critical to grasp the distinction between these two types of criteria and how to specify them effectively.

Functional requirements define the activities that the system must take in response to various inputs. These specifications might include both product characteristics and consumer expectations. Non-functional requirements, on the other hand, specify how the system should behave, with an emphasis on issues such as system usability to guarantee optimal performance.

Based on these definitions, the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' is intended to satisfy the functional and non-functional requirements listed below.

Table 3-1Table of Functional and Non-functional requirements

FUNCTIONAL REQUIREMENTS	NON-FUNCTIONAL REQUIREMENTS
- SGMS must display all recorded values into simple comprehensible data visualizations implemented within a web-based dashboard application. - SGMS must allow for both automated and control actuators such as water pump, ventilation fan and bulb via event triggers or interface controls available on the dashboard. - SGMS must provide decision making of the activation for the water pump and ventilation fan to maintain the suitable readings of parameters inside the greenhouse via a suitable Artificial Intelligence program.	- SGMS should utilize an MQTT connection protocols for the transmission of sensor values and WebSocket for real-time transmission of emergency alerts and critical event triggers. - SGMS should utilize a local MySQL database for secure data storage and query operations. - SGMS should be developed using a Laravel framework for the web-based dashboard application fit for HTML, JavaScript, C++ and Python language for the web page development and microprocessor operation of the sensors and actuators. - SGMS should display the latest recorded data collected into dashboard with five seconds update intervals. - SGMS should also be compatible with mobile web browsers.

3.3.2 SOFTWARE REQUIREMENTS

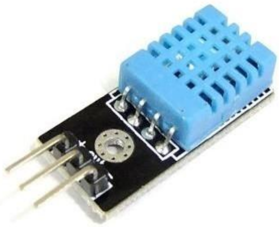
Table 3-2 Table of Software Requirements

NO.	SOFTWARE	PURPSOSE
1	Microsoft Visual Studio Code	- To allow the construction of the SGMS web application pages in PHP, HTML and JavaScript languages. - To create the events, controller and API for AI server and WebSocket.
2	XAMPP – phpMyAdmin	- Enables database storing and query within a local mySQL environment.
3	Composer	- Manages library dependencies in PHP.
4	Laravel PHP framework	- Providing a framework structure for SGMS web application development.
5	VNC viewer	- Enables AI server to send messages via WebSocket to activate the actuators controller by the Python code.
6	Arduino IDE	- Enables the sensors that connect with the ESPduino-32 to be read by using C++ languages.
7	Spyder IDE	- Platform for AI development.
8	MQTT Explore	- Checking the topic that have been sent to the MQTT server.
9	chartJS Library	- JavaScripts chart library for constructing dashboard data visualizations.
10	Google Chrome	- Web browser for SGMS web application implementation.

3.3.3 HARDWARE SPECIFICATIONS

Table 3-3 Table of Hardware Specifications

NO.	TYPE OF DEVICE	PURPOSE
1	**SERVER COMPUTER**  **CLIENT COMPUTER**  **CLIENT TABLET** 	**Server computer:** To host SGMS web application for multiple users simultaneously, local mySQL database as well as AI classification program. **Client computer and tablet:** To allow for display and interaction of SGMS web application .

2	**RASPBERRY PI 3B+**  **ESPduino-32** 	**Microcontrollers devices:** **Raspberry Pi 3b+:** To receive the events from WebSocket to activate the automation of actuators which is water pump, ventilation fan and bulb and message to make the control button at the dashboard able to function well. **ESPduino-32:** To read sensors data from DHT11, soil moisture and photocell sensors and send these data using Wifi connection to the MQTT server.
3	**DHT11 SENSOR** 	**Sensor:** To measure the temperature and humidity inside the greenhouse.
4	**SOIL MOISTURE SENSOR** 	**Sensor:** To measure the soil moisture of the medium inside the greenhouse.

5	**PHOTOCELL SENSOR** 	**Sensor:** To measure the light intensity inside the greenhouse.
6	**WATER PUMP** 	**Actuator:** To pump the water inside the water tank to the greenhouse medium.
7	**VENTILATION FAN** 	**Actuator:** To control the temperature and humidity readings inside the greenhouse to the stable and suitable value.
8	**BULB** 	**Output device:** To give sufficient of light intensity inside the greenhouse.

10.	**RELAY** 	**Output device:** To control the voltage supplied to the actuators and output devices that has been implemented in this greenhouse.

3.4 PROPOSED DESIGN

In the next subsection, the elaboration on the suggested design of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic.' This part will go through different features in depth, such as the general system sketch, its operational characteristics, the IoT architecture used,and so on. We hope to provide a full and detailed grasp of the system's architecture and operation by looking into these topics.

3.4.1 OVERALL PROPOSED SYSTEM ARCHITECTURE

An overall system sketch is also required to show how the system appears overall, but more importantly, how each component is used inside the system. This will also assist developers and users in comprehending how the system would seem once done.

The overall system sketch is included as follows:

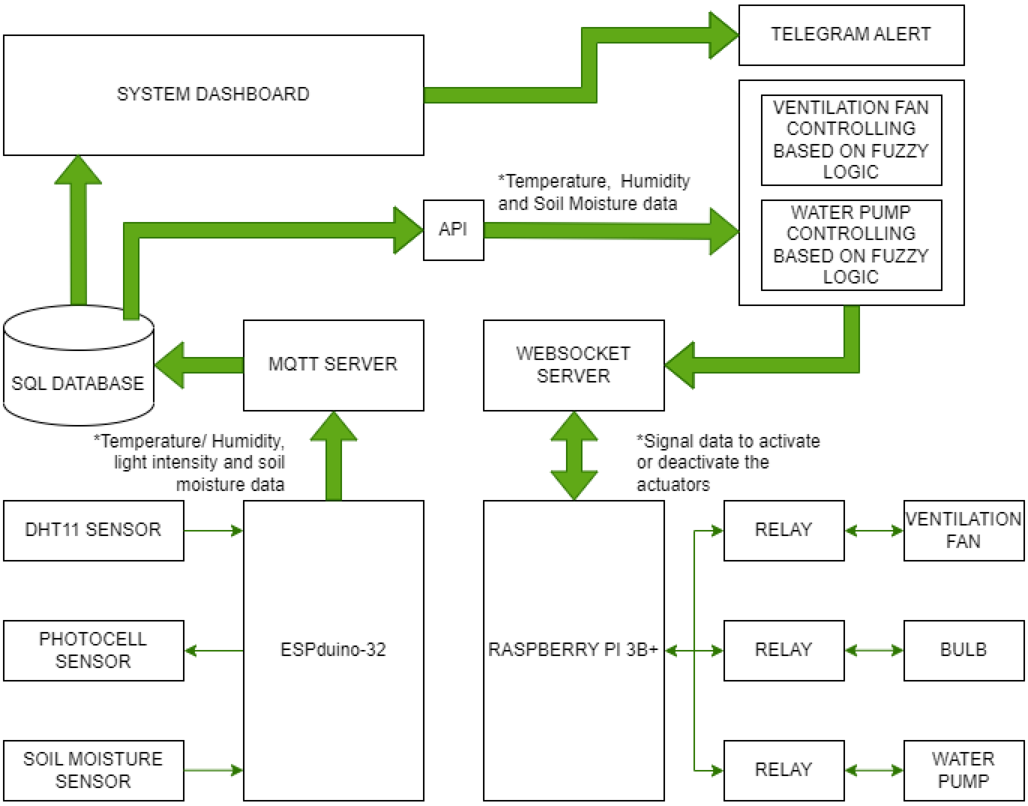


Figure 3:2 Block Diagram of SGMS

For this project, the system is to monitor the parameters inside the greenhouse and ensure the parameters readings (temperature, humidity, soil moisture and light intensity) are in a normal stage. These conditions will be done by having the automated actuators (water pump, ventilation fan and bulb) that able to control the greenhouse.

