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Fuzzy-based Greenhouse Irrigation Controller System

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Abstract – *Food and water demand have increased as a result of population growth. Conventional farming techniques could not meet the demands of the populace. The agriculture industry should implement modern technological advancements and innovative solutions to increase crop yield and maximize the use of limited resources. The automation of the greenhouse system can assist farmers in monitoring their farms to make better irrigation decisions and increase water use efficiency and crop yield. This study developed a soil moisture-based fuzzy irrigation controller that can modify the soil's volumetric moisture content in response to climatic conditions using an Arduino Nano microcontroller. The developed fuzzy irrigation controller aims to eliminate excess water consumption while optimizing plant growth in the greenhouse. The fuzzy controller was designed in MATLAB and was implemented by converting the .fis file to Arduino C code. The results demonstrate that the fuzzy irrigation controller is functional and capable of adapting to changing environmental conditions.*

Keywords – *Fuzzy Logic Controller, GSM Communication, Irrigation Management System, Sensor-based System*

INTRODUCTION

TR 11, uppercase bold, and centered. This portion includes the scope, context, and significance of the research conducted by summarizing current understanding and background information about the topic. , explaining briefly the methodological approach used to examine the research problem, highlighting the potential outcomes your study can reveal, and outlining the remaining structure and organization of the paper. Immediately under the Introduction title is the first paragraph statement with 6 spaces indentation. Leave one space for the next paragraph.

More than 70% of freshwater is used for agricultural irrigation, making agriculture the greatest user of freshwater in the world. (World Bank, 2018). Even though agricultural irrigation receives a large share of the world's water, it is one of the largest contributors to water loss. In underdeveloped nations, around 40% of the freshwater used for irrigation is wasted due to inefficient irrigation caused by leaks or over-irrigation (World Bank, 2018). In addition, according to the UN Food and Agriculture Organization (FAO), 60% of irrigated water is lost through runoff into waterways and evapotranspiration (Maddocks et al., 2016). UNESCO forecasts that the world population will increase by a third by 2050; as a result, there will be a greater need for food and water (UNESCO, 2016). In order to improve and expand agricultural production to satisfy the population's food needs, it is necessary to make efficient use of the limited water available for agriculture.

The optimal use of water cannot be achieved using conventional irrigation techniques. The conventional method of irrigation is more costly and labor-intensive (Phogat et al., 2021). In addition, traditional irrigation has a low water utilization rate because the same volume of water is applied to the field regardless of soil and water demands, resulting in a field that is either over- or under-irrigated (Daccache et al., 2015). Agriculture must be revolutionized in order to increase water utilization and crop yield through the integration of modern technological advances and innovative solutions. According to Navarro-Hellín et al. (2015), the use of intelligent agricultural systems enables farmers to increase agricultural production at a low cost.

A greenhouse is a structure designed to promote plant growth and yield by optimizing climatic conditions (Weldeslasie et al., 2021). A greenhouse is a structure used to control environmental factors to optimize plant growth (Ghani et al., 2019). Greenhouse is an important part of agriculture because it provides controlled climatic and growth condition for an abundant crop yield (Jaiswal & Ballal, 2020; Stipanicev & Marasovic, 2003). Monitoring temperature and relative humidity are crucial for greenhouse operations (Benli, 2013; Hanssen et al., 2015). The automation of greenhouses facilitates optimal plant growth by precisely monitoring and controlling microclimatic parameters. According to Ahonen et al. (2008), the most critical parameters in greenhouse automation are light, temperature, and humidity.

Monitoring and controlling the microclimatic parameters in a greenhouse through automation can increase plant growth and yield (Sivagami et al., 2018). Greenhouse automation systems use a variety of sensors, actuators, and industrial machinery to manage greenhouse processes without human intervention (Badji et al., 2022). According to Siddiqui et al. (2018), tomato growth in an automated greenhouse is twice as fast as its average growth. However, no experimental evidence was presented to substantiate their claim.

Automation can reduce greenhouse management labor costs and boost production efficiency. Additionally, adopting automation technology in agriculture reduces the sector's reliance on manual labor (Gallardo & Sauer, 2018). In the study by Sheikh et al. (2018), they implemented an automated irrigation system to assist farmers in managing and monitoring their farms to reduce worker errors. However, the high capital cost of agriculture automation technologies is one of the reasons for their low adoption (Barnes et al., 2019).

