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FUZZY LOGIC-BASED INTELLIGENT IRRIGATION SYSTEM WITH MOBILE APPLICATION

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ABSTRACT

Current irrigation scheduling is inefficient and inaccurate as it still relies heavily on human labour which can lead to over- or under-irrigation, affecting crop quality and workers productivity. This study proposes an implementation of an Internet-of-Things (IoT)-based irrigation system with fuzzy logic to improve the efficiency of the irrigation process. That includes the development of a mobile application called Chill-I, which acts as a remote reporter for the agricultural contractor. In addition, this system was developed specifically for the bird's eye chilli crop, which is grown on a large scale. With three inputs, soil moisture, humidity and temperature collected by the sensors, the system uses fuzzy logic processing capability to generate the output of water pumping at different rate. The results showed that fuzzy logic-based system increases the efficiency of automatic irrigation, rather than setting a fixed water pumping rate for the plant or only the ON/OFF option. Moreover, the mobile application allows remote monitoring of plants reducing unnecessary resources and improve intervention efficiency when needed.

Keywords: *Automated irrigation system, Fuzzy Logic, IoT, mobile application, Raspberry Pi*.

1. INTRODUCTION

Agriculture plays a crucial role in the development of the country. Therefore, the modernization in technology for the growth of crops should be proportional to the increased demands on crops production. The bird's eye chili plant [1,2] is one of the most popular crops among farmers, especially wholesalers and food companies, due to its high demand. It is widely grown in Malaysia and belongs to the Capsicum Frutescens family. This plant needs a regulated location with adequate irrigation for healthy growth. Current bird's eye chili production is no longer meets today's agricultural demands and manual irrigation is considered not enough productive due to inefficient crop irrigation rates, leading to either over- or under-irrigation.

The fuzzy logic has been widely accepted as an engine to automation system in various field [3,4]. The fuzzy logic based smart irrigation system with mobile application was developed as a prototype to automate the irrigation system via mobile application on a large scale. Fuzzy logic plays a crucial role in making real-time irrigation and water quantity decisions based on the analysis of data collected by the embedded sensors of the device.

This smart irrigation system collects data such as humidity, soil moisture, and ambient temperature as factors to determine whether the plants need to be watered and how much water is needed. In addition, the system can be monitored through the mobile application with its weather forecasting function.

It was reported that the agricultural sector consumes almost 70% of the world's water, thus affecting the total water resources of the world [5]. This system can be very feasible and efficient in improving the usage of water resources. This solution will have huge implications, especially for the large-scale producer of bird's-eye chili producer, to achieve more efficient crop management, which at the same time improves the quality and quantity of crops production.

Section 2 reviews the previous studies related to implementation of IoT system in crops production, the development of remote monitoring

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system, various computational algorithms to support efficient crop management and proper chili plant care for better productivity. Section 3 describes the proposed implementation of fuzzy logic-based irrigation system followed by its implementation and sample results. Finally, Section 4 concludes our findings from this study.

2. LITERATURE REVIEW

This section reviews 4 different topics: the IoT-based automatic irrigation system, the use of mobile applications in an automated irrigation system, the implementation of artificial intelligence in the automated irrigation system and finally, bird's eye chili plant care success stories.

2.1 IoT based Automated Irrigation System

Automated irrigation systems make use of sensor devices to capture environmental inputs subject to processing prior generating a response back to the environment. Most automated irrigation systems today include at least one sensor in the system. [6-10], for example, use a soil moisture sensor as an input parameter for crop monitoring.

More recent proposed systems have multiple sensors including the soil moisture. Naik et al. (2018) built an automatic irrigation system using an Arduino with soil moisture, humidity, and temperature sensors. Nevertheless, the parameter used to predict the water pump status is only the soil moisture sensor. The humidity sensor and the temperature sensor are only used for display in the application. [11] has also integrated the same three sensors into the system. Likewise, the only sensor that is used to decide the output response is the soil moisture sensor.

The output for the irrigation system is usually the status of the water pump (on or off) and the water level for watering the plants. Some existing systems still output a fixed value for the irrigation system. For example, [6,12] proposed an irrigation system that outputs the status of the water pump for a certain duration. It is either on or off, and the duration of the activated water pump is determined when it is turned on. It is assumed that the active duration of the water pump varies depending on the input parameters of each plant using different sensors.