3.4.2 OVERALL SYSTEM OPERATION

A comprehensive depiction of the operational processes of the 'IoT based Smart Greenhouse Monitoring System with Fuzzy Logic' will be provided through the use of flowcharts. These flowcharts serve to describe and effectively demonstrate how greenhouse owners, will operate the system independently once it is fully developed and delivered to them. The following outlines the flowchart illustrating the overall system operations:

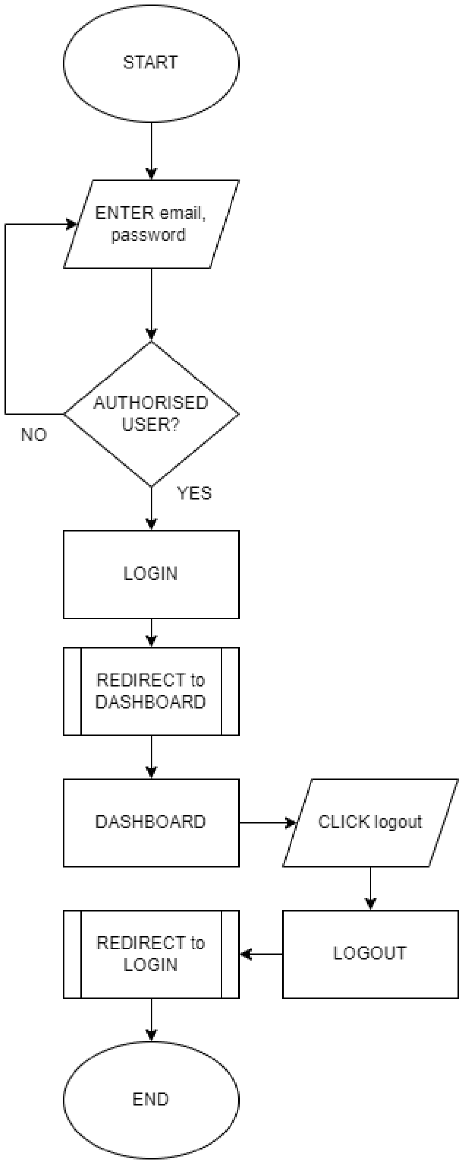


Figure 3:3 Flowchart of Dashboard page

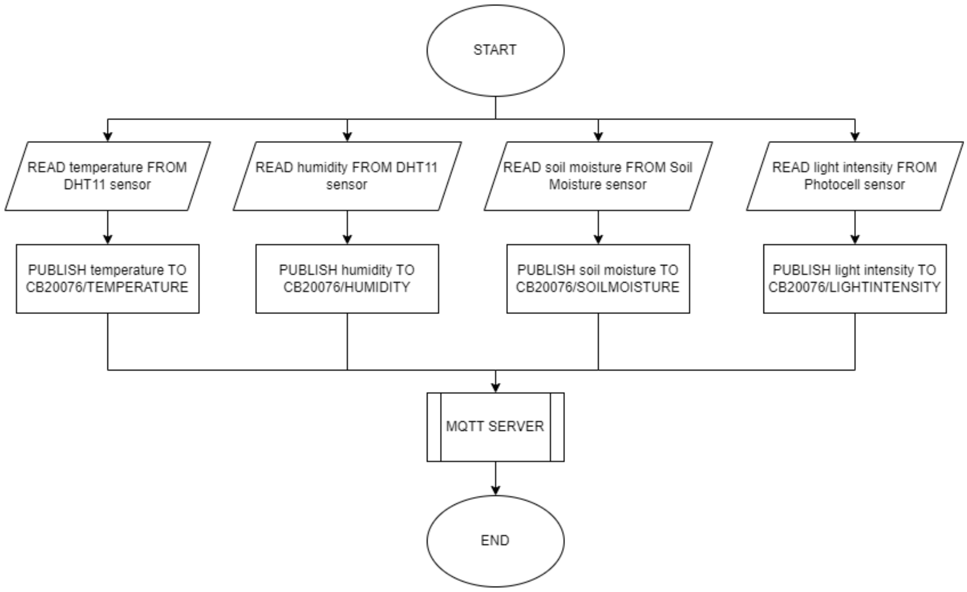


Figure 3:4 Flowchart of ESPduino-32 read the data and publish to server.

