

Differentiation of Mamdani and Sugeno Fuzzy Inference System in developing Automatic Plant Watering Systems for Domestic Use

Kartik Singhal, Rani Medhashree, Ranganath M. Singari

Abstract: Water management systems are an essential requirement for maintaining plants. One of the major problems encountered in growing plants in houses, offices or buildings with in-house kitchen gardens is irregular irrigation patterns. This leads to over irrigation of pots or elongated durations of dry soil, both conditions ill for plant growth. This problem is further aggravated when manual irrigation ignores the environmental conditions and plant specific requirements. Utilizing Fuzzy logic for developing Automatic Plant watering systems provide flexibility in manipulating input parameters such as Temperature, Humidity, Soil Moisture and Plant Growth to determine optimum flow rate of the irrigation system. In this study, multiple fuzzy systems are developed for different environments and parameters. MATLAB is used for designing the fuzzy logic controllers using both Mamdani and Sugeno Models. The requirement for the system is to adjust the flow rate in accordance with the environmental conditions and plant requirements. The paper draws comparison between Mamdani and Sugeno methods on the basis of their performance characteristics for different environments. It also provides development of an effective controller for a watering system for household plantations.

Keywords : MATLAB, Fuzzy logic, micro-irrigation, Mamdani and Sugeno Systems, House plants, Smart irrigation systems.

I. INTRODUCTION

Micro-irrigation is a low-pressure, low-flow-rate type of irrigation that can reduce the likelihood of overwatering a landscape. This form of irrigation delivers water directly to where it is needed most-the root zone of plants [1]. Micro-irrigation is a preferred method for house plants as it does not require heavy equipment and is relatively easier to manage. One of the major impediments in maintaining houseplants is inconsistent irrigation practices. Plant requirements, evapotranspiration cycles and soil capacity are often ignored when different species of plants are grown together and irrigation is done manually. Some plants like cacti require watering only once or twice in a fortnight period, while some of the climbers or vegetables require water more regularly. Apart from the frequency of irrigation, water required for improved plant growth and maintaining soil quality also varies. In this study, a fuzzy logic based controller is developed for automating irrigation systems, which determines the flow rate by assessing the input data collected

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from Sensors using Arduino microcontroller board. The output of the controller is flow rate of water pump. The following inputs are utilized: Soil moisture, Air humidity, Temperature, Plant maturity, Plant type, Soil Type. The input parameters are gauged for three different environments: Indoor conditions, Outdoor conditions (exposed environment) and Kitchen Garden. The systems are developed for both Mamdani and Sugeno Models to determine the better inference system for given conditions. Finally, Arduino Mega2560 Microcontroller is used to implement FLC, collection of data and control of water pump (using Pulse Width Modulation).

II. FUZZY SYSTEM DESIGN

Fuzzy Logic varies from Boolean Logic in the sense that instead of discrete True (1) or False (0) values it takes various degrees of variables in between 0 and 1. Membership functions are defined for the respective variables and a “degree of association” is assigned to the inputs. Fuzzy logic controllers are used in a wide ranging applications such as facial pattern recognition, air conditioners, washing machines, vacuum cleaners, anti-skid braking systems, control of subway systems and unmanned helicopters, knowledge-based systems [2].

Fuzzy Control Systems are highly suitable for applications with the following characteristics [3]:

1. Processes with ambiguous specifications,
2. Processes with large number of adjustable and interdependent variables,
3. Processes controlled by a human operator or designed to mimic humans,
4. Processes with unreliable or sensor data as input;

The following components make up a Fuzzy System Design [4]:

Inputs: Crisp values are taken as input variables for a Fuzzy Logic System (FLS). These values are preprocessed before being fed to the system. Examples of methods of preprocessing are-

1. Quantization in connection with sampling or rounding to integers;
2. Normalization or scaling onto a particular, standard range;
3. Filtering in order to remove noise;
4. Averaging to obtain long term or short term tendencies;

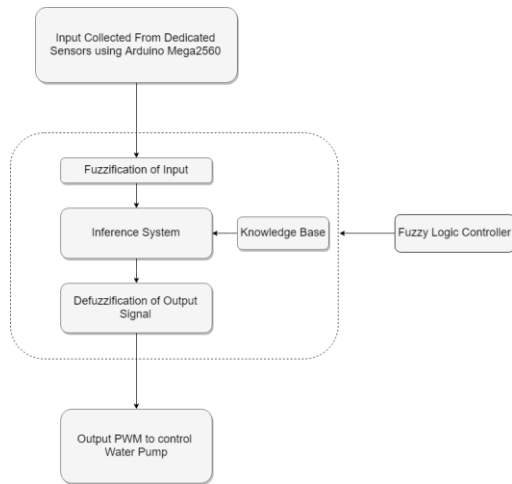


Figure 1: Description of the Fuzzy Controller

Fuzzification: The first step in an FLS is fuzzification of crisp data by associating them with defined membership functions. Each value is converted to a degree of membership function(s). In fuzzy sets elements are assigned a degree, such that the transition from membership to non-membership is gradual rather than abrupt.