A crucial function required in an automatic irrigation system is real-time monitoring. [13] proposed a computerized irrigation system with a wireless sensor network that can measure in real time. The sensed parameters and the output of the motor status can be displayed in the mobile application. [9] created a website that can connect to their real-time data retrieval. This real-time data retrieval is essential for the automatic irrigation system to allow the farmer to monitor the crop remotely and be able to monitor real-time data.

A solution developed by [14] contains three sensors soil moisture, ultrasound, and light. This system has the ability to be notified by email and mobile application. However, this system requires farmer intervention to allow water flow, which may not be suitable for automation. Moreover, the use light sensors as inputs may not be suitable for the decision making and are not very accurate. It may be that the plant needs water even though it is already night, and the humidity and temperature are low. A smart irrigation system by [8] introduced a new flame detection feature into the system. The flame detection aims to detect any fire in the farm with a buzzer as an alarm. However, flame detection in agriculture is not necessarily to be implemented in every farm because it is rare that the farm is on fire.

[15] proposed a soil moisture based automatic irrigation system to improve water productivity. The inputs for this system are soil moisture and rainfall status. This automated system will make the water pump start automatically when the moisture reaches the specified value. However, this automation requires very precise and real-time measurements to automatically turn off the water pump when the soil moisture reaches its target value.

2.2 Mobile Application Usage in Automated Irrigation System

The automation irrigation system using IoT by [13], can be monitored through a mobile or tablet application. The user interface is used to display data, i.e., input sensors such as soil moisture, temperature, and humidity, including motor status. This simple function for mobile application is good enough when the built system can be operated remotely to reduce human effort. They can monitor the status of the plant through the application without physically being in the yard.

[16] proposed a system whose main objective is to control the water supply and monitor the plant. This is a prominent feature of the automated irrigation system as it allows the farmer to control irrigation remotely through mobile applications. However, the system and the mobile application are connected via Bluetooth, and Bluetooth is known as a short-range wireless system. Therefore,

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even though the farmer can control the system remotely, there are limitations in terms of distance.

Meanwhile, [14] proposed a smart home garden irrigation system using a Raspberry Pi. This system also includes the control of a mobile application for the irrigation to be activated. It consists of two operations, normal operation and critical operation. In normal operation, the system can monitor the light and the humidity of the soil. In critical operation, it triggers an alarm for the level of the water tank. Fortunately, these two operations of the mobile application are beneficial to the farmer because it separates these two different operations, which can help identify the operation.

2.3 The Implementation of Artificial Intelligence in Automated Irrigation System

Any artificial intelligence or machine learning algorithm takes advantage of the situation at hand. For example, in an automatic irrigation system, artificial intelligence can be used to work intelligently based on different environments instead of being automated with a timer. The automatic irrigation system uses three common algorithms: K-Nearest Neighbour (KNN), Artificial Neural Network (ANN), and Fuzzy Logic algorithm.

[17-18] proposed an automatic irrigation system based on K-Nearest Neighbour. The KNN algorithm can be used on the Raspberry Pi to train and predict the dataset on humidity and temperature. KNN, which is commonly known as lazy learning, is implemented to classify the objects based on the nearest training samples.

[19-20] proposed an automatic irrigation system using ANN as an algorithm which makes the system work intelligently. An ANN is the most widely used algorithm that makes predictions and forecasts based on parallel reasoning. They mentioned that ANN can provide very accurate results by quickly analysing and processing a large amount of data. For example, [20] developed a system that uses the evapotranspiration model to convert input data (temperature, soil moisture, radiation, and humidity) into actual soil moisture. ANN was implemented to compare the required soil moisture and determine the amount of water needed for irrigation.

Fuzzy logic is also one of the algorithms commonly used in automatic irrigation systems. [21-25] all designed an automatic irrigation system with the implementation of fuzzy logic algorithm. However, [21] designed an automated irrigation system using Mamdani and Sugeno control systems. The input is humidity, temperature, sunshine illumination, solar radiation, and wind speed. At the same time, the output is only the water pumping rate. The comparison of the two types of fuzzy inference systems applied showed that Sugeno is more effective and reliable than Mamdani. Therefore, it is a promising approach to find the best algorithm suitable for the system instead of just using it without comparison.

In autonomous crop irrigation system using artificial intelligence by [26], the machine learning used predicts the rainfall and moisture content of the soil. In a brief but concise explanation, the precipitation prediction is the probability of rain in the next 30 minutes and the estimated amount of rainfall. Then decision making is done to determine the water content needed by the plant. In my opinion, this prediction is well suited to achieve the best and most accurate results for irrigation, especially in terms of irrigation timing and the amount of water used for irrigation.