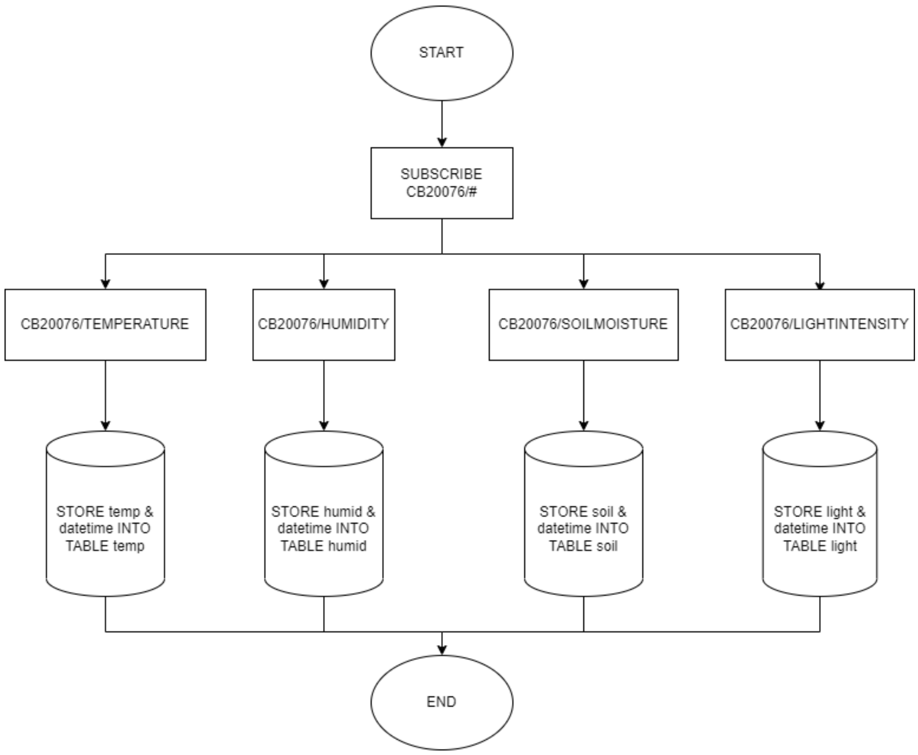


Figure 3:5 Flowchart of MQTT SUBSCRIBER and data has been stored into database

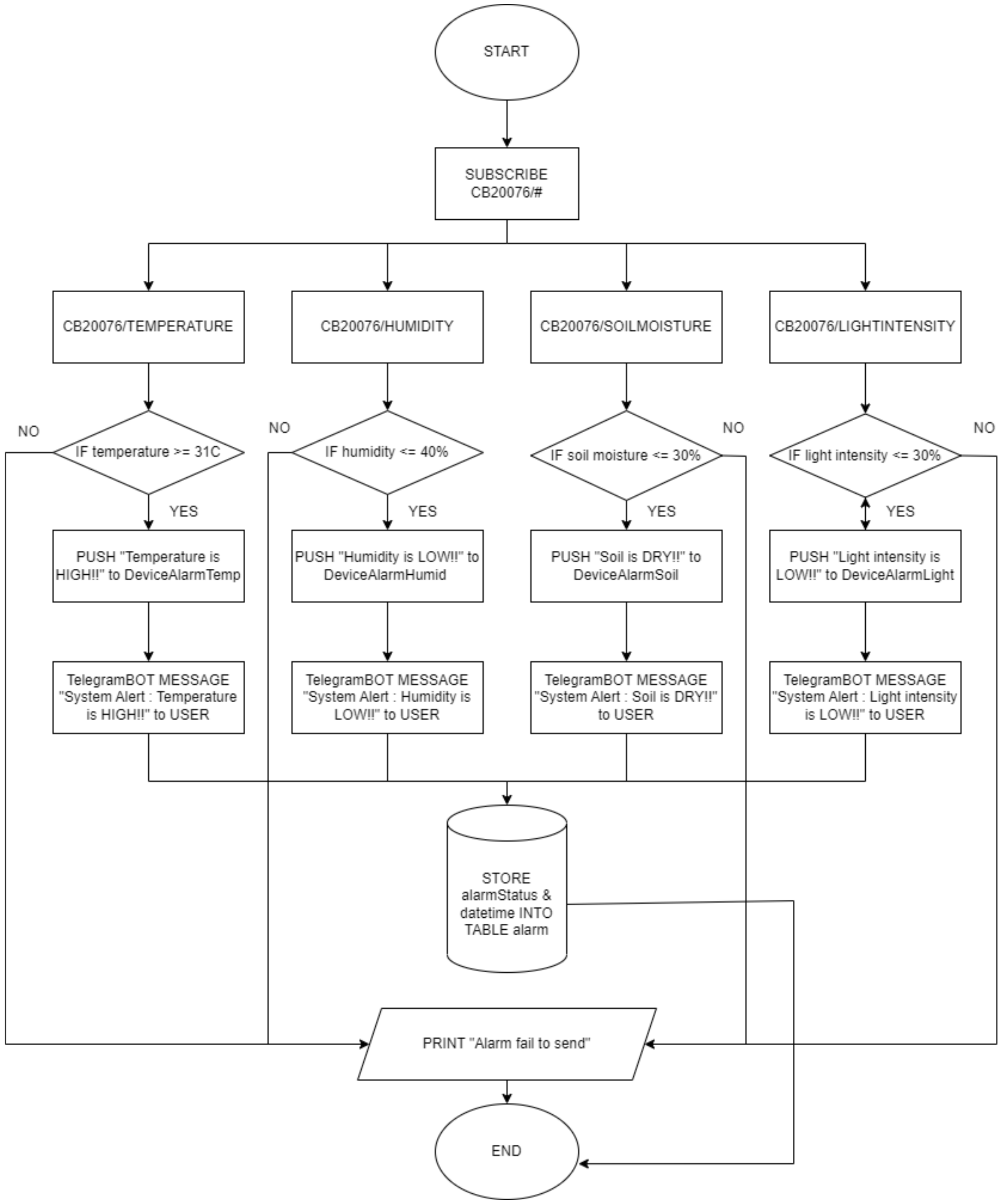


Figure 3:6 Flowchart of ALERT TRIGGER PUSH EVENT WebSocket Event

3.4.3 IOT ARCHITECTURE

Before commencing the development of the system, it is essential to gain a comprehensive understanding of the IoT architecture that will be implemented specifically for this project. This involves visualizing the overall structure of the architecture and, more importantly, comprehending the functionality of each layer and the placement of individual components within the system. This process aids in providing the client with a clear understanding of the system's final appearance and operation upon completion.

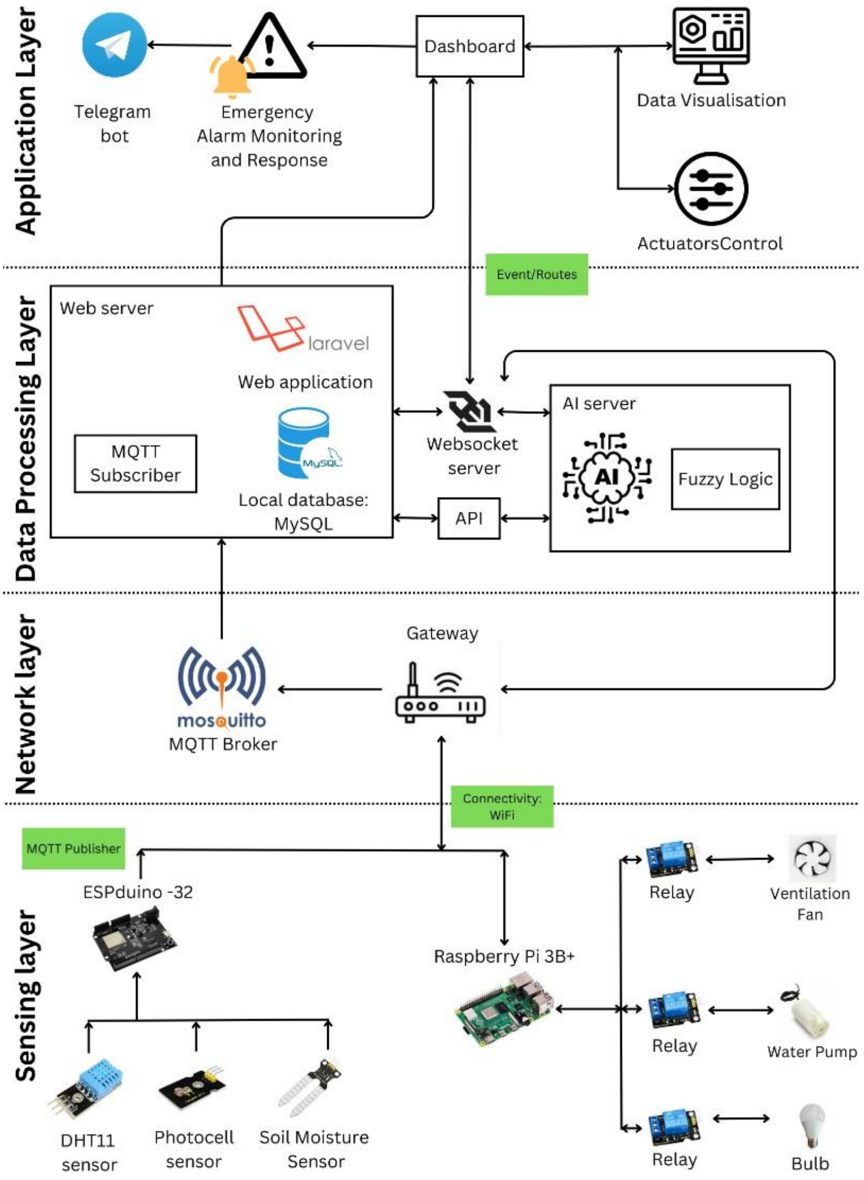


Figure 3:7 IoT architecture of SGMS

Architecture is defined as a framework for specifying a network's physical components, as well as its functional organisation and configuration, operating rules and processes, and data formats used in operation. Physical objects, sensors, cloud services, developers, actuators, communication layers, users, business layers, and IoT protocols define IoT architecture (Jabraiel Jamali, 2020).