Rule Base: Linguistic variables are developed to map the input parameters with the output value. These rules make up the Knowledge base.

Inference System: For each rule, the inference engine looks up the membership values in the condition of the rule. The rules determine how the system computes the input provided to the system to deduce a relevant output fuzzy set.

Defuzzification: The output received from the Inference System is in the form of fuzzy sets. To provide usable or human readable value defuzzification is important. The conversion of fuzzy set values into crisp values is the process of Defuzzification.

Method of Defuzzification: Mamdani and Sugeno systems differ in a way in how they perform defuzzification of fuzzy values. In the case of Mamdani Systems, the preferred method of defuzzification is the Centroid Method. In case of Sugeno Systems, the utilized method is weighted average.

III. PROPOSED SYSTEM

In the following experiment, Fuzzy system is simulated for 3 different environments, i.e. Indoor conditions, Outdoor

Air Humidity		Plant Maturity		Temperature		
S.no	Description	Params	Description	Params	Description	Params
1	Low Air Humidity	[-25 0 25]	Seedling	[20 0]	Cold	[-15 -5 5 15]
2	Medium Air Humidity	[10 35 60]	Budding	[30 50]	Normal	[5 10 20 25]
3	High Air Humidity	[45 70 95]	Matured	[20 100]	Warm	[15 25 35 45]
Soil Moisture		Output Sugeno System		Output Mamdani System		
S.no	Description	Params	Description	Params	Description	Params
1	Very Dry Soil	[-20 0 20]	Close	0	Close	[-45 -5 5 15]

conditions, Kitchen Garden. For each environment, both Mamdani and Sugeno inference systems are developed and compared to determine the suitable approach. The systems are evaluated on the basis of their responses to input parameters, quality of response graphs obtained, and their effective operation over the *universe of discourse* of inputs fed to the system. A system is considered usable if its response is effectively comparing maximum input parameters individually to the rules developed for the knowledge base. In an irrigation system, the plant takes varying quantities of water at different stages of plant growth. Unless the adequate and timely supply of water is assured, the physiological activities taking place within the plant are bound to be adversely affected, thereby resulting in reduced yield of the crop [5]. The parameter taken into account for this study impact two requirements from the system: frequency of irrigation, dependent upon the evapotranspiration losses and the amount of water given to plant per water cycle, which is dependent upon the Soil Moisture and plant requirements.

For the development of Knowledge Base following assumptions are taken into consideration: i) As the temperature increases, flow rate should also increase, ii) As Air Humidity % increases, flow rate should decrease, iii) water required is more as plant maturity increases, iv) If Soil Moisture % is: in normal range, flow rate is moderate; in saturated range, flow rate is closed or very slow; in dry range, flow rate is high. For Outdoor and Indoor conditions the following input parameters are used: **Plant Maturity, Air Humidity, Soil Moisture and Temperature**. The output parameter is the **Flow Rate** (0 - 100). The Input parameters Plant Maturity and Soil Moisture have same ranges (also, *the universe of discourse*) for both Outdoor and Indoor conditions. The Input Parameters Air humidity and Temperature have different ranges and associated membership functions under different conditions.

3.1 Indoor Conditions -

Indoor Conditions are simulated for closed environments such as living rooms, the membership functions and corresponding parameters for input values are the same for both Mamdani and Sugeno Systems.

2	Dry Soil	[0 15 30]	Partially Close	25	Partially Close	[0 20 40 60]
3	Normal Soil	[20 45 70]	Partially Open	75	Partially Open	[40 60 80 100]
4	Wet Soil	[60 75 90]	Fully Open	100	Fully Open	[85 95 100 105]
5	Saturated Soil	[70 90 110]				

Table 1: Description and Parameters for Input and Output Variables used in Indoor Conditions