2.4 Bird's Eye Chili Plant Care

Growing chili plant requires enough sunlight, suitable soil, fertiliser and most importantly water [27-28]. Most chili plants perish due to insufficient watering. It is also susceptible to waterlogging, and chilies have comparable symptoms between dry root ball and waterlogging. Always check in advance if there is a need to water your plants, because most problems in growing chilies are caused by improper watering.

Since chilies cannot tolerate excessive moisture, they should only be watered when absolutely necessary. According to [27] chili plants should be watered twice a day, once in the early morning and once in the late evening. However, as for the amount of water needed for irrigation, it cannot be controlled. The substrate, planter, sun, light, location all plays a role in deciding the amount of water. Therefore, good irrigation scheduling and monitoring are necessary to produce a good and healthy chili plant.

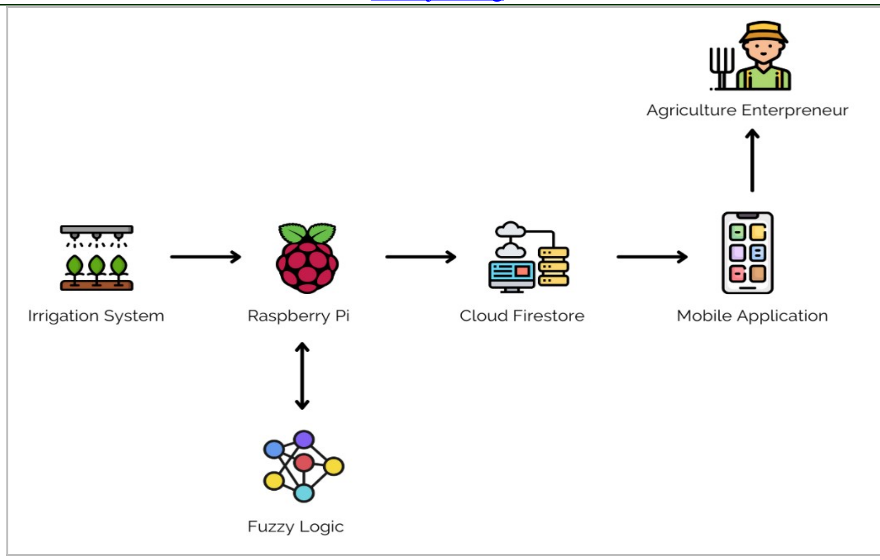

Figure 1: System architecture of the fuzzy logic based smart irrigation system

3. PROPOSED METHOD

The hardware of the irrigation system includes the main microcomputer, the Raspberry Pi 4 Model B, the sensors (FC-28 Soil Moisture Sensor, DHT22 Temperature and Humidity Sensor), MCP3008 analogue-to-digital converter, 1-Channel Relay Module, Resistor, 9V battery, breadboard, jumper wire and specific for irrigation such as Micro submersible water pump and flexible water pipe. The software used in project development includes that for IoT connectivity such as Raspberry Pi OS and VNC Viewer, mobile application development using Visual Studio Code, Python and Figma, and Matlab for fuzzy logic implementation.

3.1 System Design and Analysis

The system architecture of the fuzzy logic based smart irrigation system with mobile application is shown in Figure 1. It consists of six elements: the hardware part of the irrigation system, the Raspberry Pi for processing, the fuzzy logic, the cloud firestore, the mobile application, the user, the agricultural entrepreneur. The irrigation system is mainly powered by the Raspberry Pi. Once the sensor data is collected, it is processed by the fuzzy logic in the Raspberry Pi and the output data is stored in the cloud firestore which is accessible in real-time for agriculture entrepreneur via the mobile application.