The lowest layer in an IoT architecture is the sensor layer, followed by the network layer, the data processing layer, and the topmost tier is the application layer. For the lowest layer in IoT architecture is sensing layer. The main objective of the sensing layer is to continuously monitor changes in the physical condition of linked devices. It has sensors, which contribute to the main component of this layer. The sensor oversees assessing the physical surroundings, recognising, and finding intelligent things, gathering data, and transmitting data to the cloud layer for processing and storage. In this layer, the intended device is executed by the actuators, which are often mechanical devices like switches (Jamali, M. A. J., 2020). In this system which is IoT based Smart Greenhouse Monitoring System with Fuzzy Logic, there are three sensors that has been used which are DHT11 sensors, photocell sensor and soil moisture sensor. Each of this sensor have their own role. For DHT11 sensor, it will read the reading of temperature and humidity inside the greenhouse. If the temperature and humidity inside the greenhouse has reach the threshold that has been set in this system, the actuators which is ventilation fan will automatically be switch on. This action is to control the good range of temperature and humidity inside the greenhouse to support the growth of plants inside. Next, soil moisture sensor will read the moisture of medium inside the greenhouse. If the reading of soil moisture is in "DRY" category, the system will activate the water pump to irrigate the medium become moist. The last sensor used in this system is photocell sensor. This photocell sensor will read the light intensity inside the greenhouse. If the reading of the light intensity in the greenhouse is "LOW", the system will activate the bulb to light up. This light is wanted to supply enough light to the plants in the growth phase. All the sensors connected to ESPduino-32 for enable in read the data. This microcontroller will send the data through topic that has been declared for each sensor to the MQTT broker using connection of Wi-fi. In this system, the there are four topics that will be published, which are CB20076/SOILMOISTURE, CB20076/HUMIDITY/

CB20076/TEMPERATURE/ and CB20076/LIGHTINTENSITY. All this topic is published to the MQTT server. Another microcontroller that has been used on this system is Raspberry Pi. This microcontroller role is act as sources of activation the actuators and output devices.

The interaction between the IoT architectural levels is controlled by the network layer. This is the second layer of the IoT architecture which is network layer. The service and application layer or the cloud receives the data that was gathered at the sensing layer directly. It consists of routers, switches, and gateways connected to hardware that can't directly access the cloud. Different IoT devices are connected by protocols like CoAP, Message Queuing Telemetry Transportation (MQTT), and Lightweight Machine to Machine (LwM2M) to deliver data to higher levels (Jamali, M. A. J., 2020). In this layer, there are two components involved which are Gateway and MQTT Broker. Gateways serve as a connection point for MQTT publishers and MQTT brokers. With a wired connection, such as a LAN cable to the MQTT broker, it will connect with the MQTT publisher. For MQTT Broker, it is a server that acts as central hub for MQTT messages. This broker will receive messages from the MQTT publisher and forwarded the messages to the MQTT subscriber that subscribe that topic.

Data processing layer is sometimes referred to as the IoT system processor. The data processing layer receives data that has been gathered from sensors and other devices. Its functions include data processing, analysis, and storage. In general, the cloud processes the data produced by the edge device on a central server in a data centre. To increase computing performance, cloud computing research in the future generation will continue to decentralise some processing jobs from the cloud to edge nodes (Jamali, M. A. J., 2020). In this layer, the first components that will be the first to go through is web server. The data that has been located at the MQTT broker will be subscriber by MQTT Subscriber. The Subscriber will subscriber the topics to store that data into the local database which is MySQL. In AI server, there is components name fuzzy logic. This fuzzy logic is to control the actuators in this system such as water pump and ventilation fan. It will be controlled by switch on and off the actuators.

There is a WebSocket server that has been used to inject the data directly from the database to the AI server through API page.

Data collecting, data analysis, data visualisation, and security are just a few of the services and applications offered by the application layer. They are determined by the use cases and the functionality that end users want (Jamali, M. A. J., 2020). In this layer, the data that has been store in database will be retrieved and display in web clients which is Laravel. In this component, there are a dashboard created in this system. The dashboard will be displayed the data visualization such as the real time data for graph and current value. Other than that, it also able to control actuators and output device button from this dashboard. This dashboard also able to give an alert about their sensor data of its reach certain threshold that will give dangers to that system. This alert also can be notified through Telegram.

3.4.4 ANALYTIC FEATURE DESIGN

An Artificial Intelligence (AI) knowledge has been implemented in this system which are Fuzzy Logic Control (FLC). In this system, there are two FLC which are FLC in controlling ventilation fan and water pump. Each of FLC has two input attributes and one output attributes. The output attributes for each FLC have the same concept which is to determine the activation of actuators either on or off.

For FLC in controlling ventilation fan, the input attributes are Temperature, C and Humidity, %. These attributes will affect the activation of ventilation fan either to be on or off based on the rules that set in this system.

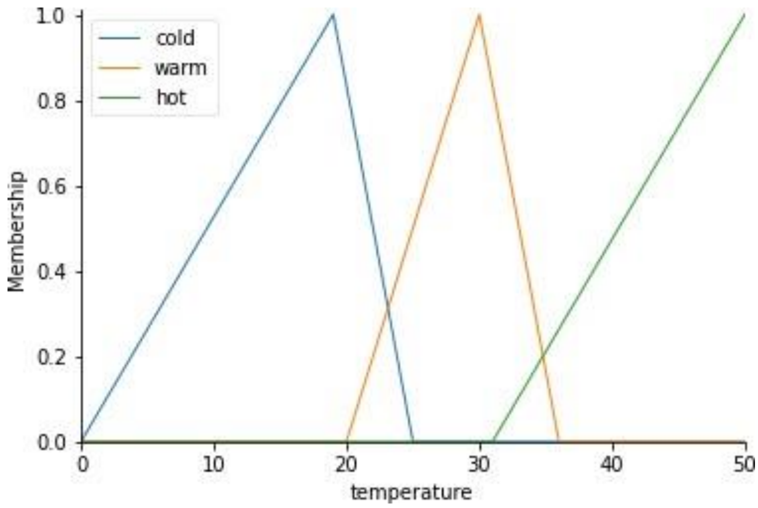


Figure 3:8: Membership function graph for Temperature

Table 3-4 Input Attributes 1 (Temperature,C)

Temperature Range, C	Classification
0 – 25	Cold
20 – 36	Warm
31 - 50	Hot

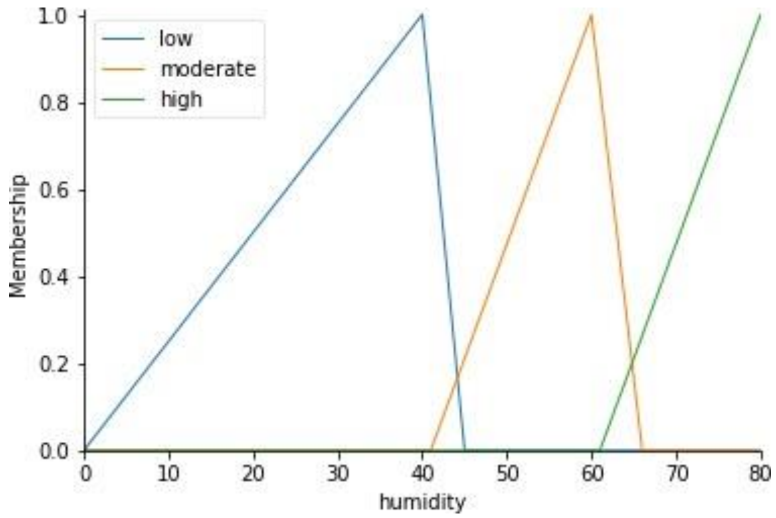


Figure 3:9: Membership function graph for Humidity

Table 3-5 Input Attributes 2 (Humidity, %)