Automation enables the precise regulation of environmental conditions and control of agricultural operation to reduce the consumption of limited resources. Jamroen et al. (2020) have created an intelligent irrigation scheduling system that takes crop and soil water variability into account. Implementing their system reduced water consumption by 59.61% and electrical energy consumption by 67.35%. Similarly, Azaza et al. (2016) have reduced energy consumption by 25% and water consumption by 33% by implementing an IoT monitoring and control system to control the greenhouse's temperature and humidity.

Recent studies in smart farming has implemented Fuzzy Logic Controller in agricultural irrigation systems to optimize plant condition and minimize waste of supplies (Gao et al., 2013; Viani et al., 2017). Several studies like (Hasan et al., 2019; Souza et al., 2020) reported reduced water consumption of 12.3% and 18%, respectively, when fuzzy logic control was implemented in irrigation system. Such Fuzzy Logic Controllers for agriculture application are designed and implemented using MATLAB (Alomar & Alazzam, 2019; Cruz et al., 2017; Pezol et al., 2020) and Embedded Fuzzy Logic Library (eFLL) (Baldovino et al., 2018; Carrasquilla-Batista & Chacón-Rodríguez, 2019; Concepcion II et al., 2020).

Agriculture automation supports farmers in overcoming difficulties such as water shortage, managing costs, and increasing agricultural production. Agriculture automation technology enhances the quality of life by minimizing human work and maximizing agricultural productivity on less farming land with fewer resources.

OBJECTIVES OF THE STUDY

The objective of this paper is to develop an integrated system to monitor the environmental parameters of a greenhouse and to control irrigation using fuzzy logic to improve water use efficiency and agriculture productivity. A GSM Module is integrated to have communication between the user and the controller to monitor the environmental parameters and irrigation status through SMS messaging.

MATERIALS AND METHODS

System Architecture

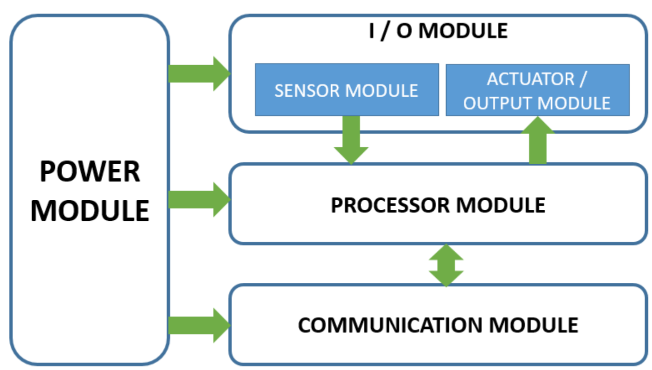

Figure 1. System Architecture of the Proposed System

The system architecture for the proposed system is depicted in Figure 1. It consists of four parts, i.e., Power Module, I/O Module, Processor Module, and Communication Module. The power module supply regulated DC voltage to the I/O, Processor, and Communication Module. The I/O module is where the various input sensors and actuators are interfaced. It is comprised of Sensor Module and the Actuator / Output

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Module. The Processor Module is responsible for executing the program uploaded by the users. Lastly, the Communication Module handles data exchange between the controller and the user.

Automation Concept and Design

Fig. 2 illustrates the layout of the automated greenhouse irrigation control. Inside the greenhouse farm are the various sensing devices, including the DHT 22 sensor to measure temperature and humidity and an array of soil moisture sensors to measure the volumetric moisture content of the soil. The soil moisture sensor array comprises three soil moisture sensors placed at a range of depths (2in, 8in, 20in).

The soil moisture sensor installed at a depth of 2 inches or less will experience the most cycles of wetness and dryness. The sensor placed at this depth will assist in determining when to irrigate. Soil moisture sensors at 8 and 20 inches of depth will be an indicator of the extent to which soil water has been depleted and will provide feedback on how much to irrigate (Peters et al., 2013). An LDR sensor is installed outside the greenhouse to determine whether it is day or night. The output of the system is the irrigation pump. The blue line represents the flow of irrigation water through a drip irrigation setup to precisely control the water delivered to the greenhouse crops. The black line represents the electrical signal connection of the input and output devices to the Arduino controller panel. The panel contains the Arduino board, GSM Module, LCD Display Screen, and Power Supply.