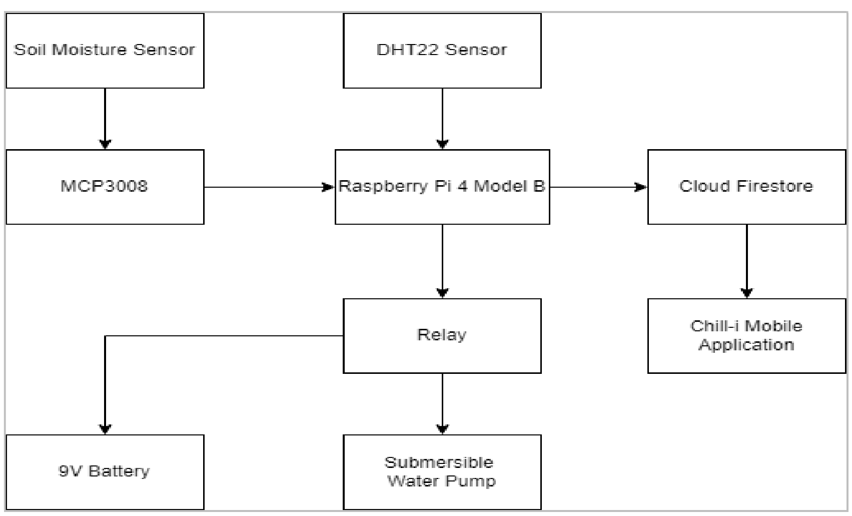

Figure 2: System block diagram

Figure 2 shows the system block diagram with the cloud firestore and the Chill-i mobile application. The brain of this system is the Raspberry Pi, every other major component is directly and indirectly connected to it.

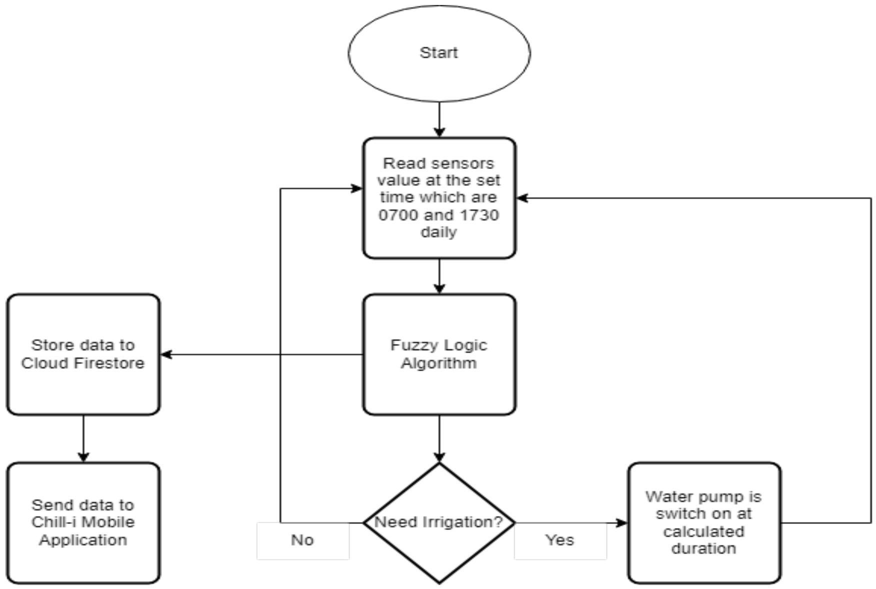

Figure 3: Fuzzy logic-based smart irrigation system flowchart

Figure 3 shows the flowchart of the whole fuzzy logic-based smart irrigation system with mobile application. Once the hardware part of the system is set up, the sensors read the data according to the set time twice a day, once at 7 am and once at 5:30 pm. The data collected is consumed by the fuzzy logic algorithm to generate the output for irrigation. The system goes through two different processes at the same time: the first is the irrigation status. If the plant needs watering, the water pump will be activated according to the output of the fuzzy logic, i.e., the duration of the water pump activation. However, if the plant does not need irrigation, the sensors collect the following data as usual. The second process is that the data is stored in the cloud firestore ready to be retrieved the mobile application Chill-i.

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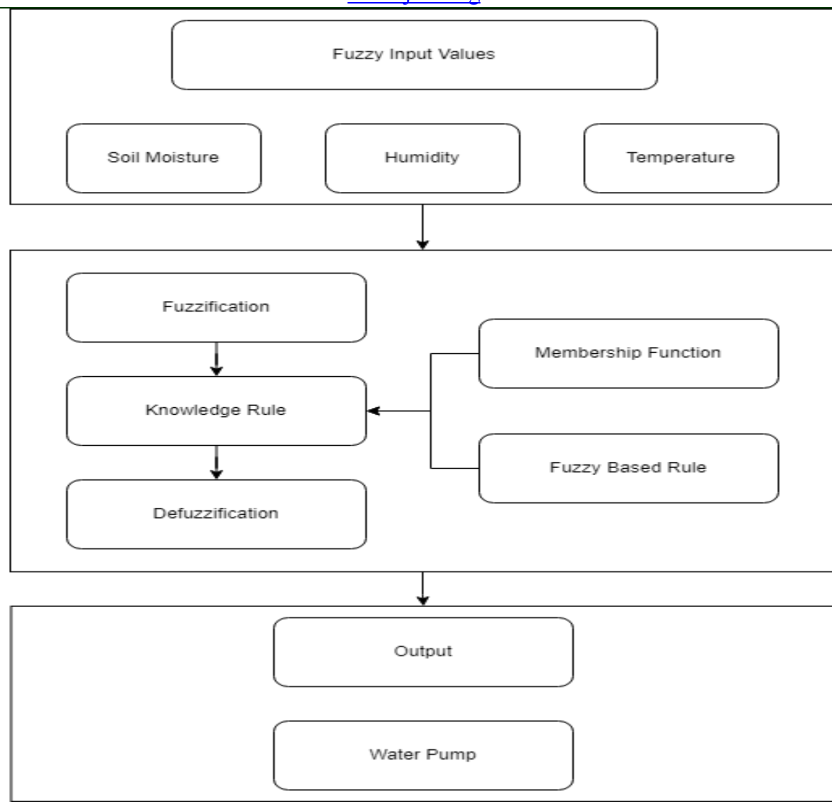