Humidity Range, %	**Classification**
0 - 45	Low
41 - 66	Moderate
61 - 80	High

Table 3-6: Tables of rules for Fuzzy Logic Control in controlling ventilation fan

Condition Ventilation, %			
Temperature, C	**Humidity, %**		
	Low	**Moderate**	**High**
Cold	On	Off	Off
Warm	On	Off	Off
Hot	On	On	On

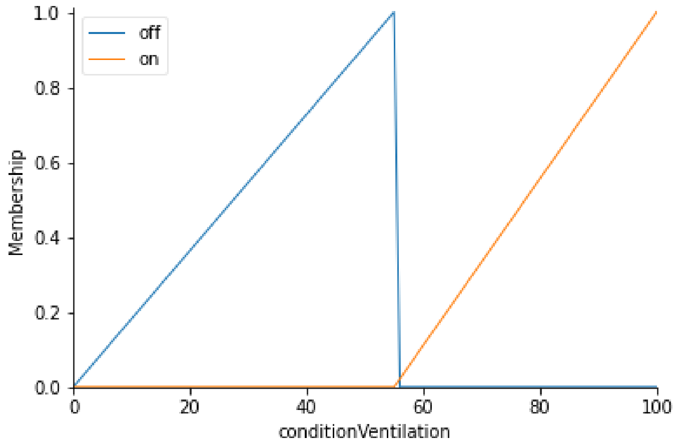


Figure 3:10: Membership function graph of Condition Ventilation

Table 3-7: Output Attributes (Condition Ventilation, %)

Condition Ventilation Range, %	Classification
0 – 56	Off
55 - 100	On

For the second FLC which is in controlling the water pump, the input attributes are Soil Moisture, % and Temperature, C. These attributes also will affect the activation of water pump either to be on or off based on the rules that set in this system.

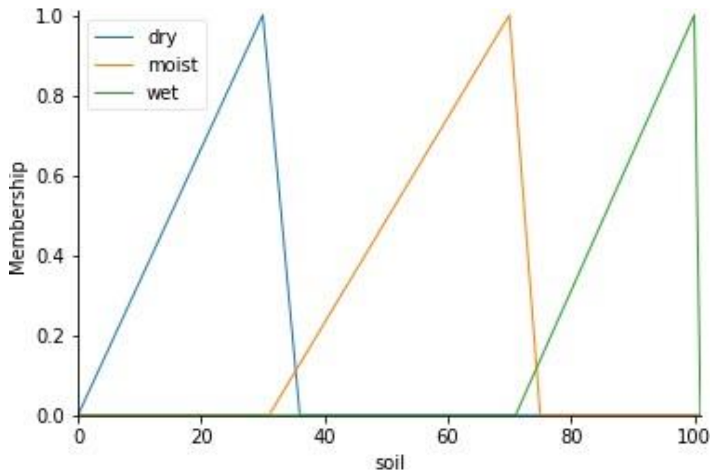


Figure 3:11: Membership function graph for Soil Moisture, %

Table 3-8 Input Attributes 1 (Soil Moisture, %)

Soil Moisture Range, %	Classification
0 – 36	Dry
31 - 75	Moist
71 - 100	Wet

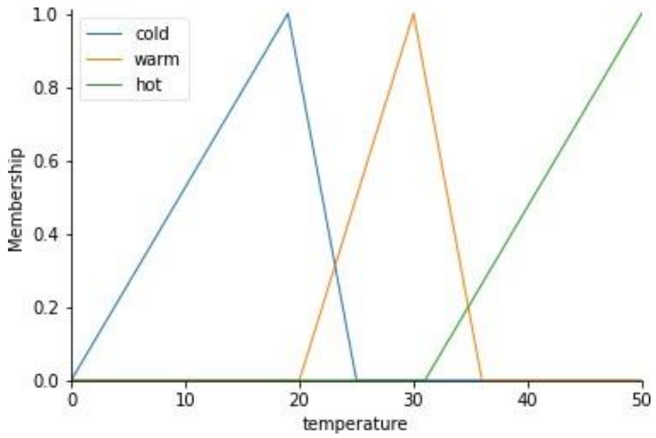


Figure 3:12: Membership function graph of Temperature,C

Table 3-9: Input Attributes (Temperature, C)

Temperature Range, C	**Classification**
0 – 25	Cold
20 – 36	Warm
31 - 50	Hot

Table 3-10: Tables of rules for Fuzzy Logic Control in controlling water pump

Condition Water Pump, %			
Soil Moisture, %	**Temperature, C**		
	Cold	**Warm**	**Hot**
Dry	On	On	On
Moist	Off	Off	Off
Wet	Off	Off	Off

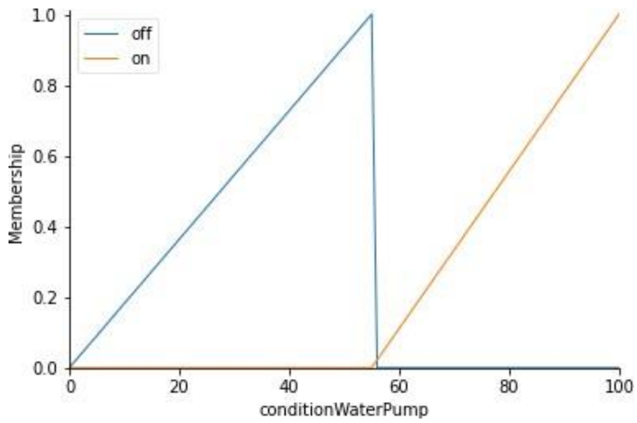


Figure 3:13: Membership function graph for Condition of Water Pump

Table 3-11: Output attributes (condition water pump, %)

Condition Water Pump Range, %	**Classification**
0 – 56	Off
55 - 100	On

For this FLC dataset preparation, the data collected through the DHT11 sensor, photocell sensor and soil moisture sensor. All this data will be recorded into the database.

The processing of read the data through sensors, the time interval was 30 seconds. Each 30 seconds, the data will be stored into database. This condition has been set up at the ESPduino-32 microcontroller which act as MQTT publisher. The topic will be published to the MQTT server every 30 seconds. The data that has been published having the condition which is all the three sensor's data need to be valued, then it will publish the data to the server. If one of the values produced out of range, the system needs to wait until it got the valuable data.

