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Optimizing irrigation for boosting gynura procumbens growth in Malaysia urban area

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ABSTRACT

Growing herbs traditionally could not meet the increasing demand for high medicinal value herbs in the pharmaceutical industry and domestic market. One of the solutions is by growing herbs using vertical structures in urban areas. Even so, the amount of water needed to optimise the growth of Asian local perennial herbs in vertical structures is yet to be explored. Hence, this paper investigated the performance of a fuzzy based irrigation method in optimising irrigation for boosting the local perennial herb growth. The understudy local perennial herb is gynura procumbens. The decision-making for irrigation relies on the data given by soil moisture, temperature, and humidity sensors. The performance of the proposed system is compared with a timer-based system, in terms of plant growth rates, given by average leaves diameter, height, and plant crown of local perennial herbs. The results have shown that the proposed intelligent irrigation system has reduced water consumption by 16.93% and the average plant growth rate has increased by at least 1.5% and to a maximum rate of 76.64%.

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1. INTRODUCTION

Asian local perennial herbs have high medicinal value and these herbs have great potential in the pharmaceutical industry [1]. In 2013, a group of researchers claimed that the domestic market value for herbs had reached billion dollars [2]. Thus, increasing herb yield is essential to meet the swiftly growing demand, which can be achieved via increasing sufficiency in food commodities, which means that farming can be executed anywhere, including in urban areas. However, it is laborious to perform urban farming in a conventional approach due to high operational expenses and lack of agricultural land. One of the solutions for this problem is to grow herbs in vertical structures due to the optimisation of limited land space. The other main concern is water consumption during irrigation, as excessive or deficient water supply may greatly affect plant growth. Hence, a smart mechanism for performing irrigation is needed.

To date, the smart irrigation method is one of the fast-growing technologies in which efficient utilisation of water in irrigation artificial intelligent (AI) algorithms for better yield quality and quantity [3], [4]. Fuzzy logic is among the commonly used AI methods for smart irrigation due to accurately measure the amount of water needed by crops that allow water saving and optimise crop quality [5]. Nevertheless, the effectiveness of the fuzzy logic classifier in controlling irrigation for herbs grown vertically in the urban area in Malaysia has not been explored yet. Hence, this paper proposed a smart mechanism of controlling irrigation, in which the decision-making is performed based on the environmental parameters in the urban area. The performance of the proposed system is compared with a conventional system, where the comparison is in terms of plant growth rates. The rest of the paper is organised as shown in. Section 2 presents related works and the proposed method for this study is presented in section 3. The performance of the proposed system is analysed in section 4, followed by conclusions and further studies in the last section.

The evolution of the irrigation systems includes the utilisation of machine learning algorithms and among all algorithms, the fuzzy logic algorithm has gained high popularity in real-time irrigation management. This is due to the potential of fuzzy logic to locate a sufficient amount of water at the particular time needed by plants [6]. The algorithm decides irrigation based on the data given by sensors and logical rules set by the user, in which the rules were designed based on the input from expertise and experiments [7], [8]. The efficiency of the fuzzy logic technique for controlling irrigation was also discussed in [9], [10]. Alfin and Sarno [9] used the fuzzy estimation approach to evaluate and control soil moisture content in the sugarcane industry. The authors showed that the fuzzy model provides quantitatively a precise amount of water required by sugarcane farms. Krishnan *et al.*, [10] Krishnan *et* al. proposed a fuzzy-based irrigation system that provides real-time humidity and temperature. The authors claimed that the proposed system consumed less water and low power. Alomar and Alazzam [11] used a fuzzy approach to reduce the irrigation frequency and increase the production rate by providing inputs such as soil moisture and temperature to control the irrigation by the water pump. The authors claimed that the proposed system could maintain the soil moisture and preserve water and energy source. Farooq *et al*. [12] proposed automated irrigation based on irrigation gates using fuzzy logic for decision making. The authors claimed that the proposed system reduces wastage of water, labour cost in irrigation, and power cost. Pezol *et al*. [13] used fuzzy logic decision-making for irrigation and fertilisation systems for chilli plants. Soil moisture and pH were used as fuzzy inputs and the outputs are acid, neutral, and alkali solutions that the water pump has controlled. The authors claimed that the proposed system’s plant growth has a better performance than the traditional method.

