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A Smart Irrigation System Using IoT and Fuzzy Logic Controller

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***Abstract*— As the world's population grows, so does its demands for resources and efficient ways of managing production against the rapidly depleting resources. Agriculture is the leading sector in water usage and wastage at the same time, due to inefficient irrigation techniques. In fact, poor mitigation techniques in cases of excessive irrigation has led to a slump in production rates. This paper aims to propose an Internet of Things based irrigation system that works at reducing the frequency of irrigation while increasing the rate of production through the use of fuzzy logic. The system consists of a Mamdani fuzzy controller that acquires environment identifiers i.e. soil moisture and outside temperature through specific sensors, then applies fuzzy rules to control water flow from the water pump and produce irrigation appropriate time and frequency. The fuzzy controller is designed and implemented using MATLAB.**

Keywords—Fuzzy modelling, fuzzy inference systems, Internet of Things, irrigation management, water stress, climate change

I. INTRODUCTION

In what is labelled as the "Global Water Crisis", UN and the World Bank released predictions of scarcity of clean water resources and as a corollary, the calamitous effect on agriculture as the demand increases, what now with extended periods of hot weather and droughts [1]. Inevitably, the effect will ripple over across the quality of life people lead in areas with direct contact to the cultivated lands as well as areas who depend marginally on them to supply their food production. The world's demand for water is likely to surge in the next few decades where rapidly growing population will drive increased consumption by people, farms, and companies. Water availability of regions naturally liable to dryness like the Arabian Peninsula are expected to drop by half in the next 25 years [2,3].

Rather unsurprisingly, efforts to restrict excessive watering and water demand control have been made and include raising the price to pose such restrictions. However, while this helps conserve water when resources are depleting, it does pose a challenge to farmers on how to micromanage their business to adapt to this change. To add to that, climate change is expected to make some areas drier and others wetter, making the need for proper efficient irrigation management systems all the more necessary[4].

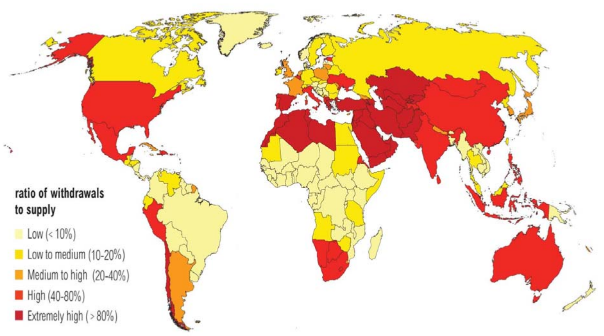

Fig. 1 Water Stress by Country 2040 [2]

Agriculture remains the worlds biggest water consumer, with farming and food production accounting up to 70% of it [2,5]. With so much water going into the sector, one would expect an over-abundance of water resources dedicated to agriculture. However, one of the largest contributors to water wastage is low irrigation efficiency. Currently, and according to the UN Food and Agriculture Organization (FAO), an astonishing 60 % of the water diverted or pumped for irrigation is wasted via runoff into waterways or evapotranspiration [3,4,5]. This has derived a high demand for intelligent irrigation systems that are capable of providing efficiency that is unobtainable without adequate data analysis and suitable implementation strategies. Such smart systems are based on the Internet of Things technology (IoT) which will largely depend on data-driven automated signals. These signals are generated and received by components; sensors and actuators, controlled by wired and wireless connections such as IEEE 802.15.4, IEEE 802.11 [6,7,8].

The paper is organized as follows: section II reviews a survey of the recent existing research activities on IoT based smart irrigations and fuzzy decision support systems. The system model will be presented in section III. The experimental results and analysis are detailed in section IV followed by the conclusion.

