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Smart Irrigation System Using a Fuzzy Logic Method

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ABSTRACT

The motivation in pursuing this work is based on the fact that majority of the world are agriculture oriented countries and the proposed system will facilitates farmers in providing irrigation that will ease their burden in taking care of crops during drought. This smart irrigation system will help in conserving moisture to counteract insufficient rainfall. This irrigation system will reduce wastage of water as well as cost of labour. The proposed smart irrigation system optimizes water usage for agriculture and this paper presents a realization of fuzzy-logic in irrigation control. The goal of this research is to develop a fuzzy logic algorithm for improvement of irrigation controller system in agriculture. In this paper, we will implement an open loop and close loop fuzzy logic control system using both Mamdani and Sugeno control system. However, the two systems were compared. Simulation results therefore confirm that Sugeno fuzzy inference system is more effective than that of Mamdani fuzzy inference system. Moreover, multiple input parameters are also effective than fewer input parameters with regards to mamdani fuzzy inference system.

Keywords - FIS, fuzzy logic mamdani control system, fuzzy logic sugeno control system, matlab, smart irrigation

I. INTRODUCTION

Agriculture is the source of livelihood of many countries and it has major influence on the economies. Systematic way of water management is a priority concern in most cropping systems. Irrigation becomes extremely difficult in case of insufficient rainfall or in the dry seasons and therefore there is the need to be automated for good yield and saving water. Water is a basic need of life. Crops need exact amount of water, too much or too little will damage the growth of crops.

Food shortages are periodic problems which cannot be solved through rain-fed agricultural production alone. In most countries, food insecurity continues to emerge, not to mention the perennial water crisis. As demand for food escalates, more and more water will continue to be used in an attempt to relieve constant food shortages. Sustainable water resources are depleting and some regulatory mechanisms have to be put in place for water consumers. This means that the water use by the agriculture sector must be reduced to 33percent by the year 2025 [1]. This calls for more orderly use of water in irrigation. The irrigation efficiency, which was estimated at 27 percent in 1990, should rise to 54 percent to decrease water usage in irrigation by the year 2025 [1].

There are two main groups in which irrigation controllers are divided namely:

Open loop controller: With this type of controller, there is no error feedback from the controlled object. The time to start and time to end are determined by the user as well as pause intervals and watering periods. The set parameters are [2]:

- The duration for the irrigation session
- How often the irrigation period should repeat itself
- The quantity of water required in the irrigation

Closed loop controllers: They are the type of controllers that have a feedback combined with feed forward from the controlled object which has the tendency to determine the quantity of water the irrigation needs. Thus the quantity of water used for irrigation varies whenever the condition changes [2].

Irrigation Decisions for closed loop controllers are based on [3]:

- Observing the state variables
- Differentiating the state variables from the desired variables.
- Determining what actions are essentials to change the system state.
- Executing the necessary actions.

A closed control loop system is event-driven and hence responds automatically to climatic and environmental changes thereby achieving high level of irrigation efficiency [3].

Input parameters that are used by the system are:

- Relative humidity
- Temperature
- Sunshine Illumination
- Solar Irradiation
- Wind Speed

Output parameter is:

- Water pump rate

I.II Related Works

Koushik Anand et al conducted research on fuzzy logic for water saving in drip irrigation system in which the system optimized the usage of water and fertilizers based on soil humidity and temperature in the field. Water pipe valves were opened for duration of the time determined by fuzzy logic. The results showed that the system could quickly and accurately calculate water demand for amount of crops which provided a scientific basis for water-saving irrigation. The system also served as a method to optimized the amount of fertilizer used [4].

In [5], Muhammad et al used simple approach to Irrigation control problem using Artificial Neural Network (ANN) Controller. The proposed system was compared with ON/OFF controller and it was illustrated that ON/OFF Controller based System failed miserably because of its limitations. The limitations were continuous oscillation around the required soil moisture and unstable system due to continuous oscillations at the output. In a nutshell, ANN based technique resulted in execution of better and more efficient control possibilities in terms of conservation and energy and water. These controllers do not need an advance knowledge of system and have basic ability to adjust to the changing conditions as opposed to conventional methods. It was noted that ANN based systems saved lot of resources (energy and water) and provided optimized results to all types of agriculture areas.

In [6], Manish et al conducted research on the Automated Intelligent Wireless Drip Irrigation System Using Linear Programming which provided a real time feedback control system. This system was monitored and controlled all the activities of drip irrigation system efficiently and assisted in the efficient water management in order to gain more profit with less cost. Using this system, one can save manpower, as well as water to improve productivity and ultimately profit. In conclusion, it can be modified in a way that it can supply agricultural chemicals like calcium, sodium, ammonium, zinc to the field along with Fertilizers with addition of modern sensors and valves.

T. A. Izzuddin et al implemented irrigation using fuzzy logic method in which the irrigation optimizes water usage for agriculture. Open loop fuzzy logic control system was implemented using mamdani control system. Simulation was done using Matlab and Simulink. Results showed that fuzzy logic system was simulated correctly and that mamdani type of fuzzy logic control system optimizes water usage for crops [2].

Our proposed smart irrigation scheme will implement open loop control system and close loop fuzzy logic control system based on Mamdani and Sugeno control fuzzy inference system. It will be simulated in MATLAB and the results will be compared to find out which fuzzy inference system is the most effective.