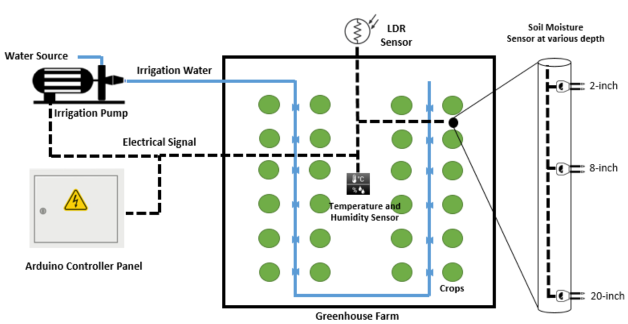

Figure 2. Layout of the Automated Greenhouse Irrigation Control

System Algorithm

The sensor reading and display algorithm are depicted in Figure 3. The microcontroller begins by reading the measurements from the three soil moisture sensors installed at various depths and the temperature and humidity measurements from the DHT22 sensor. The average soil moisture from the three sensors is then calculated. Finally, the I2C LCD screen displays the average soil moisture, temperature, and humidity measurements.

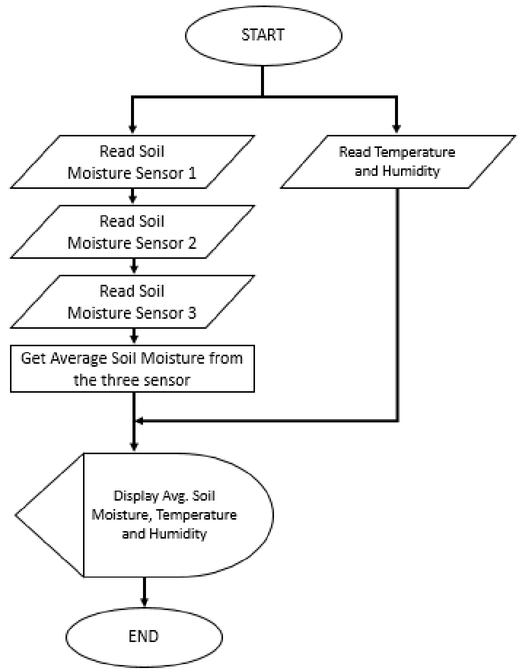

Figure 3. Sensor Reading and Display Algorithm

Fig. 4 illustrates the Fuzzy Irrigation Control Algorithm. The algorithm starts by reading the three soil moisture sensors and computing the Average Volumetric Moisture Content. If the VMC is less than 20%, the algorithm will proceed with reading the LDR sensor; otherwise, it will loop back to read the soil moisture sensor until it satisfies the condition. The LDR sensor is used to determine if it is day or night. During the day is the only time when the system is enabled to irrigate to conserve water and energy. At night, there is no sun to accelerate the evapotranspiration of the plants. This means that at night time, the plant and soil retain their moisture content longer compared to day time, so it is more efficient to irrigate the field during day time to prevent drought and withering of the plants.

When the irrigation process starts, the irrigation pump will be turned on, and an SMS notification stating that the irrigation process has started will be sent to the user. During the irrigation, the humidity and temperature values are continuously monitored. These values will be used as the Fuzzy Logic inputs to compute the VMC trigger value to stop the irrigation process. Afterward, the three soil moisture sensors will be read to compute the average volumetric moisture content. The values of the

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VMC trigger and the Average VMC will be compared. Suppose the Average VMC is greater than or equal to the VMC trigger value. In that case, the irrigation pump will be turned off, and an SMS notification stating that the irrigation process has stopped will be sent to the user.