3.4.5 UI/UX DESIGN

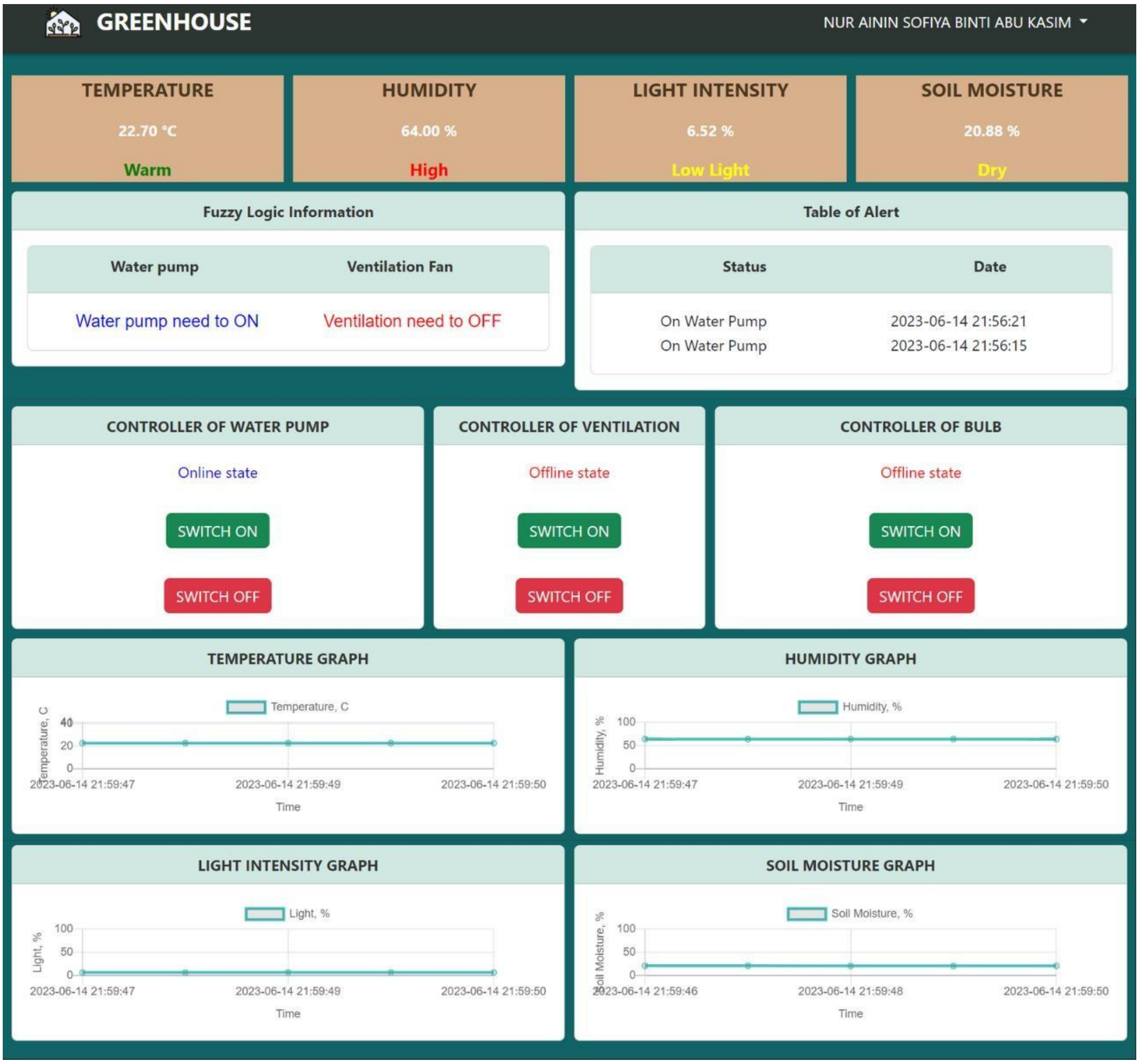


Figure 3:14 Dashboard design

This is a dashboard design of the IoT based Smart Greenhouse Monitoring System with Fuzzy Logic. There are four panels that displayed the real-time data value and give the classification for each data that appear to the dashboard. The end-user able to easily understand the conditions of their greenhouse by looking at the value appeared. For the second layer in this dashboard, there are two cards which are displayed the fuzzy logic information and table of alert. For the fuzzy logic information, it will display the status of actuators (water pump and ventilation fan) that decide by the Artificial Intelligence about their activation based on the real-time sensors data. Next for the second card in this layer, there is table of alert which will display the alert status to the used based on the sensors data read. If the sensors data reach the threshold that has been set in this, the system will display that status in this table.

For the third layer of this dashboard, there are three cards which is controller of the actuators. The end-user able to control the water pump, ventilation fan and bulb manually by click on these buttons. Finally, the fourth and fifth layers will display the graph cards. These graphs will display the real time data read by the sensors.

3.4.6 POTENTIAL USE OF PROPOSED SOLUTION

There are now several issues with practising greenhouse monitoring system traditionally, such as the necessity to physically monitor the conditions of plants every day by checking the soil moisture of medium, the temperature and humidity around the plants and the light intensity received. If the plants do not receive enough of one of these circumstances, their growth will be stunted, or they will perish.

To circumvent these issues, the end-user should develop a smart greenhouse monitoring system that uses fuzzy logic to control the temperature regulation, irrigation management and light optimization. This system will automatically monitor all the plant's growing circumstances. For example, if the temperature in the greenhouse increase to threshold set in this system, the system will activate the ventilation dan to lower the temperature and allow the plant to develop at the appropriate temperature. Besides from that, this system will monitor the moisture of soil, so the end user does not need to watering the plants manually. This system will activate the water pump when the reading of soil moisture gets into dry category. Following that, when the intensity of light in the greenhouse decrease, the system will operate, illuminating the growth light. Even through the night, the plant will receive adequate light. It will encourage plant growth.

So, by applying this method, the end user will be able to cultivate without having to worry about them and yet reap a large crop at the conclusion of maturity period.

CHAPTER 4

IMPLEMENTATION, RESULTS & DISUSSION

4.1 INTRODUCTION

This chapter describes the outcome of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' development. It will provide an understanding of the outcome of all aspects in the proposed system. The outcome and discussion will demonstrate if the proposed system functions as expected and achieves all the predetermined goals of the suggested system previously.

4.2 HARDWARE SETUP

For the 'IoT based Smart Greenhouse Monitoring system with Fuzzy Logic', the hardware is the essential basis of the system. To read the parameters data within the greenhouse, all sensors (DHT11, soil moisture, and photocell) are installed. The automated actuators can now function, and the greenhouse can be managed automatically, due to the installation of these sensors. The final hardware configuration is depicted in the pictures below.