II. THE PROPOSED MODEL

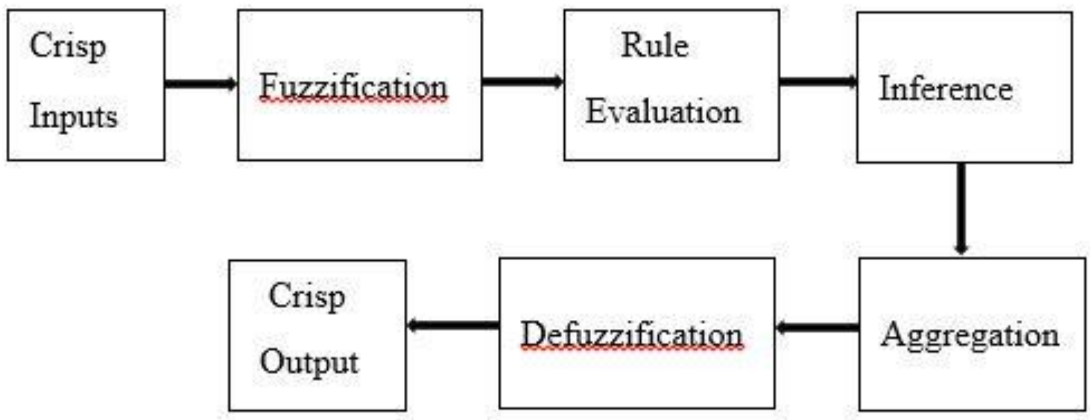

Figure 1 – Fuzzy Logic Controller Block Diagram

Figure 1 depicts Fuzzy Logic Controller block diagram. The vital unit of the Fuzzy Inference System is the fuzzy reasoning unit whose composition includes the rule base and data base. The stage of fuzzy translates or introduces inputs into real values whereby the rule base computes the output real values. The stage of defuzzification will transfer the output values into crisp output. Sugeno output is the crisp number found by multiplication of each value of input by constant value and finally adding up the two values. The advantages of using Sugeno method is that it could be used in case of mathematical analysis and is suitable for adaptive techniques [7].

II.I Proposed Fuzzy Logic Irrigation Controller Algorithm (FLIC)

The proposed fuzzy logic irrigation controller algorithm is presented whose aim is to improve the irrigation system in agriculture. For the irrigation system to take place effectively, five parameters would be considered as the input. These parameters are Temperature sensor (TEMP), Humidity sensor (HUM), Sunshine sensor (SSN), Solar Irradiation sensor (SIRAD) and Wind Speed sensor (WSD). In this proposed algorithm, a range of TEMP is taken to be 0 to 30 degrees Celcius (^{o}C), HUM varies from 0 to 80 percent (%), ILN varies from 0 to 10 candela (Cd), SIRAD varies from 0 to 30 watt per square metres (W/m^2) and WSD varies from 0 to 3 metres per second (m/s).

One parameter would be considered as the output and the parameter is Water Pump Rate (WAPMP). Also in this proposed algorithm, a range of water pump rate varies from 0 to 400 cubic metres per second (m^3/s).This algorithm will be implemented by setting up individual input and output parameters threshold for the irrigation.

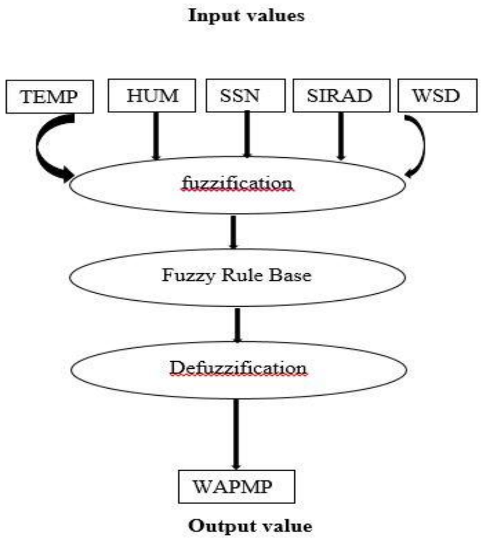

Figure 2 – Flow Chart of the Proposed Model

Crisp Input

The crisp inputs (temperature, humidity, sunshine, solar irradiation and wind speed) are the five signals fed into the system.

Fuzzification

This is a process in which crisp value is made fuzzy. In other words it represents the mapping from crisp value to a fuzzy set. The main aim of this step is the conversion of crisp values into fuzzy sets. Gaussian membership will be used since it improve the robustness and reliability of the system.

In this paper, input parameters will be described by three linguistic regions: ‘LOW’, ‘MEDIUM’ & ‘HIGH’ for temperature sensor, ‘DRY’, ‘MODERATE’ & ‘MOIST’ for humidity sensor, ‘DARK’, ‘NORMAL’ & ‘BRIGHT’ for Sunshine, ‘SHORT’, ‘MEDIUM’ & ‘LONG’ for radiation sensor and ‘SLOW’, ‘NORMAL’ & ‘FAST’ for wind speed.

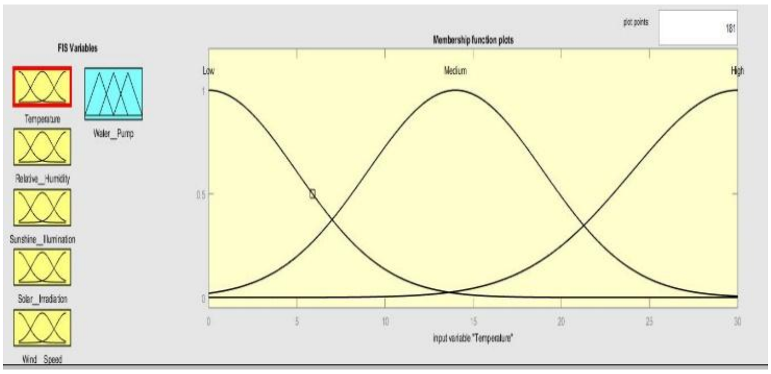

Figure 3 – Input Membership Function of Temperature using Mamdani Method

Table 1. Description of Input Variable Temperature using Mamdani Method

Serial Number	Temperature	Threshold (^oC)
1	Low	[0 14]
2	Medium	[0 14 30]
3	High	[14 30]

The universe of discourse for temperature is between 0 to 30 degrees Celsius and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 3 and Table 1.