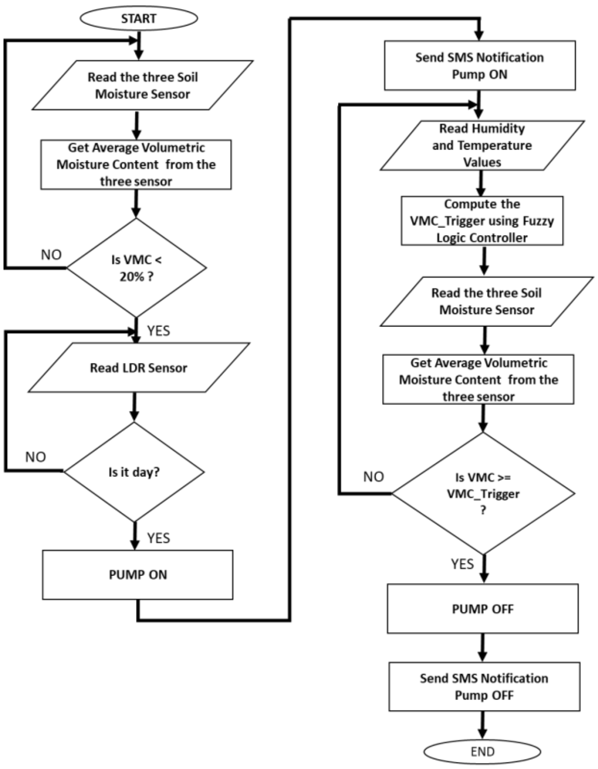

Figure 4. Fuzzy Irrigation Control Algorithm

Fuzzy Logic Controller

Lotfi Zadeh's Fuzzy Logic Control (FLC) was implemented to control the developed system. In Fuzzy Control, a single-valued or crisp input is mapped to a fuzzy input stated in a linguistic variable. Next, The linguistic rules are integrated into an inference mechanism that processes the fuzzy inputs to produce the corresponding fuzzy outputs. Defuzzification, or the reversal of the fuzzification process, will then be applied to generate a crisp output (Lee, 1990; Zadeh, 1965).

Mamdani's fuzzy inference technique is the most often used method in fuzzy controllers. Mamdani fuzzy inferences were initially conceived as a technique for developing a control system by synthesizing a set of linguistic control rules obtained from the knowledge of skilled human operators. (Mamdani & Assilian, 1975). Expert system applications that depend on Mamdani systems are an excellent fit for a set of rules derived from human expertise due to the clarity and simplicity of their rule bases (Mathworks, n.d.). Fig. 5 shows that Mamdani Fuzzy Inference System employs linear membership functions.

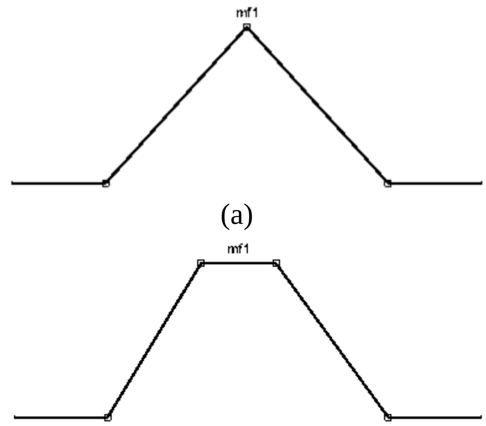

Figure 5. Linear Membership Functions: (a)Triangular, (b) Trapezoidal

This paper developed a Mamdani fuzzy controller to set the VMC Trigger value to stop the system's irrigation. This controller's inputs are air temperature and relative humidity, and its output is the VMC Trigger value. The developed fuzzy controller was designed and developed in MATLAB. The .fis file is translated to C for Arduino code implementation using MakeProto. Fig. 6 depicts the fuzzy irrigation controller.

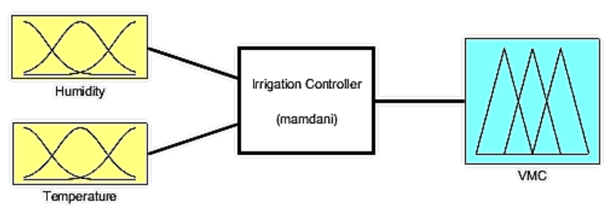

Figure 6. Fuzzy Irrigation Controller

The value of the field's Volumetric Moisture Content is used as a trigger to stop the irrigation pump from supplying water to the field in order to control the volume of irrigated water to the field. The VMC trigger ranges from 50 to 100 %, with a higher VMC value indicating that the soil has more moisture. The fuzzy control concept is to modify the VMC trigger value depending on the temperature and humidity inputs.

For example, suppose the humidity is low, and the temperature is high. In that case, the VMC values must be set to maximum. If the humidity and temperature are both high, the VMC trigger value should be between 50 and 100 %. The sensors continuously monitor the temperature and humidity, and the output VMC trigger

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value is modified accordingly. Linguistic levels established the VMC trigger values to develop a control system based on the Mamdani Fuzzy Inference System. Table 1 shows the summary of the linguistic rules of the fuzzy logic controller of the irrigation system. Tables 2 and 3 show each membership function's legend and fuzzy relation, while Figs. 7 to 9 illustrate the membership functions plot of its inputs (Humidity and Temperature) and outputs (Volumetric Moisture Content).