Figure 4: Fuzzy Inference System

Fuzzy logic is the automation backbone for this fuzzy logic-based intelligent irrigation system with mobile application. A fuzzy inference system maps inputs to outputs using fuzzy set theory. Figure 4 shows how the input is mapped to the fuzzy set theory to produce the output.

1) Crisp inputs.

Three unique inputs are fed into the system: Soil moisture, humidity, and temperature.

2) Fuzzification

Fuzzification converts a clear quantity to a fuzzy quantity or a fuzzy quantity to a fuzzier quantity. This process essentially converts precise, unique input values into language variables.

This system uses a triangular membership function based on Mamdani method (refer to Figure 5, Table 1, Figure 6, Table 2, Figure 7, Table 3), which is one of the most widely accepted and used membership functions in the development of fuzzy controllers. Three parameters define the triangle that fuzzifies the input: a, b, and c, where c indicates the base and b defines the height of the triangle. Meanwhile, the input parameters are described by three linguistic regions: 'DRY,' 'MEDIUM,' 'WET' for the soil moisture sensor, 'LOW,' 'MEDIUM,' 'HIGH' for humidity, 'COLD,' 'WARM,' 'HOT' for temperature.

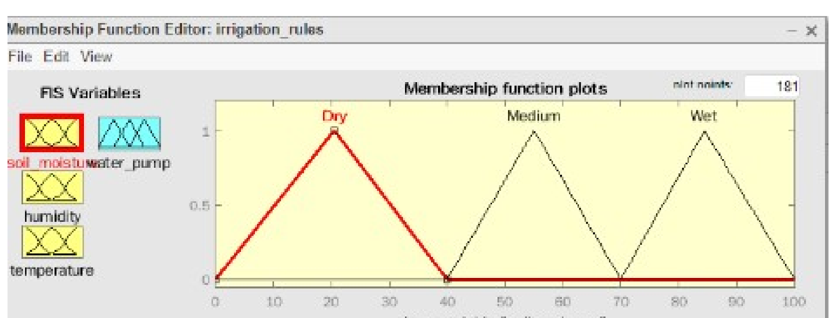

Figure 5: Membership Function for Soil Moisture Sensor

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Table 1: Description of Input Variable of Soil Moisture using Mamdani Method

Sensor	Name of MF	MF Type	Range	Parameters (%)
Soil moisture	Dry	Triangular	[0, 100]	[0, 20.5, 40]
Soil moisture	Medium	Triangular	[0, 100]	[41, 55, 70]
Soil moisture	Wet	Triangular	[0, 100]	[71, 84.5, 100]

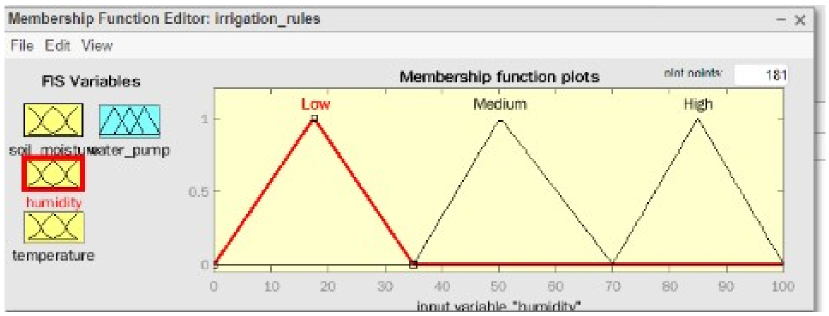

Figure 6: Membership Function for Humidity Sensor

Table 2: Description of Input Variable of Humidity using Mamdani Method

Sensor	Name of MF	MF Type	Range	Parameters (%)
Humidity	Low	Triangular	[0, 100]	[0, 17.5, 30]
Humidity	Medium	Triangular	[0, 100]	[31, 50.2, 70]
Humidity	High	Triangular	[0, 100]	[71, 85, 100]