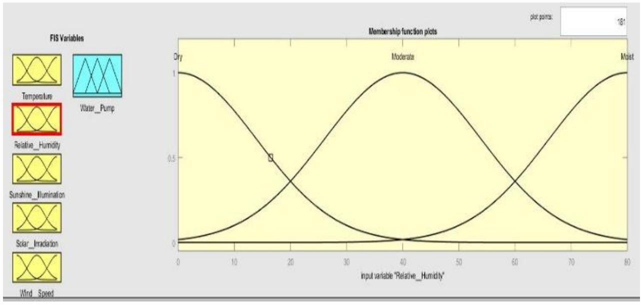

Figure 4 – Input Membership Function of Relative Humidity using Mamdani Method

Table 2 – Description of Input Variable Relative Humidity using Mamdani Method

Serial Number	Relative Humidity	Threshold (%)
1	Dry	[0 40]
2	Moderate	[0 40 80]
3	Moist	[40 80]

The universe of discourse for temperature is between 0 to 80 percent and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 4 and Table 2.

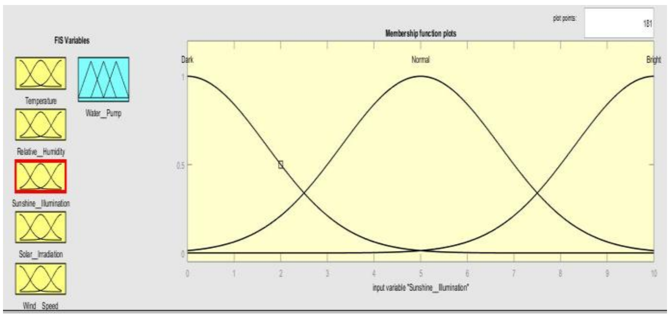

Figure 5 – Input Membership Function of Sunshine Illumination using Mamdani Method

Table 3 – Description of Input Variable Sunshine Illumination using Mamdani Method

Serial Number	Sunshine Illumination	Threshold (cd)
1	Dark	[0 5]
2	Normal	[0 5 10]
3	Bright	[5 10]

The universe of discourse for temperature is between 0 to 10 candela and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 5 and Table 3.

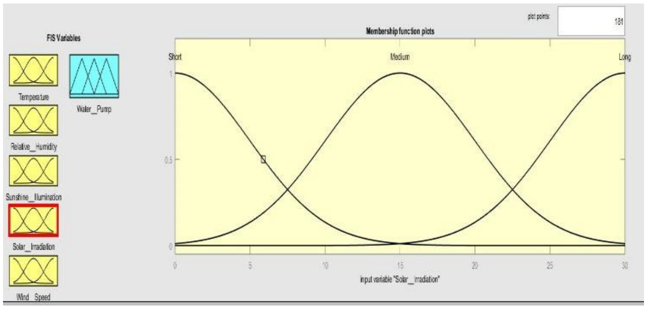

Figure 6 – Input Membership Function of Solar Irradiation using Mamdani Method

Table 4 – Description of Input Variable Solar Irradiation using Mamdani Method

Serial Number	Solar Irradiation	Threshold (W/m^2)
1	Short	[0 15]
2	Medium	[0 15 30]
3	Long	[15 30]

The universe of discourse for temperature is between 0 to 30 Watts per square meters and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 6 and Table 4.

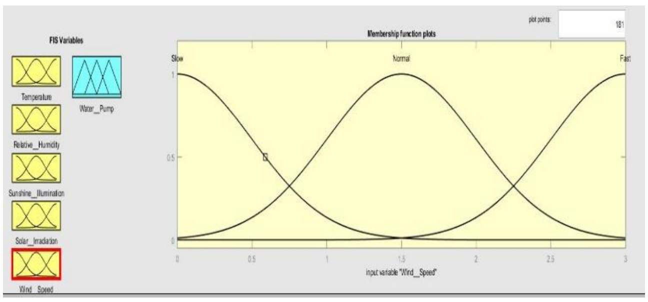

Figure 7 – Input Membership Function of Wind Speed using Mamdani Method

Table 5 – Description of Input Variable Wind Speed using Mamdani Method

Serial Number	Wind Speed	Threshold (m/s)
1	Slow	[0 1.5]
2	Normal	[0 1.5 3]
3	Fast	[1.5 3]

The universe of discourse for temperature is between 0 to 3 meters per second and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 7 and Table 5.

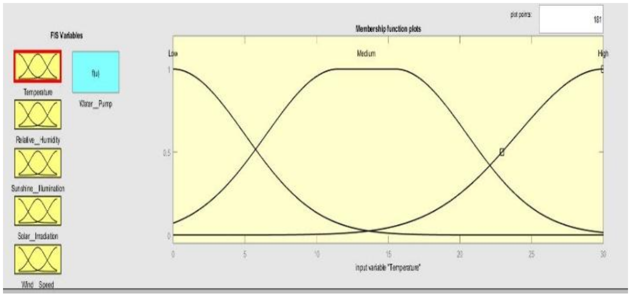

Figure 8 – Input Membership Function of Temperature using Sugeno Method

Table 6 – Description of Input Variable Temperature using Sugeno Method

Serial Number	Temperature	Threshold (^oC)
1	Low	[0 14]
2	Medium	[0 14 30]
3	High	[14 30]

The universe of discourse for temperature is between 0 to 30 degrees Celsius and the type of membership function is Gaussian 2 as denoted as gauss2mf that is illustrated in figure 8 and table 6.