Fuzzy logic has been applied for other fields as well. For example, Elashiri and Shawky [14] used fuzzy logic approach for crop tracking systems. The proposed system was focus on observing the climate condition and helping farmers to make a decision. The authors claimed that the proposed system has improved learning efficiency, enhanced prediction accuracy, and been implemented effectively. The authors in [15], [16] used a fuzzy-based approach in robotics. Pană *et al*. [15], the authors used fuzzy to control robotic arms for a smart electric wheelchair to assist people with movement disabilities. The authors claimed that the fuzzy controller allowed the robotic arms to control desired tasks. Abood *et al*. [16], the authors used fuzzy to control the mobile robot's position to follow the tracks on the floor and control the angular momentum of left and right wheels. The authors claimed that the system could efficiently drive the robot inside the curve path, manoeuvre freely at different speeds, and avoid obstacles without any collision. According to Ouda *et al*. [17] employed a single-input fuzzy logic controller (SIFLC) to manage the force between the pantograph and the catenary. It is shown that SIFLC successfully tracked the supplied contact force with less overshoot, a 2% difference in peak-to-peak response from the actual force, and a fast response time of 5.27s. Ouda *et al*. [17] used a fuzzy approach to control wireless networks and congestion using various configurations. The authors claimed that the influence of communication time and its link with the stability of the system’s operation can be used to manage the system's behaviour and test the balance when it is modified with time delay.

2. MATERIALS AND METHODS

2.1. System structure and process

The experiments were conducted at the Faculty of Engineering, Universiti Putra Malaysia, using two vertical structures, in which each structure consists of 20 pots (five pots in each layer) and has a dimension of 81x64x100 cm. The structures were placed in the corridor, where the herbs could receive sufficient light from the sunlight. Light is one of the crucial environmental factors for plant growth and is considered the most significant energy required for photosynthesis and many other physiological processes [18], [19]. Besides photosynthesis, light is also important for the regulation and direction of growth and development and the synthesis of chemical compounds [20], [21]. Other materials include NodeMCU ESP-12E, non-corrosive soil moisture sensor (SKU: SEN0193), humidity and temperature sensor (DHT11). Each structure is equipped with a 15-litre water tank, a 10-litre fertiliser tank, pumps, irrigation tubes, and water drippers. The growing media used in this experiment is a mixture of peat moss, perlite, and vermiculite with a ratio of 2:1:1, a common growing media mixture for vertical farming. The irrigation controlled by a fuzzy logic algorithm produces the duration of irrigation as the output, based on the input given by all sensors. All the data were displayed on a website and can be controlled remotely via a mobile application. The overall system architecture is illustrated in Figure 1. Arduino-UNO also controls the irrigation performed in the second structure, but the irrigation was performed twice a day only, following the conventional method and the recommended frequency of watering in Malaysia due to the high day temperature that is over 29 °C. The fuzzy logic controller block diagram is shown in Figure 2 [22].