II. RELATED WORKS

IoT is a general concept for the ability of network devices to feel and collect data from the world around us, and then share that data across the Internet where it can be processed and applied for several interesting purposes. Whereas other technologies center on evolving previous services or providing ease of use and ergonomic products, IoT prioritizes optimization above all, with optimization techniques being critical to the success of any of its systems [8,9]. Several studies have been conducted on utilizing IoT technology as well as fuzzy inference systems in the field of agriculture. The use of such systems aims at achieving higher yield and overall improved quality of products. In [10] a proposed system developed to measure weather condition values and use these values to calculate the required water quantity for irrigation. Another system architecture is proposed in [7] that evaluates a cloud-based wireless communication system that can be also used to monitor and

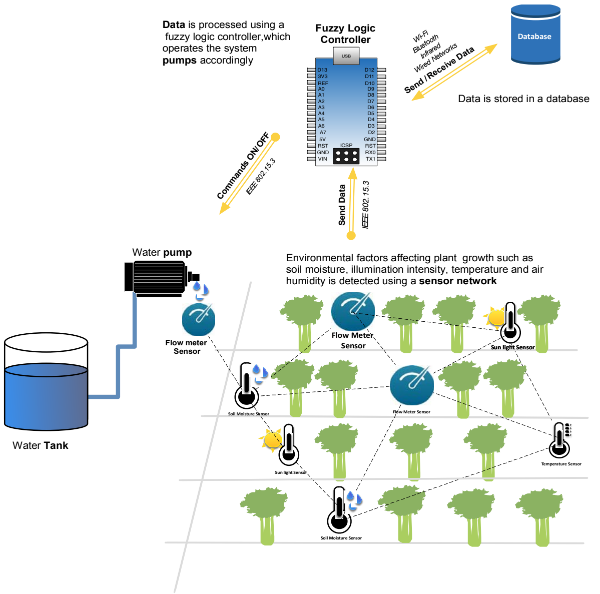

Fig. 2 The design of the Irrigation System

control a set of sensors and actuators to assess the plants water need. Providing decision support system will facilitate irrigation in a controlled manner, where areas with less water content are highlighted and alternatively areas with large water content will less likely to be adversely irrigated, maintaining soil moisture at even levels all across the land targeted. Many studies have discussed irrigation systems using conventional feedback control systems such as open-loop and closed-loop control systems [12,13,14]. However, and in order to tackle the real uncertainty and the complexity of the environmental conditions, fuzzy theory is used to improve the ability to make correct decisions [15]. Fuzzy set theory and fuzzy logic provide a powerful method to represent and process human knowledge in the form of fuzzy "IF-THEN" rules, that can be then translated into a form of a controller. Thus, fuzzy logic controllers like Mamdani Controller are simpler than other traditional controllers since they are closer to human thinking and natural language[16].

III. System Model

The system architecture of the smart irrigation system is shown in Fig. 2. Composed of five components, the smart irrigation system is implemented by a series of actions taken by each of the individual components, first of which is a network of sensors to record environments variables, a control unit and a communication media. The use of IOT technology will facilitate the communication between the soil and the water flow controller.

A. Sensors and Communication Media

Five sensors were used to log the environment variables, namely, light intensity, LM 393 soil moisture, DHT11 temperature and air humidity. Other sensors such as flow meter sensors are used to ensure optimize irrigation frequency to a minimum value by moderating the rate of water flow during the day or night time. Data acquired by sensors is processed by the microcontroller and IEEE 802.15.4 is used as the communication media between the systems components.

B. Fuzzy Controller for water pump

Mamdani's fuzzy inference technique is the most generally utilized fuzzy approach used in fuzzy controllers. Mamdani's strategy was one the most important control frameworks constructed utilizing fuzzy set theory. It was found in 1975 by Ebrahim Mamdani as an attempt to control a steam engine and heater blend by integrating an arrangement of linguistics control rules acquired from experienced human administrators. Mamdani's technique depended on Lotfi Zadeh's 1973 paper on fuzzy calculations for complex frameworks and choice procedures. Mamdani-type deduction utilizes piecewise linear membership functions; triangular fuzzy numbers (TFN) and trapezoidal fuzzy numbers (TrFN) as appeared in Fig. 3.
The common way to specify a TFN in analytical form is displayed in equation 1 below:

$$\mu_{\mathrm{TFN}}(x;a_1,a_2,a_3)=\begin{cases}0, & x\le a_1\\ \dfrac{x-a_1}{a_2-a_1}, & a_1<x\le a_2\\ \dfrac{a_3-x}{a_3-a_2}, & a_2<x\le a_3\\ 0, & x>a_3\end{cases} \qquad (1)$$