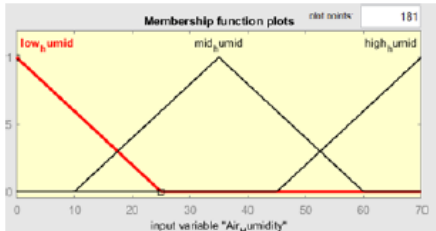


Fig 2: MF for Air Humidity

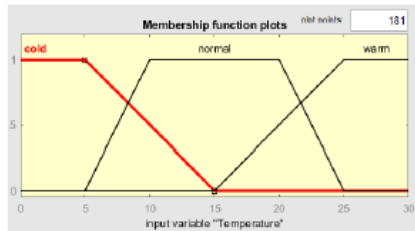


Fig 3: MF for Temperature

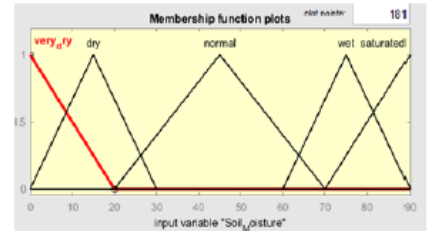


Fig4: MF for Soil Moisture

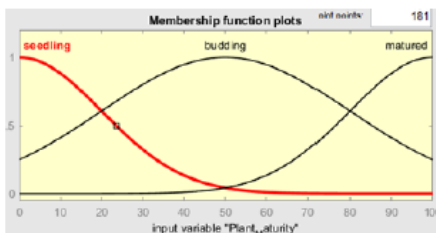


Fig 5: MF Plant Maturity

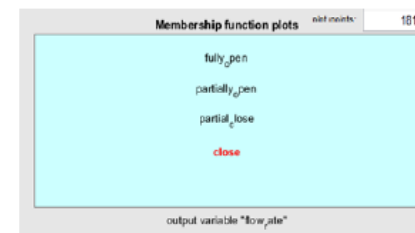


Fig 6: MF for Output Sugeno

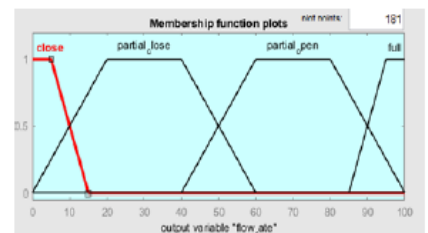
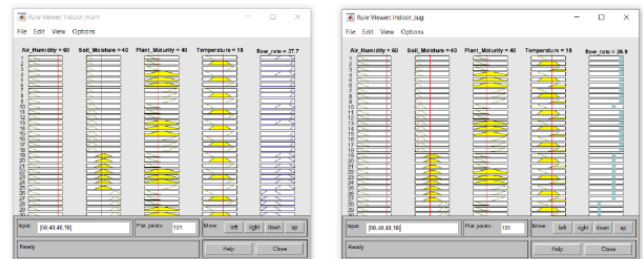
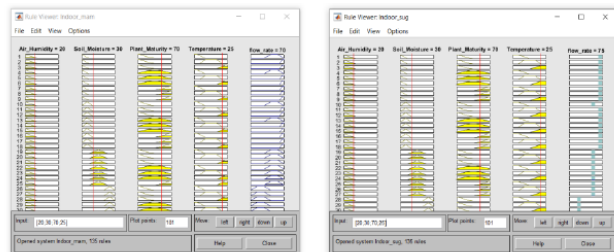


Fig 7: MF for Output Mamdani

Simulations and Results for Indoor Conditions

Both Mamdani and Sugeno System’s Inference Engine utilizes **135** rules to determine the output flow rate for different values of input parameters. Similar Set of Crisp Values is used for both systems.



The Following Graphs shows surface when Output (Flow Rate) is plotted against respective Input Variables.

CASE 1: Input Values: Air Humidity= 20%, Soil Moisture = 30%, Plant Maturity = 70%, Temperature = 25 C.

The following data is obtained(Fig 8):

1. From Mamdani Inference System the flow rate is observed to be 70%.
2. From Sugeno Inference System the flow rate is observed to be 75%.

CASE 2: Input Values: Air Humidity= 60%, Soil Moisture= 40%, Plant Maturity= 40%, Temperature= 18 C.

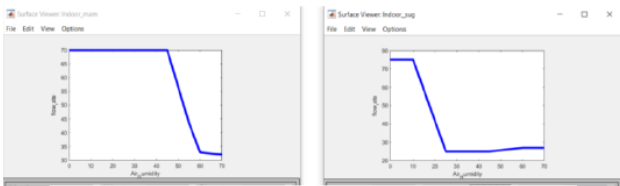
The following data is obtained (Figure 9):

1. From Mamdani Inference System the flow rate is observed to be 37.7%
2. From Sugeno Inference System the flow rate is observed to be 26.9%

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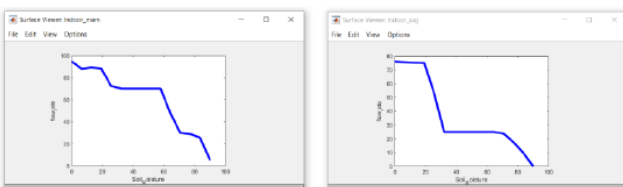
Comparison of the plots obtained for Air Humidity vs Soil Moisture vs Flow Rate (Figure 10).