Table 1. Summary of the Linguistic Rules of the Fuzzy Irrigation Controller

		Temperature		
		L	M	H
Humidity	L	W	SW	EW
	M	MW	W	SW
	H	M	MW	W

Table 2. Fuzzy Input Legend and Fuzzy Relation of Membership Functions

Humidity	**Fuzzy Relation**
L – Low	[0 0 50 72.5]
M – Medium	[50 72.5 95]
H – High	[72.5 95 100 100]

Temperature	**Fuzzy Relation**
L – Low	[0 0 15 25]
M – Medium	[15 25 35]
H – High	[25 35 40 40]

Table 3. Fuzzy Output Legend and Fuzzy Relation of Membership Functions

VMC Trigger Value	**Fuzzy Relation**
M – Moist	[0 0 50 60]
MW – Moderately Wet	[50 60 70]
W – Wet	[60 70 80]
SW – Severely Wet	[70 80 90]
EW – Extremely Wet	[80 90 100 100]

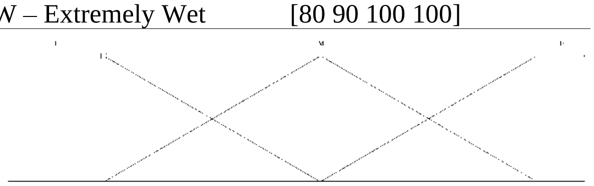

Figure 7. Membership Function for Humidity

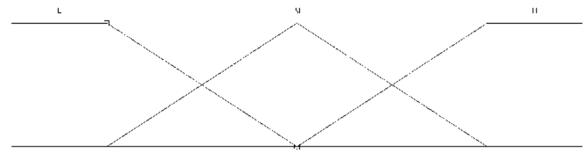

Figure 8. Membership Function for Temperature

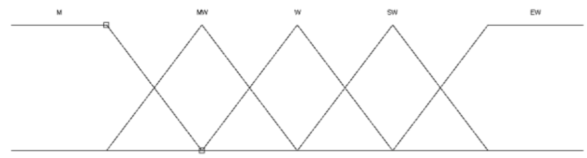

Figure 9. Membership Function for Volumetric Moisture Content Trigger

RESULTS AND DISCUSSION

Surface Viewer of the Fuzzy Irrigation Controller

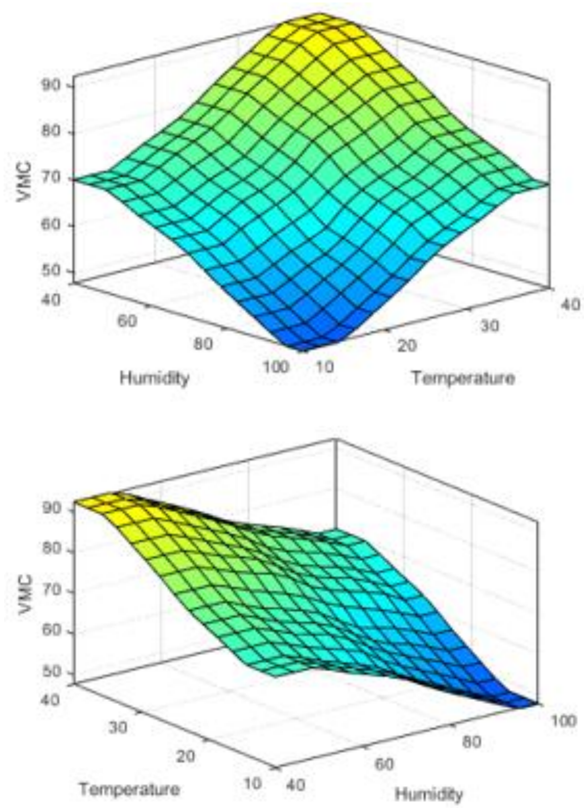

Figure 10. Surface View of the Fuzzy Irrigation Controller

The fuzzy irrigation controller was simulated in MATLAB to determine the system's predicted output. The Fuzzy Inference System (FIS) simulation was used to test the system. The Surface Viewer Function of MATLAB's Fuzzy Logic Toolbox was used to illustrate and analyze the simulation's multiple crisp input and output values. The surface viewer, as shown in Fig. 10,

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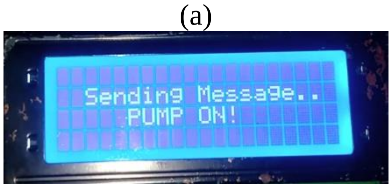
depicts the relationship between the Fuzzy Irrigation Controller's inputs and outputs. The surface viewer shows that low relative humidity and a high temperature result in a high VMC value, denoted by the yellow surface hue. On the other hand, high relative humidity and low temperature result in a low VMC value, as indicated by the blue surface hue.