The common way to express the general form for a TrFN is displayed in equation 2 below:

$$\mu_{\mathrm{TrFN}}(x;a_1,a_2,a_3,a_4)=\begin{cases}0, & x\le a_1\\ \dfrac{x-a_1}{a_2-a_1}, & a_1<x\le a_2\\ 1, & a_2<x\le a_3\\ \dfrac{a_4-x}{a_4-a_3}, & a_3<x\le a_4\\ 0, & x>a_4\end{cases} \qquad (2)$$

In this paper, a Mamdani fuzzy controller is used to control water flow from the water pump. There are two inputs for this controller, soil moisture and outside temperature, and one output which is the water flow from the water pump. The fuzzy controller is designed and implemented using MATLAB. The Controller is shown in the Fig. 4.

In order to control the water flow from the pump a rotary switch is used. The switch range is from zero to five; where zero means no water flow and five is the maximum flow. The idea is to control the position of this switch automatically based on the inputs. In order to build the fuzzy control system that will control the water flow to a desired level, we would need to define two inputs; the first one is the soil moisture (SM) and the second one is the outside temperature (TE). These two inputs will be used to control the water flow by automatically changing the switch position in the water pump.

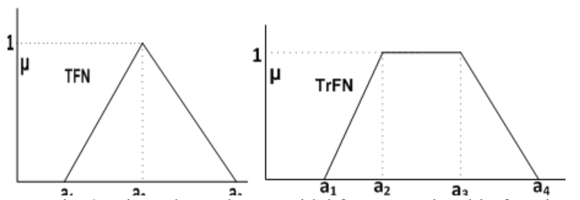

Fig. 3 Triangular and trapezoidal fuzzy membership functions

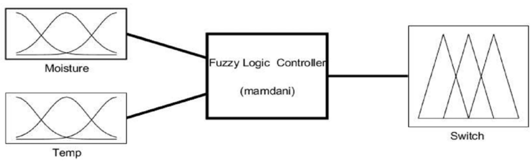

Fig. 4 Fuzzy Logic controller for the water pump

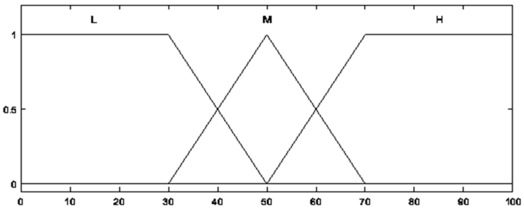

Fig.5 Fuzzy relation for the first input (R_{SM})

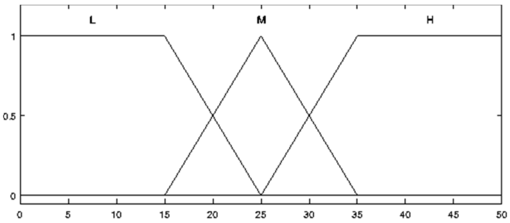

Fig. 6 Fuzzy relation for the second input (R_{TE})

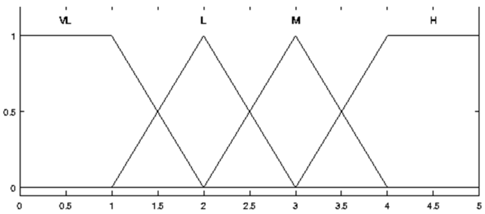

Fig. 7 Fuzzy relation for the output (RSctl)

For instance, if the soil moisture is low, and the temperature is high ,then the switch position need to be set to maximum flow. However, if the moisture is medium and the temperature is high, we want to set the switch half way between zero and five. The two inputs are continuously monitored using the sensors, and the output status is adjusted accordingly. Now, we need to build our control system based on the Mamdani fuzzy logic inference system. In this case the switch position will be defined by linguistic levels rather than numerical values, so a zero or off position will be very low and half way position will be medium. The inputs for the robot speed control in fuzzy terms are defined as:

$t_{SM} = t_{TE}$ = {L, M, H}
where:
SM: soil moisture
TE: outside temperature
t_{SM}: fuzzy terms for SM
t_{TE}: fuzzy terms for TE
L: low, M: medium, H: high

The output in fuzzy terms will be:
t_{SW} = {VL, L, M , H ,VH}
where:
VL: very low
L: low
M: medium
H: high

TABLE I: FUZZY RULES FOR THE WATER FLOW CONTROLLER

		t_{SM}		
	$Y_{Sctrl}(t_{SM},t_{TE})$	***L***	***M***	***H***
t_{TE}	***L***	H	L	VL
	M	H	L	VL
	H	H	M	VL

The switch output, Y_{Sctl} = [0,5] which includes all the real numbers between zero and five. Fuzzy relations (R) has been used for the inputs based on TrFN membership functions for the low and the High and TFN for the medium:

For R_{SM} →	For R_{SC} →
L:(0,0,30,50)	L:(0,0,15,25)
M:(30,50,70)	M:(15,25,35)
H:(50,70,100,100)	H:(25,35,50,50)

And for the output (switch) TrFN membership functions were used for the (VL,H) and TFN membership function were used for the (L,M):

For R_{Sctl} →
VL: (0,0,1,2)
L:(1,2,3)
M:(2,3,4)
H:(3,4,5,5)

These fuzzy relations for the inputs and the output for the fuzzy controller are shown in figures (5-7). The fuzzy rules for the flow controller are designed to be as shown in table I, using these fuzzy rules the output of the Controller Y_{Sctl} will be changed to fuzzy linguistic terms. The logic we used in this table is based on the knowledge of what we want the water flow to be based on the moisture and the temperature (inputs). The range for the first input is [0-100] and for the second input is [0-50]. The values for these inputs are continuously measured using sensors, and the output position (switch) is changed based on this logic. There is a total of nine rules; table I can also be expressed as a set of rules as shown in table II.

The proposed water flow controller is based on Mamdani Fuzzy inference system which consists of four steps:

- Fuzzification of the inputs: the input is transformed from numerical value into linguistic term. To do that, we can use the membership function for the triangular fuzzy numbers with substituting the right values for a_1, a_2, a_3.
  After this step, the input will look something like
  SM′ = 0.6/L + 0.3/M …etc.
- Fuzzification of the output: the output is calculated from the inputs in terms of fuzzy linguistics term. In this step, the output in fuzzy linguistic terms will be something like: Sctl′ = 0.4/L + 0.2/M
- Transfer the fuzzy subset of the set of linguistic terms for the output to a fuzzy subset of the set of numerical values. In order to do that, we need to use fuzzy composition using the Max-Min Rule. Expressing the max-min Rule as it relates to our specific speed control design, we could write the following:

TABLE II: LINGUISTICS RULES

Rule No.	Fuzzy Input 1 (SM)	Operator	Fuzzy Input 2 (TE)	Fuzzy Output (t_{sw})
1	L	and	L	H
2	L	and	M	H
3	L	and	H	H
4	M	and	L	L
5	M	and	M	L
6	M	and	H	M
7	H	and	L	VL
8	H	and	M	VL
9	H	and	H	VL

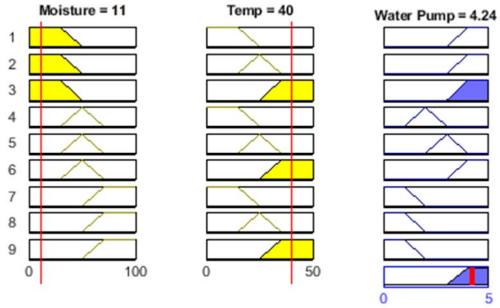

Fig. 8 The switch output for Water flow controller when (SM=11, TE= 40)