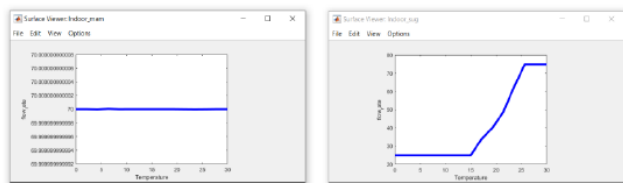
Comparison of the plots obtained for Air Humidity vs Flow Rate (Figure 11).



Comparison of the plots obtained for Plant Maturity vs Flow Rate (Figure 12).



Comparison of the plots obtained for Soil Moisture vs Flow Rate (Figure 13).



Comparison of the plots obtained for Temperature vs Flow Rate (Figure 14).

For the Four Inputs - One Output Indoor conditions environment, both Mamdani and Sugeno Inference Systems have performed with similar results. The following distinction between the systems is observed: the Sugeno system responds to the whole range of flow rate control, i.e., [0 100], while in Mamdani system the lowest possible value obtained is 5.14% and the maximum value is 94.9%. Both Mamdani and Sugeno systems have produced similar curves with respective individual parameters, except in the case of **Temperature vs Flow Rate** graph.

3.1 Outdoor Conditions -

Outdoor Conditions are simulated for exposed environments, the membership functions and corresponding parameters for input values are the same for both Mamdani and Sugeno Systems.

		Air Humidity		Plant Maturity		Temperature	
S.no	Description	Params	Description	Params			
1	Low Air Humidity	[-30 0 30]	Seedling	[20 0]	Cold	[-10 -5 10 15]	
2	Medium Air Humidity	[10 40 70]	Budding	[30 50]	Normal	[7.5 15 22.5 30]	
3	High Air Humidity	[50 80 110]	Matured	[20 100]	Warm	[22.5 27.5 37.5 42.5]	
		Soil Moisture		Output Sugeno System		Output Mamdani System	
S.no	Description	Params	Description	Params	Description	Params	
1	Very Dry Soil	[-20 0 20]	Close	0	Close	[-10 -5 10 20]	
2	Dry Soil	[0 15 30]	Partially Close	25	Partially Close	[10 25 40 55]	
3	Normal Soil	[20 45 70]	Partially Open	75	Partially Open	[45 60 85 100]	
4	Wet Soil	[60 75 90]	Fully Open	100	Fully Open	[80 90 105 110]	
5	Saturated Soil	[70 90 110]					

Table 2: Description and Parameters for Input and Output Variables used in Outdoor Conditions