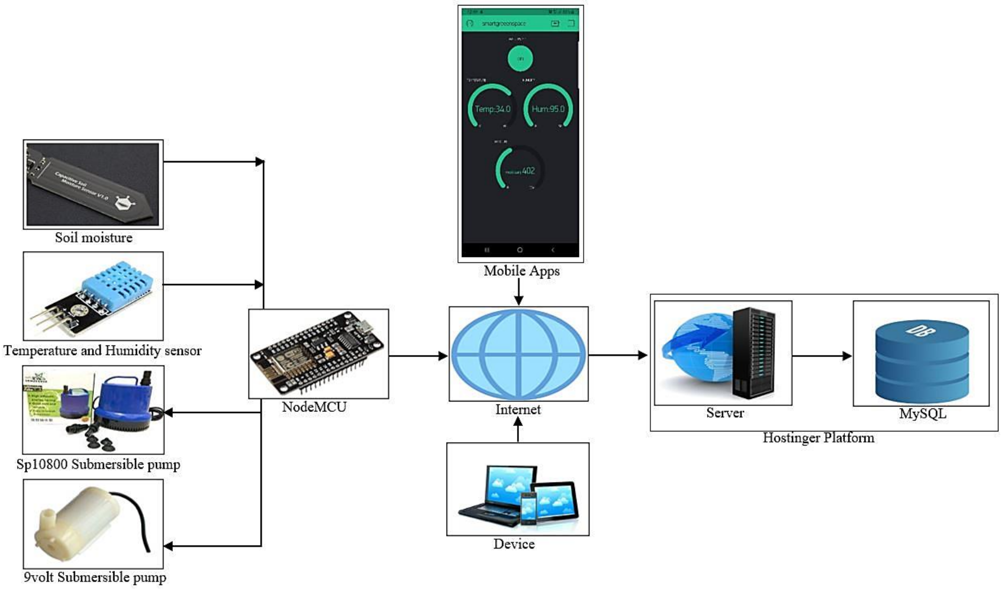

Figure 1. Real-time monitoring and controlling system architecture

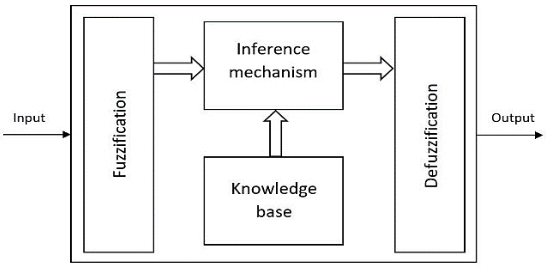

Figure 2. Fuzzy logic controller block diagram

2.2. Fuzzy rules and membership functions

The parameters commonly used by fuzzy logic to control irrigation are temperature, humidity, and soil moisture content [23], [24]. Following these studies, the irrigation duration for this experiment is based on the moisture content of the growing media, humidity, and temperature. Nevertheless, the temperature variable is expressed as "Hot", "Normal" and "Cold" with the average values of 35 °C, 29.5 °C, and 24 °C, while the humidity variable is expressed as "High", "Modest" and "Low" with the average values of 85%, 67.5%, and 50%, respectively. These values were obtained through sensor calibration, representing the conditions of a very hot day and heavy rain in Serdang, Malaysia. The temperature sensor gave a minimum value of 24 °C when it is raining and a maximum of 37 °C during the hot day. Meanwhile, the sensor gave a minimum value of 55% when the humidity is low and a maximum value of 91% when high. The soil moisture variable is expressed as "Dry", "Moist", and "Wet", with the average values of 405, 355, and 290, respectively. It was found that the growing media was in the "wet" when the soil moisture sensor values ranging from 250 to 330, "moist" when the sensor values ranging from 310 to 400, and "dry" when the sensor values ranging from 390 to 420. The fuzzy sets used in the experiment are as stated in Figure 3 to Figure 5. The trapezoid pertinence functions were used in these experiments. This shape is chosen as we would like to study the effect of irrigation on the herb's growth.

The approximate reasoning is also based on fuzzy rules, as stated in Table 1. For the condition where the soil is wet or dry, the action performed by the fuzzy operation is off the pump and long irrigation, respectively. The irrigation time for long irrigation is 5 minutes, equal to 160 mL of water collected from the water dripper when the SP10800 submersible water pump pumps in the water. Other actions decided by the fuzzy operation are categorised under short irrigation where the irrigation time ranges from 3 seconds to less than 5 minutes, which depends on the moisture content of the growing media and temperature and humidity of the surroundings.