Hardware Testing and Simulation

A %VMC value of less than 20%, as illustrated in Figure 11a, indicates that the soil in the field is dry. Furthermore, the irrigation pump will be activated to deliver water to the field. The LCD will display the Pump Status as ON. Following that, an SMS will be sent to the user to notify them that the irrigation process has begun.

(a)



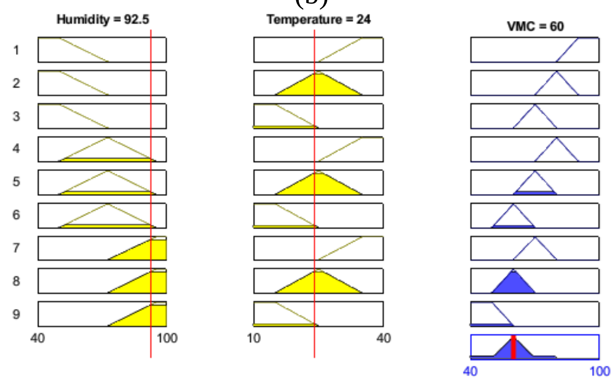
(b)

Figure 11. Dry Soil Condition: (a) Sensor Values, (b)SMS Notification (start irrigation)

While the field is irrigated, the air temperature, relative humidity, and volumetric moisture content of the soil are continuously measured. The fuzzy control is implemented in this stage. Looking at the values in Fig. 12a, for example, when the temperature is Medium (24. 00℃) and the humidity is High (92.50%), the %VMC value output is 60, indicating that the soil moisture needs to be Moderately Wet, according to the rule viewer of the fuzzy irrigation controller in Fig.12c. Fig. 12a shows that the VMC value of 61% triggered the pump to turn off, as indicated by the pump status OFF. In contrast, the values in Fig. 13a show that when the temperature is High (33.30℃). The humidity is Low (61.30%), the %VMC value output is 84.1, indicating that the soil moisture has to be Severely Wet, based on the rule viewer of the fuzzy irrigation controller in Fig. 13c. This demonstrates that the hardware implementation agrees with the software simulation. Following that, an SMS will be sent to the user to alert them that the irrigation process is done.

(a)

(b)



(c)

Figure 12. High Humidity and Medium Temperature Condition: (a) Sensor Values, (b) SMS Notification (stop irrigation), (c) Rule Viewer

(a)

(b)

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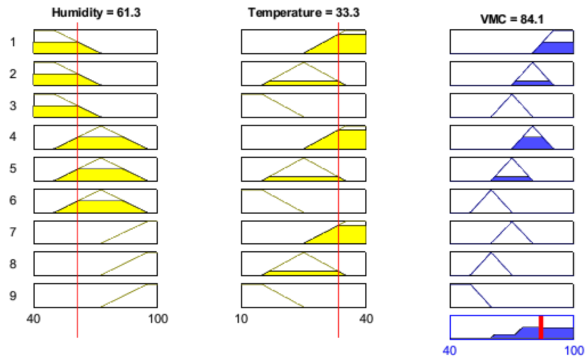

(c)

Figure 13. Low Humidity and High-Temperature Condition: (a) Sensor Values, (b) SMS Notification (stop irrigation), (c) Rule Viewer

Conclusion and Recommendation

The use of fuzzy logic control with GSM technology was presented as a method for creating an intelligent irrigation controller that improves water and energy conservation. Based on the MATLAB simulation and hardware testing, it is apparent that the developed fuzzy irrigation controller can respond to different climatic conditions to provide plants with the optimal environment for better growth and increased yield. The system's Fuzzy surface output could identify the moisture level required by the soil for a given climatic condition. The Mamdani Fuzzy Inference System, which employs trapezoidal and triangular membership functions, served as the foundation for the fuzzy controller. To manage the volume of irrigated water and enhance resource usage efficiency, the fuzzy control facilitated adjusting the trigger value of the volumetric moisture content of the soil based on the microclimatic conditions inside the greenhouse. A GSM module was incorporated to monitor the system remotely and alert the user.

This study could be introduced to local greenhouse farms and put into implementation. Testing and validation could be performed to evaluate the performance of the developed fuzzy logic controller and compare the water consumption of a greenhouse using fuzzy irrigation control and traditional irrigation methods.

For future studies, the researcher recommends implementing a vision system with an artificial neural network (ANN) to monitor the growth and development of crops inside the greenhouse to achieve a more robust control system.

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Volume 8, Issue 1, 2023
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