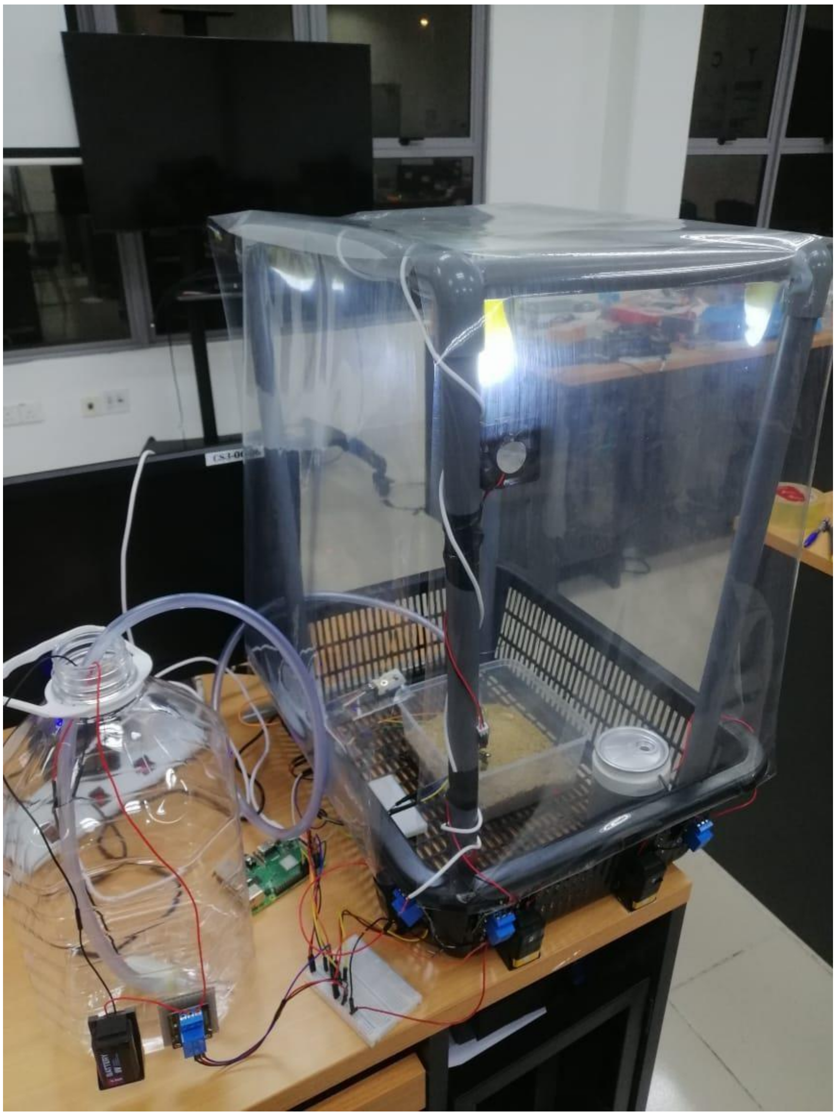


Figure 4:1Hardware Setup

4.3 IMPLEMENTATION PROCESS OF DASHBOARD

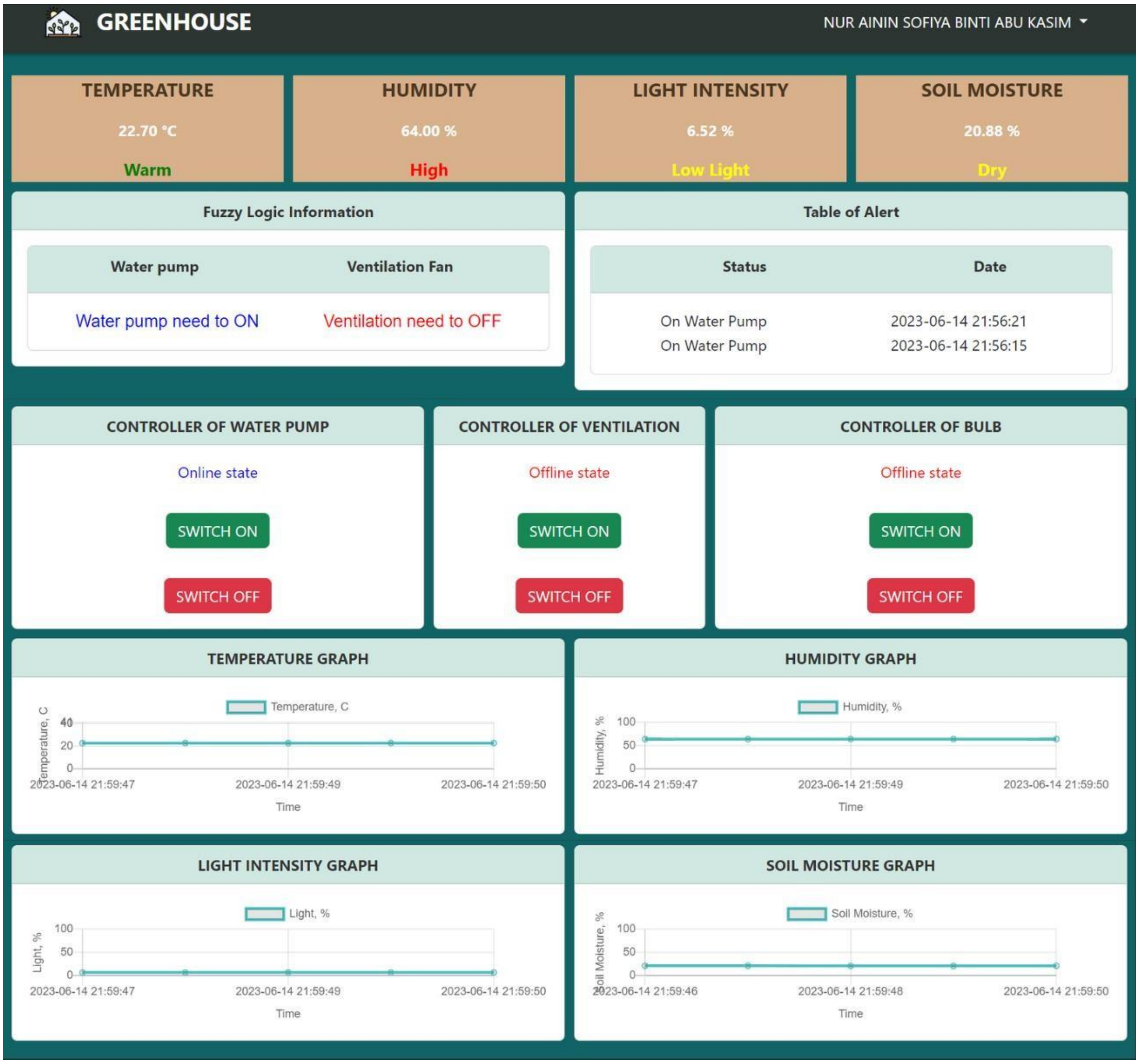


Figure 4:2 Dashboard Implementation

Based on the figure above, this is a screenshot of the system's dashboard. There are 13 cards that have their own information to be displayed to the user. For the first layer in this dashboard, there are four card that known as panel which is displayed the real-time sensors data with the status of that value. For example, the first card at the first layer is shown the value of temperature in Celsius and state the status of that value either in the "COLD", "WARM" or "HOT" status.

Next, for the second card, this card will display the current value of humidity in percentage and state the status of it. The classification of each humidity readings is “LOW”, “MODERATE” and “HIGH”. For the third and fourth card, the data will display the real-time value of light intensity and soil moisture in percentage, %. This value is converted from analog to the percentage unit. Each of this read have their own status which are “LOW LIGHT”, “MEDIUM LIGHT”, and “HIGH LIGHT” and for the soil moisture, the classification is “DRY”,” MOIST” and “WET”.

For the second layer of this dashboard, there are two cards which display the status of FLC and table of alert. For the status of FLC, this card will display the status of FLC result. In this system, there are two FLC has been implemented which are FLC in controlling the activation of water pump and ventilation fan. The status will be displayed based on the result produced by this FLC either the actuators should be on or off. Each FLC result is affected by their own input attributes. For FLC in controlling water pump, the input attributes are soil moisture and temperature. If the soil moisture is DRY and the temperature in between the three of the classification of temperature [COLD. WARM. HOT]. The system will display the status of FLC in this dashboard and activate the water pump to be on. This concept is same with the next FLC which is in controlling the ventilation fan. The inputs attributes of this FLC is temperature and humidity. When the temperature is HIGH, and humidity is HIGH or MODERATE, the system will display the status of FLC to the dashboard about this system need to on the ventilation and it will switch on the ventilation fan in the greenhouse.

For the second card in this layer, there is table of alert. This table is to show the historical data that have been alert the end user through the Telegram. The system will send alert to the end user when each of these sensors used in this system has read the value of data that in critical value. For example, for temperature the critical value is when temperature is greater than 30C while for humidity, the value is lower than 40%. For light intensity and soil moisture, the critical value is less than 30%. When the sensors have reached the critical value, the system will send the notification to the user via Telegram. At the same time, in the dashboard, the system will show the historical data of alerting the end-user and together with date and time,

For the third layer of this dashboard, there are three cards that function as controller for water pump, ventilation fan and bulb. Each of these buttons able to control the switch activation of these actuators and output device. The switch on button is to activate the actuators while the switch off button is to deactivate the actuators. Finally, the fourth and fifth layer, there are four card that display the real-time data of data visualization which is displayed in the line graph. These graphs are to observe the pattern of the sensors data at the five back. It will show the increment, decrement, or static pattern in the graph. The first card between these data at the fourth layer is displaying temperature graph followed by humidity graph, light intensity graph and soil moisture graph.