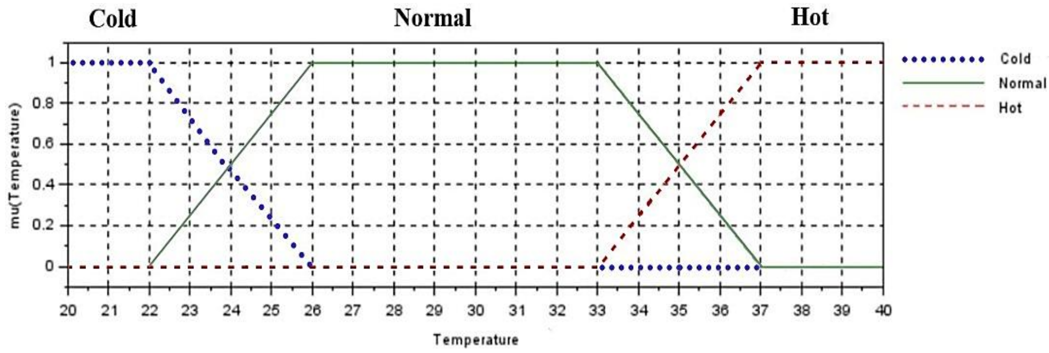

Figure 3. Membership function for temperature

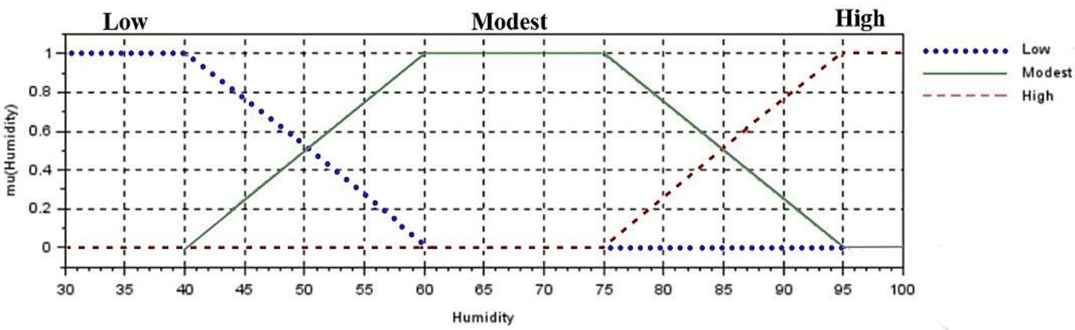

Figure 4. Membership function for humidity content

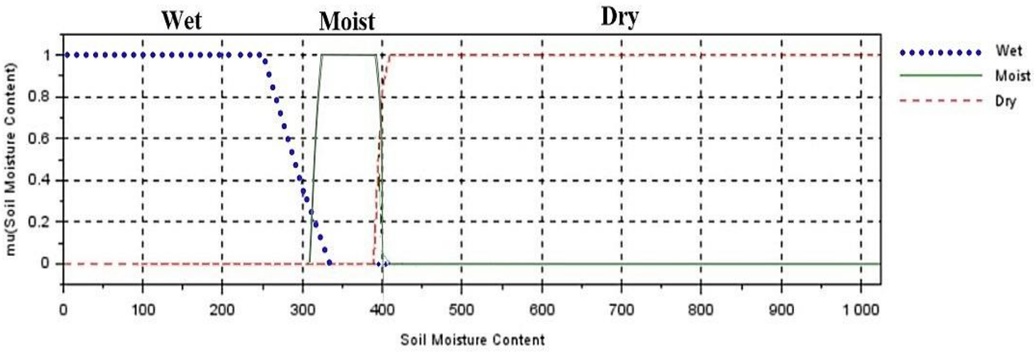

Figure 5. Membership function for soil moisture content

Table 1. The fuzzy rules

Rules		Condition Moisture content		Temperature		Humidity	Action (Irrigation)
1		Wet		NA		NA	Off
2		Dry		NA		NA	Long
3		Moist		Cold		Low	Short
4		Moist		Cold		Modest	Off
5		Moist		Cold		High	Off
6	IF	Moist	AND	Normal	AND	Low	Short
7		Moist		Normal		Modest	Off
8		Moist		Normal		High	Off
9		Moist		Hot		Low	Long
10		Moist		Hot		Modest	Short
11		Moist		Hot		High	Off

4. RESULTS AND DISCUSSION

The considered plant growth rates are the average values of the measured plant height, leaf diameter, and plant crown. The values were calculated using (1) [25], using the data measured in three cycles. In each cycle, the measurement was conducted manually weekly for four weeks. The reason for performing weekly measurement is because of the visible increment of herb growth. The performance of both systems is compared based on the herb growth rates.