Fig 15: MF Plant Maturity

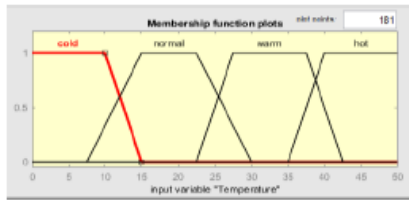


Fig 16: MF for Temperature

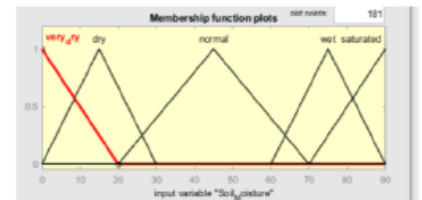


Fig 17: MF for Soil Moisture

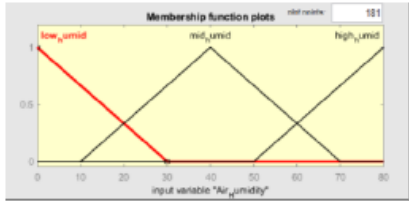


Fig 18: MF for Air Humidity

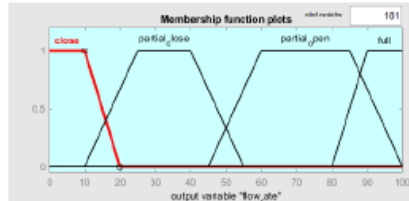


Fig 19: MF for Output Mamdani



Fig 20: MF for Output Sugeno

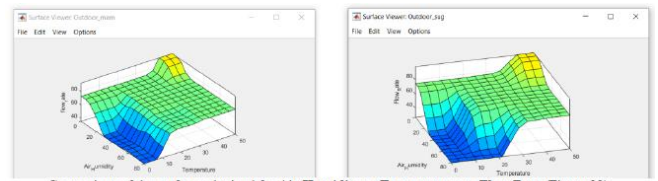
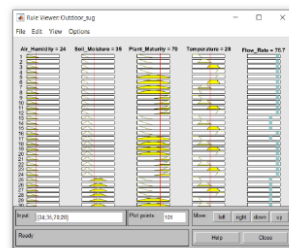
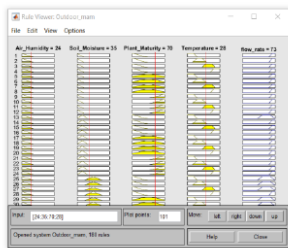
Simulations and Results for Outdoor Conditions

Both Mamdani and Sugeno System's Inference Engine utilizes **180** rules to determine the output flow rate for different values of input parameters. Similar sets of crisp values are fed to the Fuzzy logic Controller to find the result for different cases.

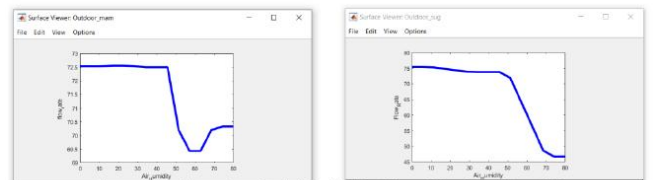
CASE 1: Input Values: Air Humidity= 24%, Soil Moisture = 35%, Plant Maturity = 70%, Temperature = 28 C.

The following data is obtained (Figure 21):

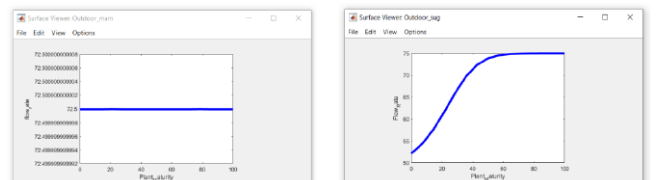
3. From Mamdani Inference System the flow rate is observed to be 73%.
4. From Sugeno Inference System the flow rate is observed to be 76.7%.



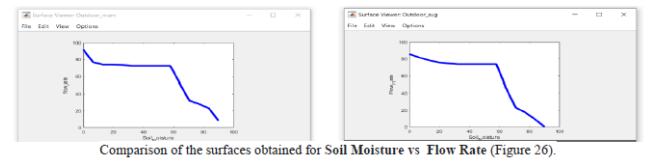
Comparison of the surfaces obtained for Air Humidity vs Temperature vs Flow Rate (Figure 23).



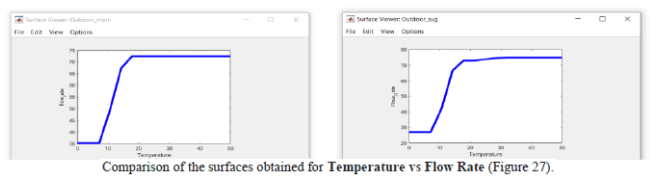
Comparison of the surfaces obtained for Air Humidity vs Flow Rate (Figure 24).



Comparison of the surfaces obtained for Plant Maturity vs Flow Rate (Figure 25).



Comparison of the surfaces obtained for Soil Moisture vs Flow Rate (Figure 26).

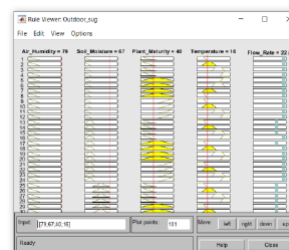
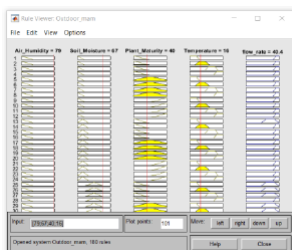


Comparison of the surfaces obtained for Temperature vs Flow Rate (Figure 27).

CASE 2: Input Values: Air Humidity= 60%, Soil Moisture= 40%, Plant Maturity= 40%, Temperature= 18 C.

The following data is obtained (Figure 22):

3. From Mamdani Inference System the flow rate is observed to be 40.4%.
4. From Sugeno Inference System the flow rate is observed to be 22.6%.