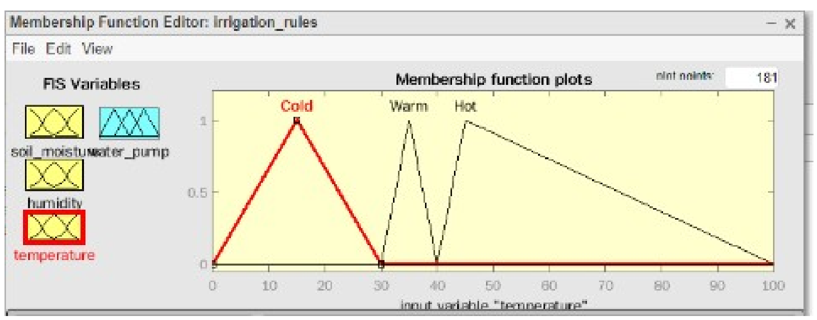

Figure 7: Membership Function for Temperature Sensor

Table 3: Description of Input Variable of Temperature using Mamdani Method

Sensor	Name of MF		MF Type	Range	Parameters (%)
Temperature	Cold		Triangular	[0, 100]	[0, 15, 30]
Temperature	Warm		Triangular	[0, 100]	[31, 35, 40]
Temperature	Hot		Triangular	[0, 100]	[41, 45, 100]

1. *Knowledge Rule*

The fuzzy inference system is the central component of a fuzzy logic system that handles decision making. It creates basic decision rules using the "IF... THEN" rules and the connectors "OR" or "AND." The fuzzy rule base configuration assigns relationships between fuzzy input and output to construct the fuzzy rule base.

It includes a collection of rules that represent the knowledge base and reasoning structure of the problem solution. The fuzzy engine would apply rule-based rules to produce a fuzzy value. The rule base contains rules modeled by training and information.

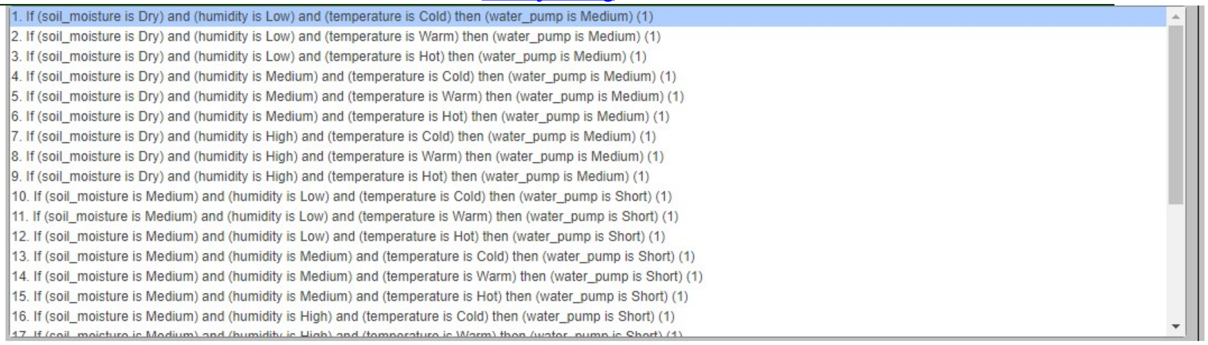

Figure 8: Some of Fuzzy If-Then Rules

This system has three input variables, each with three different linguistic domains. Consequently, there are $3^3 = 27$ rules for the input parameters (Figure 8). When creating fuzzy logic, a set of IF-THEN rules must be created to describe the linguistic mapping from input to output. These rules are derived from operator experience. The Mamdani approach is used to construct the rules, with simulation performed using MATLAB.