$$Growth\ Rate = \frac{S2 - S1}{T} \quad (1)$$

where $S2$ is the latest measurement of the perennial herbs, $S1$ is the first measurement and T is the number of days of each cycle. The average plant height is the average value of the highest stem height, medium height, and shortest stem height. Figure 6 shows the average height of gynura procumbens. Figure 7 shows the average leaf diameter values of gynura procumbens. The average value of the leaf diameter is obtained by averaging the largest-sized leaf, the medium-sized leaf, and the smallest-sized leaf.

The results show that the average height values and leaf diameter of the herbs grown by a fuzzy-based system superceed those grown by a timer-based system in all cycles. Table 2 shows the growth rates calculated for each cycle, where the average growth rate of plant height for the fuzzy-based and timer-based systems are 69.05% and 8.40%, respectively, with a difference of about 60.65%. For the leaf diameter, the difference is 0.88%.

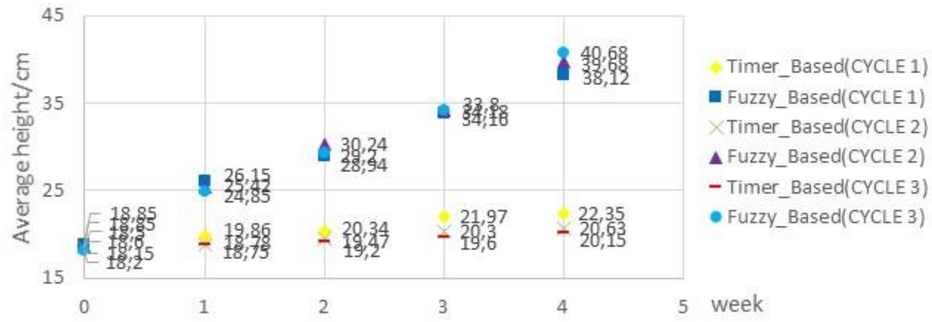

Figure 6. Average height for gynura procumbens

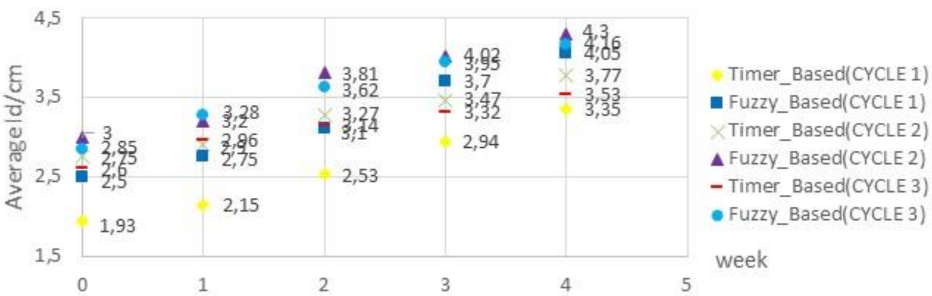

Figure 7. Average leaf diameter for gynura procumbens

Table 2. Growth rate percentage for plant height and leaf diameter

Growth parameters	Plant height		Leaf diameter	
Cycle	Timer_Based	Fuzzy_Based	Timer_Based	Fuzzy_Based
1	11.67	64.23	4.73	5.17
2	6.87	68	3.29	4.19
3	6.67	74.93	3.1	4.37
Average growth rate	8.40	69.05	3.71	4.58

The plant crown is the plant's measurement taken from the plant's top cross-section view that constitutes a measurement of x and y that represent width and length from the top view of the plant, respectively [25]. The average plant crown values are shown in Figure 8. The results show that the average plant crown values of the herbs grown by the fuzzy system are larger than those grown by the timer-based system. The average growth rates for gynura procumbens grown using a fuzzy system are about 20% higher than the herbs grown using a timer-based system, as in Table 3. Furthermore, it is also observed that the total amount of water used for irrigation by the fuzzy-based system for each cycle is less than the timer-based system, as shown in Table 4. The timer-based system performed irrigation twice a day and 5 minutes per irrigation, while the fuzzy system performed irrigation based on the temperature and humidity of the surroundings and the moisture content of growing media. Overall, the water consumption by the fuzzy system is 16.93% lower than the timer-based system.