For the Four Inputs - One Output Outdoor conditions environment, both Mamdani and Sugeno Inference Systems perform with similar results. It should be noted that the difference in output from both systems is now more distinctive than observed in Indoor Conditions. Similar surfaces are observed in both Mamdani and Sugeno Systems except for the following distinction: The Sugeno system responds to the whole range of flow rate control, i.e., [0 100], while in Mamdani system the lowest possible value obtained is 7.58% and the maximum value is 92.5%. Again (as observed with Indoor



conditions) the flow rate does not entirely stop or reaches its full capacity in Mamdani System.

3.3 Kitchen Garden Conditions-

The input conditions for a kitchen garden environment are different than the conditions for the previous two environments. Here five input parameters are utilized to effectively compute a single output function: flow rate. This is done to provide more adaptable irrigation system for different varieties of plants, i.e., Roots, Solanum family plants, fruits and vegetables. Input Parameter Soil Type affects the water holding capacity of the soil and thus, in turn, regulates the amount of water required per irrigation cycle. Different Crop Types require different soil conditions to grow. Thus adjusting the flow rate in accordance with the Soil type - Plant type combination is also a challenge that will be addressed in this system design. The input parameters are:

1. Crop Type,
2. Soil Type,
3. Soil Moisture,
4. Air Humidity,
5. Temperature;

The following tables show the relationships between the irrigation requirements for different climatic conditions, plant and soil types. This data is utilized for developing the knowledge base - rules for the inference engine and to determine input parameters.

	More Irrigation Required	Less Irrigation Required
Climate	Hot, dry, windy (Calm, cool, humid (low evaporative)

	high evaporative)	
Plants	Shallow-rooted, complete ground cover	Deep-rooted, healthy plants, incomplete ground cover
Soil	shallow, coarse-textured	Deep, fine textured

Table 3: Based on Drip Irrigation for Row Crops, University of California, Davis

Soil Texture	Water holding Capacity (inches/foot of soil)
Coarse Sand	0.25 - 0.75
Fine Sand	0.75 - 1.00
Sandy Loam	1.25 - 1.40
Clay Loam	1.20 - 1.70
Silty Clay Loam	1.80 - 2.00

Table 4: The following Table shows the Water-holding Capacity for different textures of Soil

The membership functions and corresponding parameters for input values are the same for both Mamdani and Sugeno Systems.

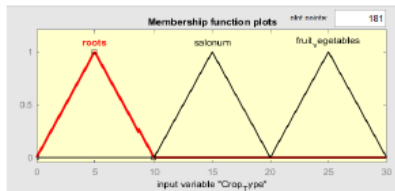


Fig 28: MF for Crop Type

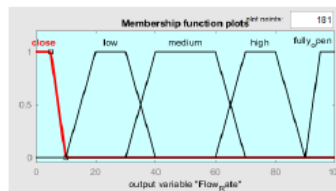


Fig 29: MF for Mamdani

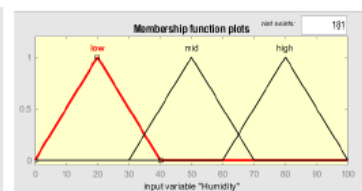


Fig 30: MF for Humidity



Fig 31: MF for Output Sugeno

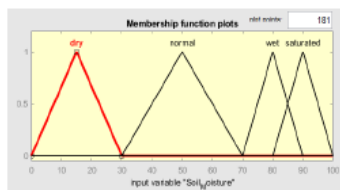


Fig 32: MF for Soil Moisture

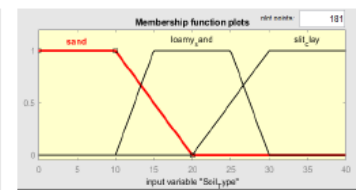


Fig 33: MF for Soil Type

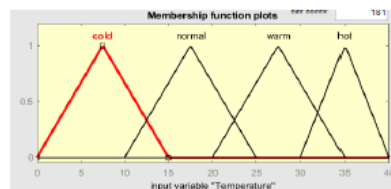


Fig 34: MF for Temperature

Air Humidity			Crop Type		Soil Type	
S.no	Description	Params	Description	Params	Description	Params
1	low	[0 20 40]	Roots	[0 5 10]	Sandy	[-10 0 10 20]
2	mid	[30 50 70]	Solanum Family	[10 15 20]	Loamy Sand	[10 15 25 30]
3	high	[60 80 100]	Vegetables and Fruits	[20 25 30]	Silt Clay	[20 30 40 50]
Soil Moisture			Output Sugeno System		Output Mamdani System	
S.no	Description	Params	Description	Params	Description	Params
1	Dry	[0 15 30]	Close	0	Close	[-10 -5 10 20]
2	Normal	[30 50 70]	Partially Close	25	Partially Close	[10 25 40 55]
3	Wet	[70 80 90]	Partially Open	75	Partially Open	[45 60 85 100]
4	Saturated	[80 90 100]	Fully Open	100	Fully Open	[80 90 105 110]
Temperature						
S.no	Description	Params	S.no	Description	Params	
1	Cold	[0 7.5 15]	3	Warm	[20 27.5 35]	
2	Normal	[10 17.5 25]	4	Hot	[30 35 40]	