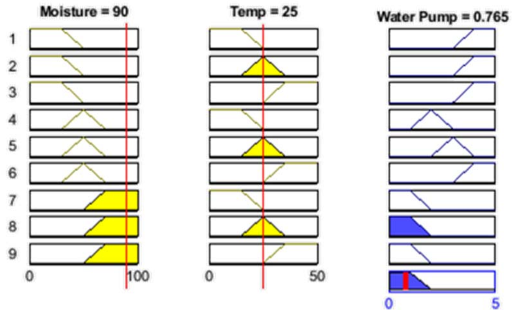

Fig. 9 The switch output for Water flow controller when (SM=90, TE= 25)

$$\mu_{Y''} = \text{Max } \{\text{Min } [\ \mu_{Y'}(t),\ \mu_{Y'}\ \text{It},\ y)]\};$$
$$\text{for all } y \in\ Y\ S_{ctl} \qquad (3)$$

In our design for the output Y_{Sctl} takes all the real numbers [0, 5].

- Defuzzification: Transforming the fuzzy set of the output in one numerical value, which can be estimated using the central of gravity method:

$$Sctl=\sum_{y=a}^{b}\frac{Y\times\mu_{Y''}}{\mu_{Y''}\ dY} \quad ;$$

Sctl: is the control switch position (4)

In this step, we multiply the membership value that we got from the last step by each output value and find the summation. Afterwards, we divide this sum by the sum of all the output value by assuming that the estimated output is integer between a and b. If the output is the set of all the real numbers between a and b, we have to do integration instead of the summation in the formula mentioned above. MATLAB is employed for this calculation, since the numbers we use in our speed ccontrol design are all real numbers between 0 and 5.

IV. Experimental Results and Analysis

In this paper, the Fuzzy controller for controlling the speed of a robot was built using Mamdani inference system as discussed earlier. The two inputs SM and TE were used to control the switch position (VL, L, M, H). MATLAB was used to build the fuzzy Controller. The output of the speed controller will be the switch position and it is given as a numerical value from zero to five, with zero being the lowest and five means that the switch is set to the maximum position (highest water flow). Two outputs of the MATLAB program for the flow Controller are shown in figure (8-9).

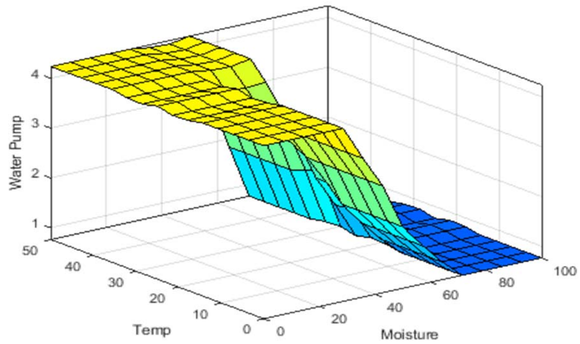

Fig. 10 Relationship between the inputs and the output for the fuzzy controller

From Fig. 8, when the soil moisture is low (11%) and the temperature is High (40ºC) then the output of the controller was (4.27) which means the water flow will be high. Also, in Fig. 9 when the soil moisture is high, then the output of the water flow very low (0.765) which means that the switch is set close to the minimum, and this again agrees with our fuzzy rule table, since the output is expected to be very low in this case. The relationship between the two inputs (soil moisture and temperature) is shown also in the MATLAB surface plot in Fig. 10. It can be seen from this surface plot the when the moisture is low then the water flow in the pump is high (yellow color), and when the moisture is high then the water flow is very low (blue color).

V. Conclusion

Fuzzy logic and IoT technology were presented as a strategy to develop an intelligent irrigation approach that fosters water conservation and better irrigation management in areas with high levels of water stress. The developed fuzzy controller, based on Mamdani fuzzification using trapezoidal and triangular membership functions, efficiently set the time and duration of irrigation for a given crop. The use of fuzzy control helped maintaining the soil moisture above a pre-set value with smooth variations preventing frequent system's run-off and preserving water and energy. In order to monitor system in real time, a wide-range ZigBee based wireless network was also used. The system is easy to implement. And economically justifiable.

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