Besides that, each parameter for the timer-based and fuzzy-based systems was analysed using analysis of variance (ANOVA) [26] to find the significant effect on a different system to average plant height, average leaves diameter, and plant crown of perennial herbs. Table 5 shows the growth parameters used in ANOVA analysis from the first day of week one until week four.

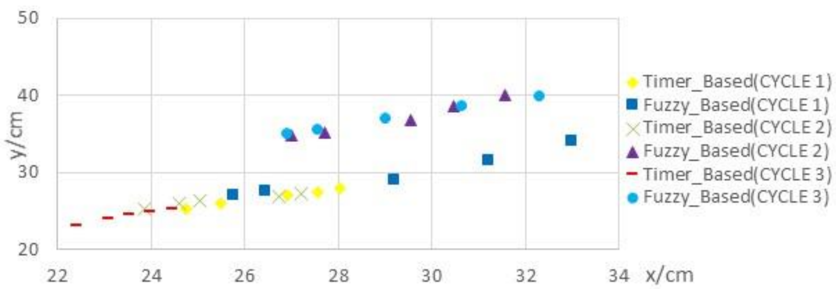

Figure 8. Plant crown data for gynura procumbens

Table 3. Growth rate percentage for plant crown (%)

Plant	Cycle	Timer_Based		Fuzzy_Based	
		$\bar{x}$	$\bar{y}$	$\bar{x}$	$\bar{y}$
	1	10.97	8.93	24.17	23.67
Gynura procumbens	2	10.81	6.61	14.71	16.71
	3	6.87	7.47	24.37	22.64
Average growth rate		9.55	7.67	18.96	18.93

Table 4. The amount of water used to irrigate herbs in each cycle

Cycle/System	Timer-based		Fuzzy-based	
	Time of irrigation (minutes)	Amount of Water (litres)	Time of irrigation (minutes)	Amount of Water (litres)
1	300	9.6	236	7.55
2	310	9.92	265	8.48
3	300	9.6	255	8.16
Total	910	29.12	756	24.19

Table 5. Height, leaf diameter, and plant crown data. Data are the average value (n=5, p<0.05)

Plants	Week	Systems	Height (cm)	Leaf Diameter (cm)	Plant crown (cm)	
					$\bar{x}$	$\bar{y}$
Gynura procumbens	1	Fuzzy	18.85$_a$	2.5$_a$	25.75$_a$	27$_a$
		Timer	18.85$_a$	1.93$_a$	24.75$_a$	25.2$_a$
	4	Fuzzy	38.12$_b$	4.05$_a$	33$_b$	34.1$_b$
		Timer	22.35$_b$	3.35$_a$	28.04$_b$	27.88$_b$

*a in each column represents no significant difference, b represents a significant difference between the two systems.

During the first day of week one, there was no significant difference for each parameter between fuzzy-based and timer-based systems, but in week four, gynura procumbens showed significant differences in height, stem perimeter, and tree crown between the two systems. The fuzzy-based system showed the highest average value of plant growth when compared to the timer-based system. In addition, leaf diameter has shown no significant difference between each system in week four.

5. CONCLUSION

The experiment results have shown that the understudy local perennial herb can achieve optimum growth rate when the irrigation is performed by a fuzzy-based system, where the irrigation decision is based on the environment of the surrounding and moisture content of the growing media. Furthermore, the proposed fuzzy system was developed using a trapezoidal membership function that can reduce water consumption, which is 16.93% lower than a timer-based system. It is also found that gynura procumbens growth varies in each cycle, where it achieved optimum growth in the first and third cycles. As for the ANOVA analysis result, it is shown that there is a significant difference between the two systems in terms of height, stem perimeter, and tree crown. The effect of the fuzzy-based system on the growth of other herbs and the effect of different fuzzy logic functions on herb growth are the other aspects that will be investigated in the future.

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