Table 5: Description and Parameters for Input and Output Variables used in Kitchen Garden Conditions

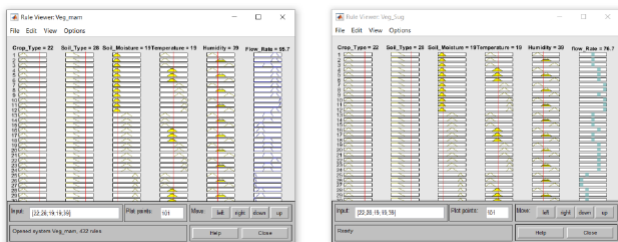
Simulations and Results for Kitchen Garden

Both Mamdani and Sugeno System’s Inference Engine utilizes **432 Rules** to determine the output flow rate for different values of input parameters. Similar sets of crisp values are fed to the Fuzzy logic Controller to find the result for different cases.

CASE 1: Input Values: Crop Type= 22, Soil Type = 28, Soil Moisture = 19%, Temperature = 19 C, Humidity= 39%.

The following data is obtained (Figure 36):

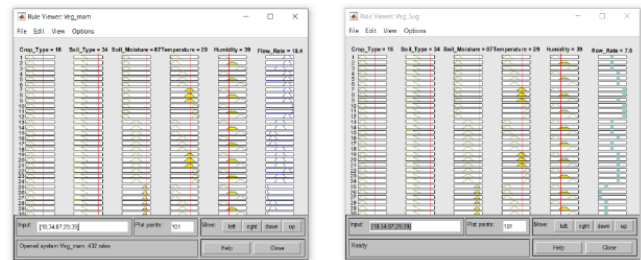
1. From Mamdani Inference System the flow rate is observed to be 95.7%.
2. From Sugeno Inference System the flow rate is observed to be 76.7%.



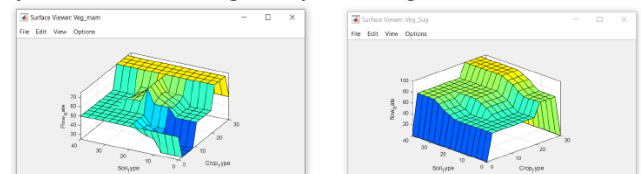
CASE 2: Input Values: Crop Type= 18, Soil Type = 34, Soil Moisture = 87%, Temperature = 29 C, Humidity= 39%.

The following data is obtained (Figure 37):

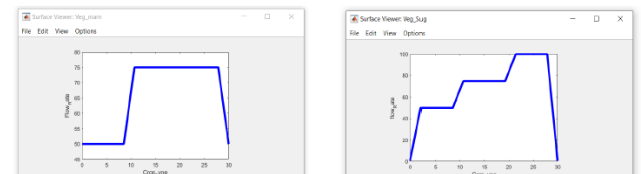
1. From Mamdani Inference System the flow rate is observed to be 18.4%.
2. From Sugeno Inference System the flow rate is observed to be 7.5%.



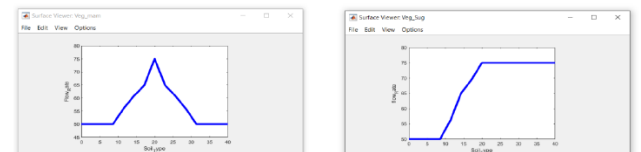
The following Graphs shows the trend observed when input parameters are plotted against the flow rate in Mamdani Systems (left) and Sugeno Systems (right).