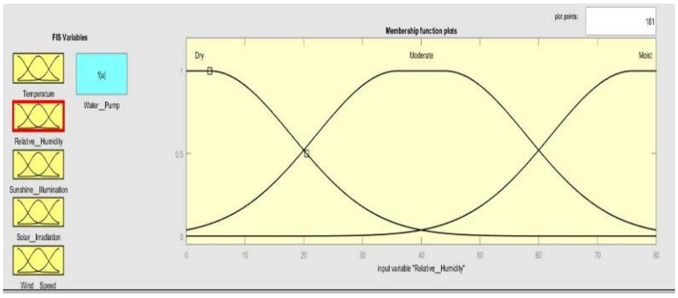

Figure 9 – Input Membership Function of Relative Humidity using Sugeno Method

Table 7 – Description of Input Variable Relative Humidity using Sugeno Method

Serial Number	Relative Humidity	Threshold (%)
1	Dry	[0 40]
2	Moderate	[0 40 80]
3	Moist	[40 80]

The universe of discourse for relative humidity is between 0 to 80 percent and the type of membership function is Gaussian 2 as denoted as gauss2mf that is illustrated in figure 9 and table 7.

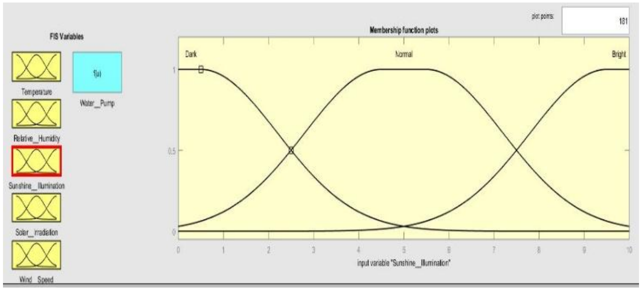

Figure 10 – Input Membership Function of Sunshine Illumination using Sugeno Method

Table 8 – Description of Input Variable Sunshine Illumination using Sugeno Method

Serial Number	Sunshine Illumination	Threshold (cd)
1	Dark	[0 5]
2	Normal	[0 5 10]
3	Bright	[5 10]

The universe of discourse for temperature is between 0 to 10 candela and the type of membership function is Gaussian 2 as denoted as gauss2mf that is illustrated in figure 10 and table 8.

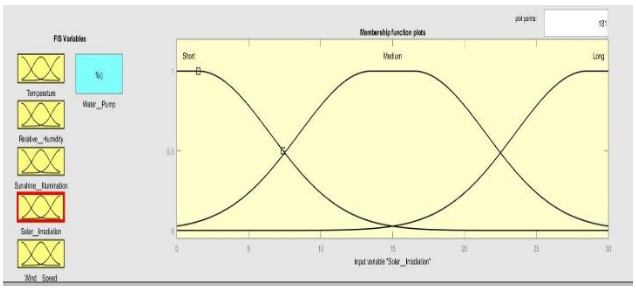

Figure 11 – Input Membership Function of Solar Irradiation using Sugeno Method

Table 9 – Description of Input Variable Solar Irradiation using Sugeno Method

Serial Number	Solar Irradiation	Threshold (W/m^2)
1	Short	[0 15]
2	Medium	[0 15 30]
3	Long	[15 30]

The universe of discourse for temperature is between 0 to 30 Watt per square meters and the type of membership function is Gaussian 2 as denoted as gauss2mf that is illustrated in figure 11 and table 9.

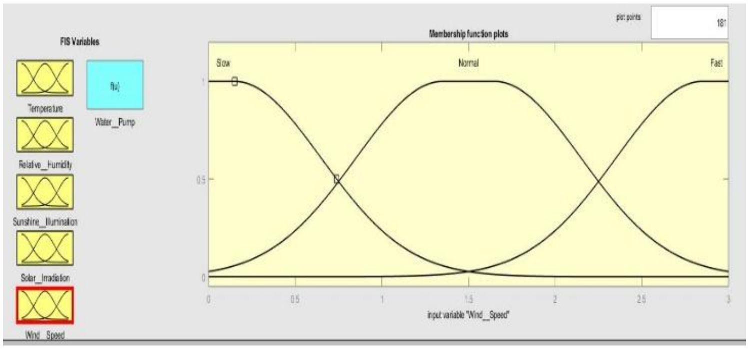

Figure 12 – Input Membership Function of Wind Speed using Sugeno Method

Table 10 – Description of Input Variable Wind Speed using Sugeno Method

Serial Number	Wind Speed	Threshold (m/s)
1	Slow	[0 1.5]
2	Normal	[0 1.5 3]
3	Fast	[1.5 3]

The universe of discourse for temperature is between 0 to 3 meter per seconds and the type of membership function is Gaussian 2 as denoted as gauss2mf that is illustrated in figure 12 and table 10.

Inference Engine and Rule Base

It consists of set of rules which would represent the knowledge base and the reasoning structure of the problem solution. The fuzzy engine would apply rules in the rule base to output a fuzzy value. The rule base has rules that are modelled based on knowledge and experience. For this problem, the number of input variables is five, each having three specific linguistic regions. Thus resulting number of rules will be 3^5 = 243 for the input parameters which is illustrated in figure 16:

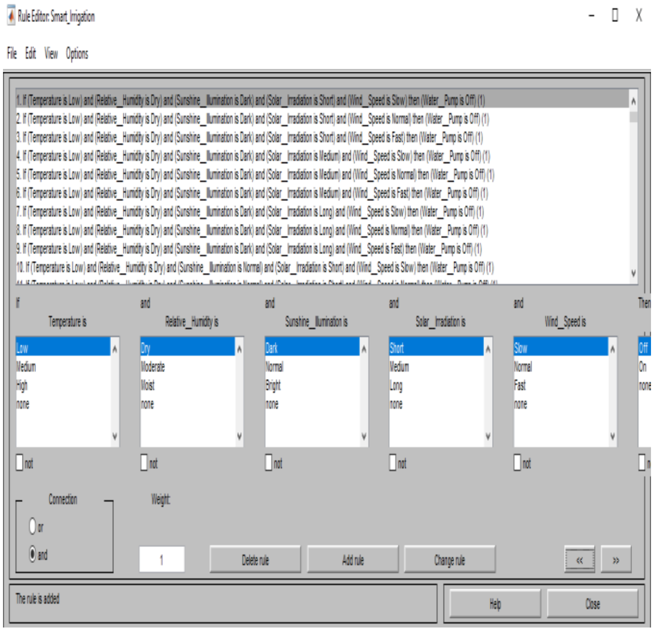

Figure 13 – If Then Rules

When designing an FLC, set of IF-THEN rules have to be defined that will represent mapping of input to output in the linguistic terms [8]. Such rules being extracted from operators experience. Mamdani and Sugeno method will be used in the development of the rules where the simulation will be done using MATLAB. Fuzzy inference will gather input values of temperature sensor, humidity sensor, wind speed sensor and solar irradiation sensor as the crisp inputs then assessing in accordance to interference rule base.