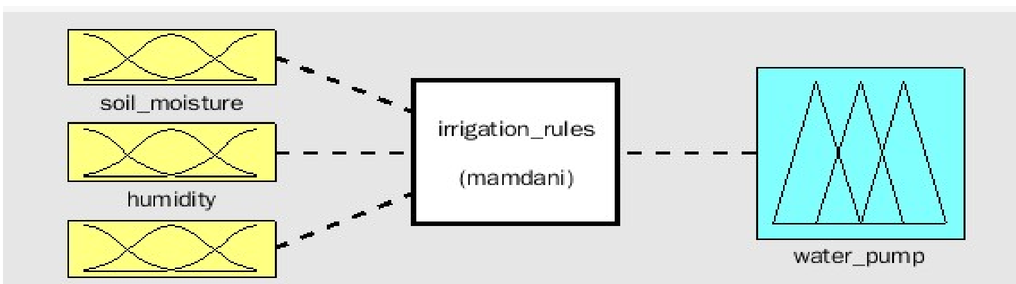

Figure 9: Fuzzy Logic Controller of Intelligent Irrigation System using Mamdani Method

Fuzzy inference captures unique input variables such as soil moisture, temperature, and humidity, and then analyses them using an interference rule base (Figure 9).

2. Defuzzification

In defuzzification, the crisp input is converted to a fuzzy value by fuzzification. The fuzzy output of the fuzzy inference engine is defuzzified into a crisp value that can be passed to the controller.

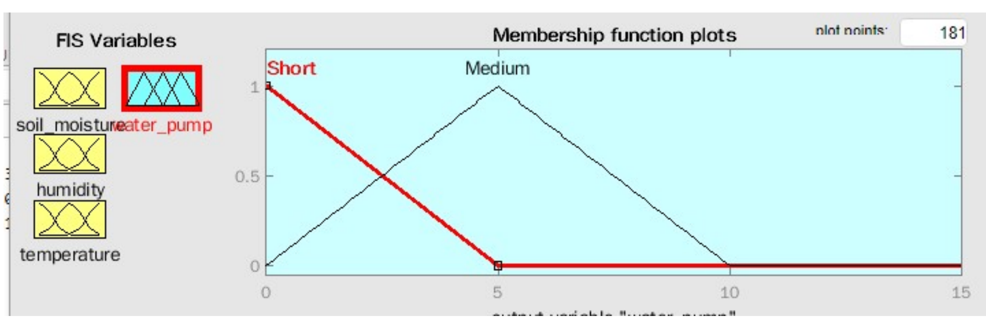

Figure 10: Membership Function of Water Pump Output

Table 4: Description of Output Variable of Water Pump using Mamdani Method

Sensor	Name of MF	MF Type	Range	Parameters (%)
Water Pump	Short	Triangular	[0, 20]	[0, 5, 10]
Water Pump	Medium	Triangular	[0, 20]	[11, 15, 20]

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The resulting fuzzy outputs cannot be used in any application where decisions must be made based solely on crisp values, which is understood by the controller. Therefore, the fuzzy output must be converted into a unique value as shown in Figure 10 and Table 4.

3.2 System Implementation

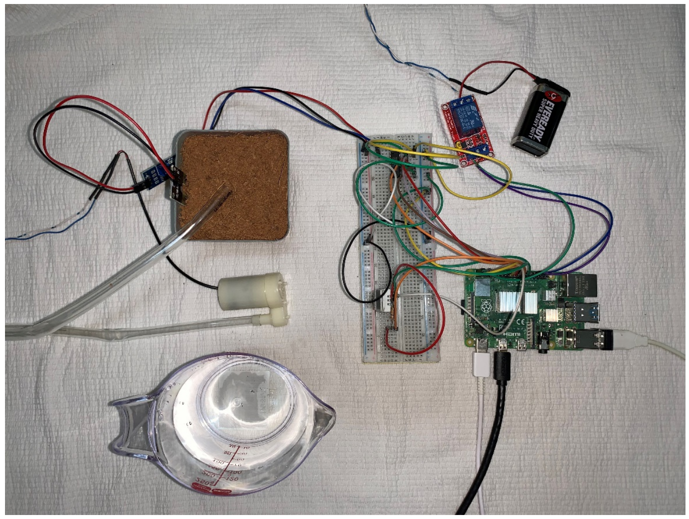

Figure 11: Hardware components of the system

Figure 11 shows the hardware components of the Fuzzy Logic Based Intelligent Irrigation System with Mobile Application. It shows how all the sensors and other components are connected to each other on the Raspberry Pi. A pot of coco peat medium is included as the testing soil for the system. In addition, a jar of water is also available as the water source for the system.