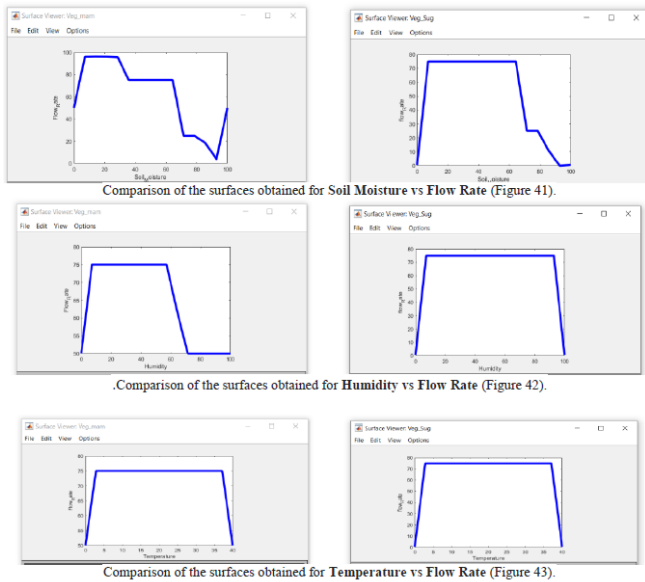
Comparison of the surfaces obtained for Soil Type vs Crop Type vs Flow Rate (Figure 38).



Comparison of the surfaces obtained for Crop Type vs Flow Rate (Figure 39).



Comparison of the surfaces obtained for Soil Type vs Flow Rate (Figure 40).



IV. CONCLUSION

It should be noted that for the first two simulations, both Mamdani and Sugeno systems are comparable in computing input variables. From the simulations conducted for Kitchen Garden Conditions, it is observed that performance characteristics for Sugeno Inference Engine are better than Mamdani Inference Engine when multiple parameters and a more complex knowledge base are taken into consideration. In this case, 432 rules were developed (as compared to 135 & 180 rules developed for previous 2 simulations). In development of Fuzzy Logic Controllers, one or more input variables can be assigned more weight than the others to improve the system for a specific implementation. This can be done to improve the application of the system if one or more parameters are more prominent for decision making than the others. In the first two cases mentioned in this paper, both Mamdani and Sugeno systems have provided similar output values for required flow rate, yet Mamdani systems have lacked in a sense as they do not provide full range of flow at saturated conditions which is not a suitable feature. In the third Simulation, Mamdani system produced output flow rate of 95.7% (maximum output from this system) with average Input conditions. Thus it can be inferred that the system will not be adequately responsive for the input values that fall at high extreme side of the current input conditions. This behavior makes the proposed Mamdani system unreliable for kitchen garden conditions. By referring to the respective surfaces produced in the Graphical Rule Viewer, it can be concluded that Sugeno system for the given conditions and inputs is proved to be a better choice as it provides continuous operative characteristics. This is an essential feature for smooth working of controller and to prevent abrupt behavior when input (collected from sensor data) is varied.

V. FUTURE WORK

Our aim with this study is to prevent both extreme conditions of drying of soil or over flooding while maintaining an optimum irrigation routine as per the environmental requirements which seemed to be fulfilled with the proposed systems here. Fuzzy logic Controllers can efficiently support

the development of small scale garden irrigation systems. This can help in automating irrigation routines. The methodology followed in this paper required manual development of a large knowledge base in accordance to combinations of considered environmental conditions to establish a knowledge base for the Inference engine. This can be a repetitive process when multiple simulations are taken into account. In further studies, the real time data (external conditions & water pump flow rate) accumulated from sensors for these experiments can be utilized to develop improved fuzzy based controllers by studying the actual behavior of the irrigation system with environmental changes with the help of Adaptive Neuro-Fuzzy Inference Systems. This will also assist by eliminating redundant variables and the need of manually developing a large number of rules required. The most important development from this can be reducing the memory usage by microcontroller and increased efficiency of the fuzzy system for Automatic Plant Watering System.

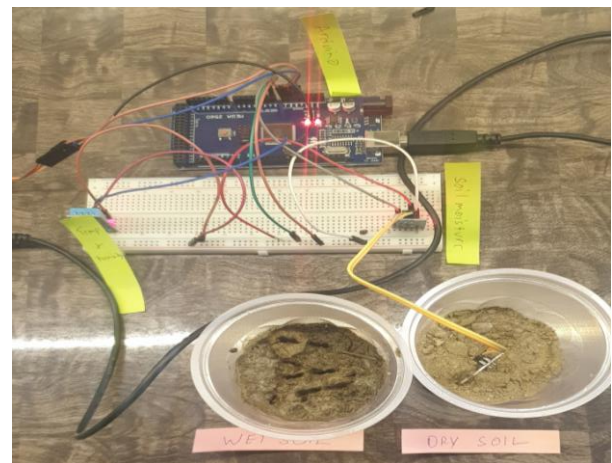


Fig 44: The fuzzy logic controller is implemented on Arduino Mega2560 Board

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