Figure 14 and 15 shows the fuzzy logic controller of smart irrigation system using both Mamdani and Sugeno method as shown below:

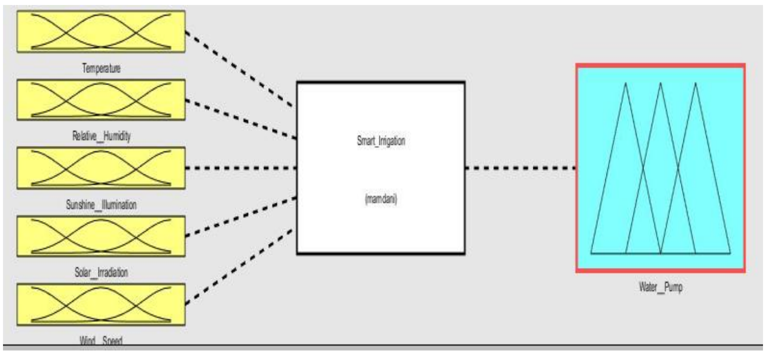

Figure 14 – Fuzzy Logic Controller of Smart Irrigation System using Mamdani Method in Matlab

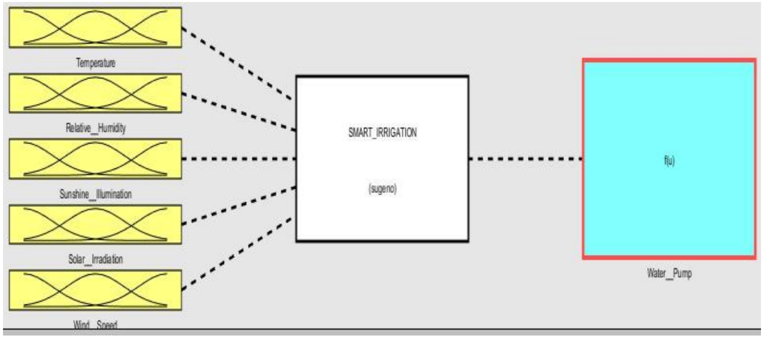

Figure 15 – Fuzzy Logic Controller of Smart Irrigation System using Sugeno Method in Matlab

Aggregation

The Mamdani method prescribes specific aggregation which is performed through computing center of gravity of each fuzzy set

Defuzzification

Output membership degree each for the linguistic regions as inputs to the Fuzzification process. The major objective of this process will be to convert output values to real numbers (back to crisp ouputs) using centroid and Suego uses wtaver.

Crisp Output

The crisp output is water pump rate.

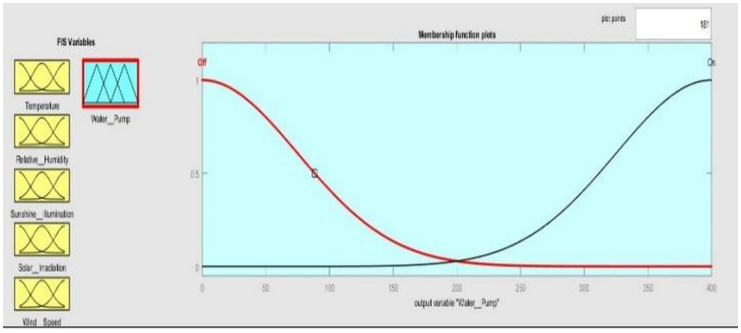

Figure 16 – Output membership function of Water Pump using Mamdani Method

Table 11 – Description of Output Variable Water Pump using Mamdani Method

Serial Number	Water Pump	Threshold (m^3/s)
1	Off	[0 200]
2	On	[200 400]

The universe of discourse for water pump rate is between 0 to 400 meter per seconds and the type of membership function is Gaussian as denoted as gaussmf that is illustrated in figure 16 and Table 11.

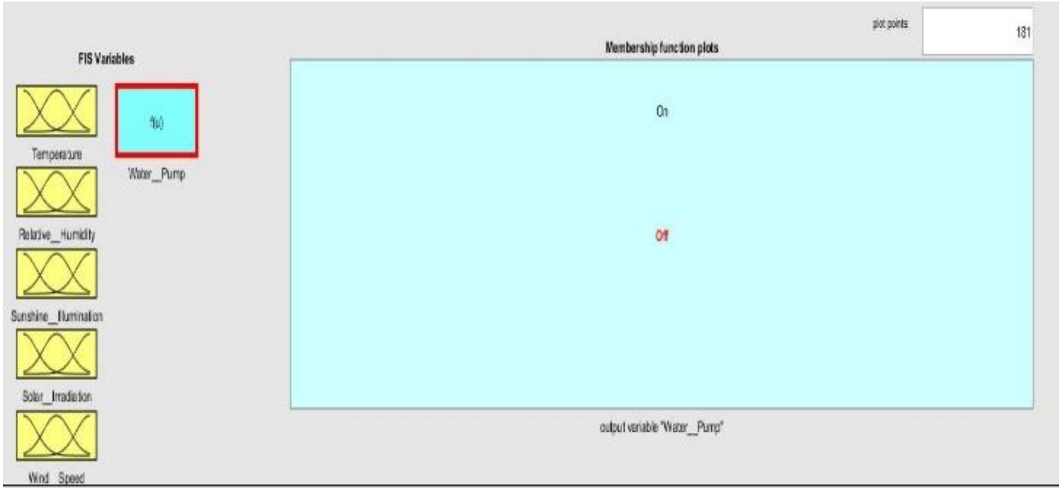

Figure 17 – Output Membership Function of Water Pump using Sugeno Method

Table 12 – Description of Output Variable Water Pump using Sugeno Method

Serial Number	Water Pump	Threshold (m^3/s)
1	Off	[0]
2	On	[400]

The universe of discourse for water pump rate is between 0 to 400 meter per seconds and the type of membership function is constant that is illustrated in figure 17 and table 12.