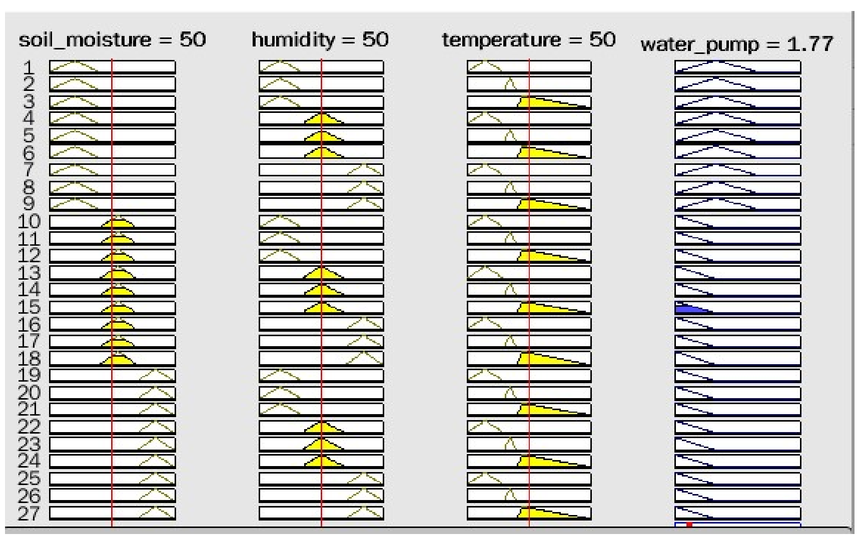

Figure 12: MATLAB Fuzzy Reasoning Rule

Figure 12 shows the table of fuzzy reasoning rules when the value of inputs is included according to the Mamdani method. For example, an input of 50 for soil moisture, 50 for humidity, and 50 for temperature is considered to produce the output value, water pumping rate. It can be seen that for these inputs, a water pumping rate of 1.77 seconds is generated for the crisp output.

This fuzzy rule is suitable for testing the accuracy of the membership function created in the previous phase. Any value can be used as input to evaluate the output of the fuzzy logic.

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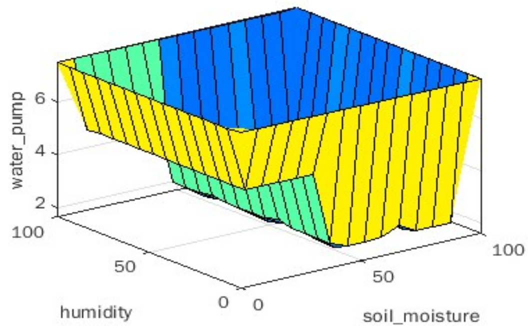

Figure 13: MATLAB Surface Rule Viewer

Figure 13 shows the Surface Rule Viewer in MATLAB using the Mamdani method. It shows the view of soil moisture and humidity versus water pump.

Figure 14: Some of Chill-i user interface

Figure 14 shows some of the important interfaces included in the Chill-i. For example, there is an interface for the home page, which displays the current temperature for that day at the current location. There is also the weather forecast for the current day, which is retrieved through the API. Finally, the interface displays the real-time data for each facility in each area.

This includes the data collected by the sensors in the plant such as soil moisture, humidity and temperature.

3.3 System Evaluation

The system was expected to increase the effectiveness (and accuracy) of the irrigation system. Thus, input factors such as soil moisture, humidity and temperature are used to control the water pump and optimize water delivery to the plants.

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Table 5: Summary of The Intelligent Irrigation Output

No	Soil Moisture (%)	Humidity (%)	Temperature (°C)	Water Pump (ml)
1	71.3	66.3	29.2	49.9
2	72	80	27.9	50
3	22.97	54.7	31.2	150
4	27.47	76.9	14.6	146
5	31	54.7	31.2	150
6	18.2	66.8	29	151
7	75.3	71.1	29.9	50
8	68.2	73.7	29.1	50
9	40.4	61.9	30.0	48
10	37.7	74.4	29.4	145.5
11	45.3	67	29.9	50
12	19.1	74.6	29	145.8

Based on the three inputs, the system determines the irrigation output in term of water volume. Table 5 summarizes the output of water pump from our irrigation system based on the collected data. In general, fuzzy decision making provides much accurate measurement of water volume to be distributed on each crop level and thus maximize its growing process.

4. CONCLUSION

Agricultural monitoring has become a necessity in today's world, as the increase in food production leads to an increase in agricultural practices. The fuzzy logic based smart irrigation system with mobile application helps the agricultural entrepreneurs to integrate technology in their daily routine. The implementation of fuzzy logic in the system helps to produce better quality and ensures good crop irrigation without the need for constant human intervention. Mobile applications also allow them to monitor the operation remotely, hoping to increase the farmer's time efficiency.

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