4.4 FUZZY RESULT AND DISCUSSION

In this system, there are two implementations of Fuzzy Logic Control (FLC) which are in controlling the ventilation fan and water pump. By having this FLC in this system, it makes this system be more effective and easier to handle. The actuators will be being automated in this system. These actuators are being triggered with the FLC result. FLC result are came from the set of rules and combinations of two input variables which are data from sensors that has been used in this system.

For the first FLC, there is FLC in controlling the ventilation fan. The inputs attributes of this FLC are Temperature, C and Humidity, %. When the FLC has been process, the output attributes will be shown which is the condition of the ventilation fan. These conditions are classified into two terms which is “ON” and “OFF”. When the FLC produced the outputs, the system will used this data to trigger the actuators. By having this output, it makes this system looks automated.

Figure below shows the result of FLC in controlling the ventilation fan. When the first inputs data which is Temperature is 25 C and the second inputs data which humidity is 88%. The output attributes will result as 38.5999999. Based on this result, the system will switch off the ventilation fan. It shows that the value of temperature and humidity are in the good value.

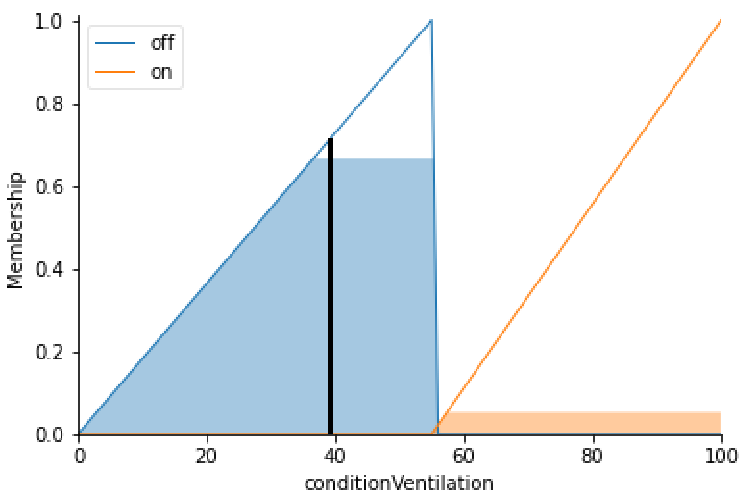


Figure 4:3: Result of FLC 1

For the second FLC, there is FLC in controlling the water pump. The inputs attributes of this FLC are soil moisture, % and Temperature, %. When the FLC has been process, the output attributes will be shown which is the condition of the water pump. These conditions are classified into two terms which is “ON” and “OFF”. When the FLC produced the outputs, the system will used this data to trigger the actuators.

Figure below shows the result of FLC in controlling the water pump. When the first inputs data which is soil moisture is 90% and the second inputs data which temperature is 29 C. The output attributes will result as 36.4999999. Based on this result, the system will switch off the water pump. It shows that the value of temperature and soil mositure are in the good value.

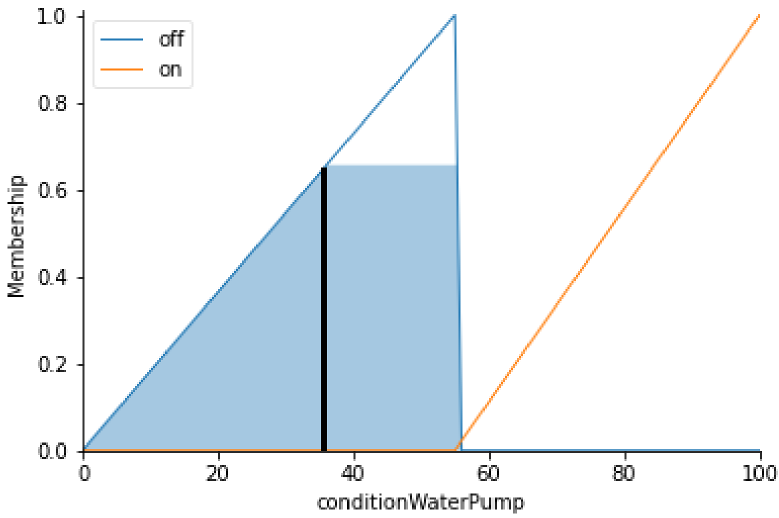


Figure 4:4: Result of FLC 2

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter describes the outcome of the 'IoT-based Smart Greenhouse Monitoring System with Fuzzy Logic' development. It will provide an understanding of the outcome of all aspects in the proposed system. The outcome and discussion will demonstrate if the proposed system functions as expected and achieves all the predetermined goals of the suggested system previously.

5.2 CONCLUSION

We build on the considerable research, development, and assessment undertaken throughout this thesis to present a thorough conclusion for our IoT-based smart greenhouse monitoring system with fuzzy logic in this last chapter. This system is a unique approach for monitoring and managing important environmental factors in a greenhouse setting, such as temperature, humidity, light intensity, and soil moisture. My system successfully automates the activation of actuators, especially the ventilation fan and water pump, to maintain an ideal growth climate for plants by harnessing the power of IoT and fuzzy logic control.

The primary goal of this thesis was to address the critical need for effective greenhouse management approaches that allow for exact control of environmental parameters. Our technology uses modern IoT technologies to build a real-time link between the physical greenhouse and a centralised monitoring platform, allowing farmers or growers to remotely access and monitor critical plant development statistics. This IoT integration not only provides ease, but also provides consumers with vital information and decision-making abilities.

Furthermore, the utilisation of fuzzy logic control in our system constitutes a big step forward in greenhouse automation. We have harnessed the power to make intelligent judgements based on imprecise and uncertain facts by utilising fuzzy logic techniques. This allows our system to constantly adapt and respond to changing environmental conditions within the greenhouse, resulting in optimal plant growth and resource utilisation.

We conducted comprehensive trials to validate the usefulness and efficiency of our IoT-based smart greenhouse monitoring system throughout the development and assessment phase. The results proved the system's capacity to precisely detect and manage temperature, humidity, light intensity, and soil moisture levels, so providing plants with a stable and hospitable environment. We obtained a better degree of precision and responsiveness in maintaining the appropriate conditions by automating the ventilation fan and water pump using fuzzy logic control, hence improving plant health and development.

Furthermore, our system's user-friendly interface enables users to engage with the monitoring platform and receive real-time data visualisations and reports in an easy manner. This provides producers with vital information about the overall health and performance of the greenhouse, allowing them to make educated decisions, optimise resource allocation, and quickly minimise possible hazards or difficulties.

While our IoT-based smart greenhouse monitoring system with fuzzy logic control has shown promising results, it is critical to recognise its limits and opportunities for further improvement. Future work may, for example, concentrate on adding additional sensors or investigating sophisticated machine learning approaches to improve the system's capabilities and decision-making processes. Furthermore, increasing the system's scalability and interoperability with other greenhouse setups and crops may add to its general adoption and application.

Finally, this thesis proposed a comprehensive IoT-based smart greenhouse monitoring system with fuzzy logic control that effectively tackles greenhouse management difficulties. Our system's integration of IoT technologies provides real-time monitoring of critical environmental factors, while the use of fuzzy logic control improves automation and flexibility. The system's capacity to automate the activation of actuators, notably the ventilation fan and water pump, guarantees that the growth environment is steady and optimised. We think that our technology has the potential to transform greenhouse management practises, contribute to more sustainable and efficient agriculture practises, and create a more environmentally conscious approach to food production.

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