Fuzzy logic is an intelligent system that can be used in developing irrigation algorithms. The process of decision making is very important for irrigation system process to be successful. This research work will evaluate impact of fuzzy logic for irrigation system taking into consideration its parameters. This fuzzy logic will be used to compare and analyze the performance of the developed system.

III. RESULTS

Using Mamdani method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 18 below, the values of 28, 75, 9.5, 28 and 2.8 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is 328.

Figure 18 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are best using Mamdani Method

Using Mamdani method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 19 below, the values of 15, 40, 5, 15 and 1.5 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is 61.2.

Figure 19 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are average using Mamdani Method

Using Mamdani method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 20 below, the values of 2, 5, 0.5, 2 and 20.2 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is 55.4.

Figure 20 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are worst using Mamdani Method

Using Sugeno method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 21 below, the values of 28, 75, 9.5, 28 and 2.8 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is 399.

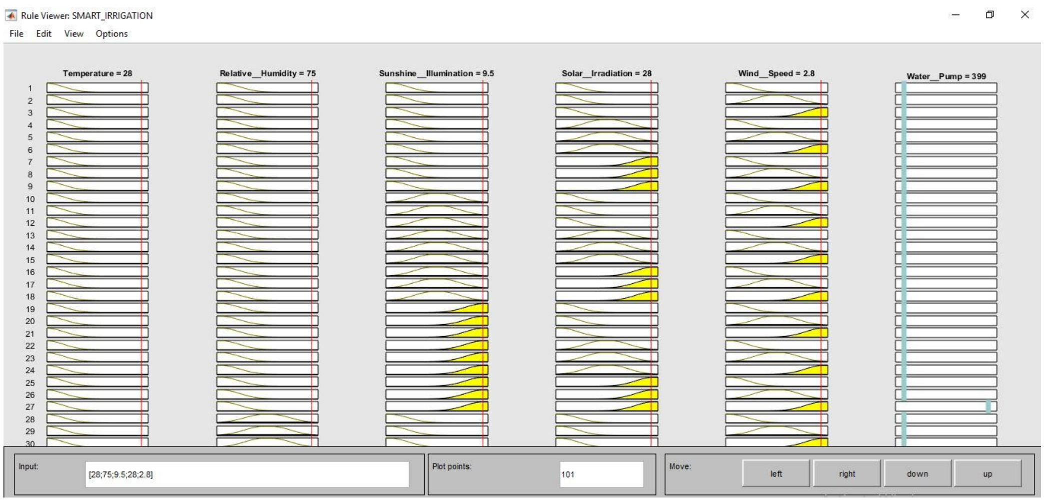

Figure 21 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are best using Sugeno Method

Using Sugeno method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 22 below, the values of 15, 40, 5, 15 and 1.5 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is 0.108.

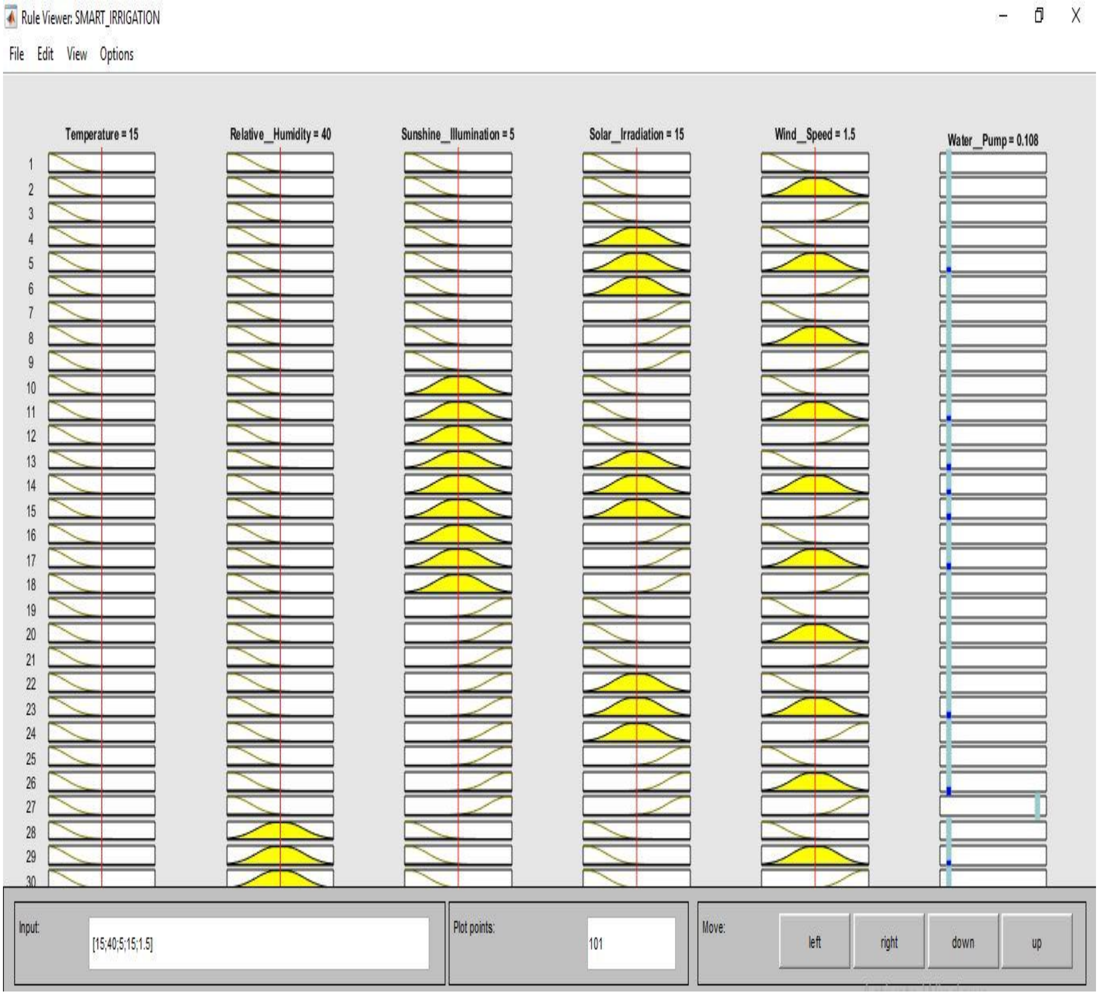

Figure 22 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are average using Sugeno Method

Using Sugeno method in Matlab, a set of crisp values have been applied to the fuzzy logic control system. In Figure 23 below, the values of 2, 5, 0.5, 2 and 0.2 have been applied to the input variables of temperature, relative humidity, sunshine illumination, solar irradiation and wind speed and the corresponding crisp output of the fuzzy logic on Water pump is $5.08{\times}10^{-14}$.

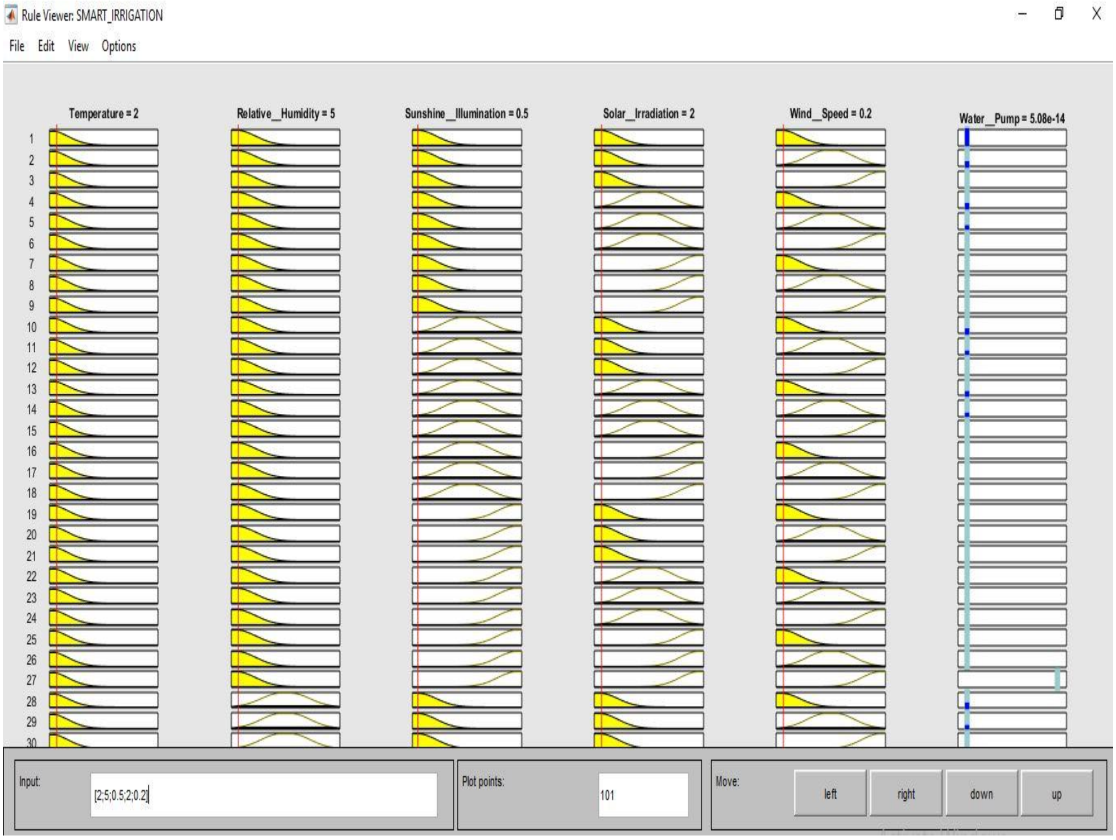

Figure 23 – Fuzzy Reasoning Rule table for threshold values when Crisp inputs are worst using Sugeno Method

The temperature and relative humidity vs water pump have been showed in Figure 24 using the “Surface” rule viewer in Matlab (Mamdani Method).

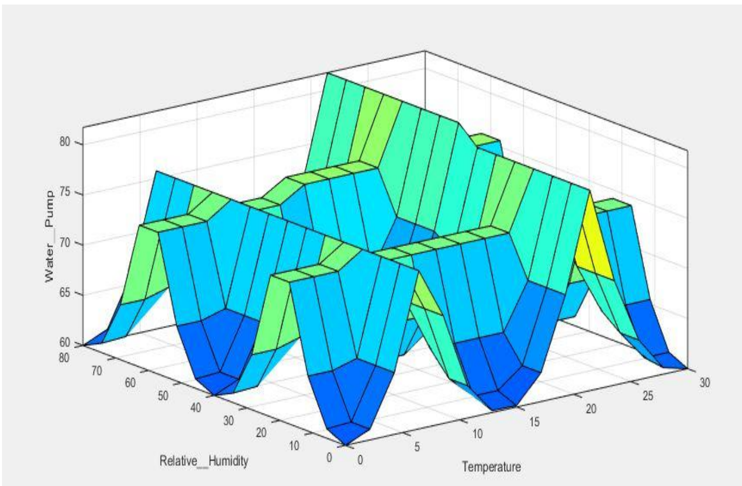

Figure 24 – Temperature and Relative Humidity vs Water pump using Mamdani Method

From figure 24, the threshold value is low that means off when the temperature and relative humidity decreases. The water pump has a low threshold of 60.

The temperature and relative humidity vs water pump have been showed in Figure 25 using the "Surface" rule viewer in Matlab (Sugeno Method).

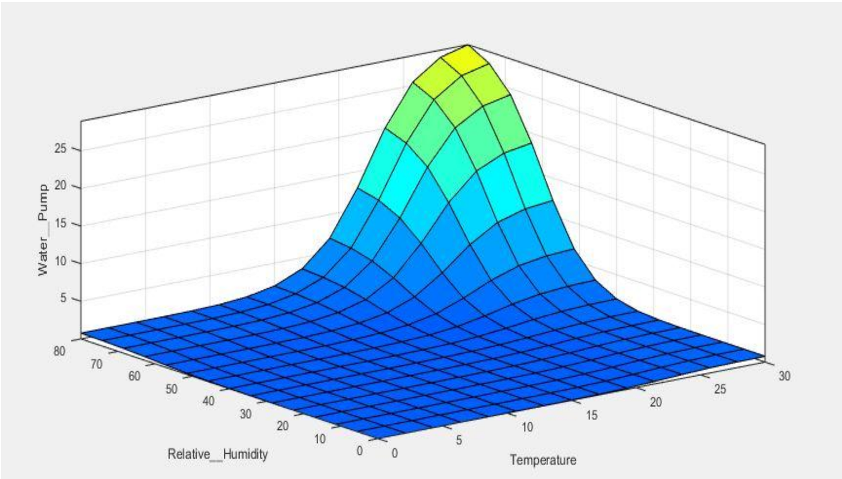

Figure 25 – Temperature and Relative Humidity vs Water pump using Sugeno Method

From figure 25, the threshold value is low that means off when the temperature and relative humidity decreases. The water pump has a low threshold of 1.

IV. DISCUSSION

First, the proposed system needs to make irrigation system more effective and reliable and that is why the input parameters such as temperature, relative humidity, sunshine illumination, solar irradiation and wind speed are used to control the water pump to improve the optimization of water to the crops. The system will then calculate the irrigation thresholds using the five input parameters and the table 4.1 will also summarize the thresholds in details.

Table 13 Comparison of Mamdani & Sugeno method results

I/O Parameters	Temperature	Relative Humidity	Sunshine Illumination	Solar Irradiation	Wind Speed	Water Pump (Mamdani)	Water Pump (Sugeno)
Best	28	75	9.5	28	2.8	328	399
Average	15	40	5	15	1.5	61.2	0.108
Worst	2	5	0.5	2	0.2	55.4	5.08×10^{-14}

For the proposed system to be at its best, the temperature should have a threshold of 28, relative humidity to be 75, sunshine illumination to be 9.5, Solar irradiation to be 28, Wind Speed to be 2.8 for the input parameters. At least, three of the input parameters should be at its best to enable the water pump to be turned on. When temperature is high, relative humidity is moist, Sunshine Illumination is bright, Solar irradiation is long and wind speed is fast, the water pump will turn on with a threshold value of 328 and 399 using mamdani and sugeno in figure 21 and figure 24 respectively .

For its average, the temperature should have a threshold of 15, relative humidity to be 40, sunshine illumination to be 5, Solar irradiation to be 15, Wind Speed to be 1.5 for the input parameters. Therefore, when temperature is medium, relative humidity is moderate, Sunshine Illumination is normal, Solar irradiation is medium and wind speed is normal, the water pump will turn off with a threshold value of 61.2 and 0.108 using mamdani and sugeno in figure 22 and 25 respectively.

For its worst, the temperature should have a threshold of 2, relative humidity to be 5, sunshine illumination to be 0.5, Solar irradiation to be 2, Wind Speed to be 0.2 for the input parameters. Therefore, when temperature is low, relative humidity is dry, Sunshine Illumination is dark, Solar irradiation is short and wind speed is slow, the water pump will turn off with a threshold value of 55.4 and 5.08×10^{-14} using mamdani and sugeno in figure 23 and 26 respectively.

Comparing the values gain by T.A Izzudin et al that is for its average, its temperature was 29.8, relative humidity was 62 and illumination was 215, it gave a water pump output of 72 taking into consideration temperature range from 0-100, humidity range from 0-100 and illumination range from 0-500. The ranges was on a high side and if the ranges was on the low side, the water pump output would be low than 61.2 and this shows that the efficiency of multiple input parameters are effective than fewer input parameters.

Comparing the threshold value for the water pump with respect to Mamdani and Sugeno method in figure 27 and 28, we found out that the water pump is more effective with the Sugeno type of method using the surface rule viewer.

V. CONCLUSION

An efficient irrigation system has been proposed. This paper was on the smart irrigation system using fuzzy logic method to enable the system to be more reliable and effective taking into account its input parameters and membership functions. The main objective of this work was to develop a fuzzy logic algorithm controller to improve irrigation system in agriculture.

The results from this paper showed that the possible way to improve the efficiency of irrigation system is by comparing the two types of fuzzy inference system. It was reported from this paper that sugeno type of fuzzy inference system is effective and reliable than mamdani fuzzy inference system taking into consideration the number of input parameters. The proposed algorithm has also been tested using matlab and it has proven to be more effective in terms of optimization of water usage for crops.

In a future study, another method of fuzzy inference system must be used taking into consideration real climatic data from meteorological agency

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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