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Intelligent Irrigation System Using Rain Water Harvesting System and Fuzzy Interface System

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ABSTRACT

Shortage of water has become a predominant problem all over the world as water plays an important role in agriculture, domestic and industry. In certain parts of the world, farmers face problems watering their crops especially during the dry season. Limited water resources with low efficiency greatly affect crop growth. Therefore, this study proposes an intelligent irrigation system using Rain Water Harvesting (RWH) and Fuzzy Interface System (FIS) for crops watering process. The RWH is a system that collects, centralises and stores rainwater, while the FIS uses temperature and soil moisture sensors to determine the time and amount needed for the watering process. Thus, the intelligent irrigation system will ensure the process of watering the crops to be efficient. The results of this study show that FIS can analyse temperature and soil moisture data, which improves the efficiency of crops watering process and the use of RWH will make it sustainable. The developed project is currently operating at the Institute of Sustainable Agro Technology, i.e. a university-owned agricultural research institute.

Keywords: Irrigation system, Rain harvesting, Fuzzy system

1. INTRODUCTION

The main challenge facing most countries is the supply of food for its citizens and residents. Food is an essential element for humans and they cannot live without it. Food production begins with agriculture and the agricultural ecosystem that usually requires water resources is the main provider of human food [1]. Based on the technology and weather, the agricultural sector uses 60% to 90% of water resources while the rest is for domestic and industrial [2]. Data shows that world production should supply at least 70% of market needs to meet food needs by 2050 [3]. Therefore, the use of water resources in agriculture will increase and this will lead to water shortages in most parts of the world [4]. Moreover, inefficient use of groundwater in agriculture can pose problems to human life.

Because of the growing need for water resources, other water sources such as Rainwater Harvesting (RWH), which is a free and sustainable natural resource, are a good solution for the industry. Rainwater naturally fills the earth with a supply of untreated water that does not contain chlorine to ensure crops grow well. The RWH system, described as the collection and accumulation of rainfall, typically for agricultural irrigation and domestic needs is an important solution to water shortage [5]. This technique will provide a flexible solution that can effectively meet the water resource needs for agriculture or domestic activities with minimum cost, good accessibility and easy maintenance [6]. This technique can also reduce the effects of dry spells and increase crops production such as corn and rice [7].

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The crop irrigation techniques usually depend on their suitability based on cost, accessibility, rainfall intensity, crops type and soil texture. The RWH systems for agriculture that combine with intelligent irrigation processes will result in efficient and optimal use of water resources. This technology will increase the efficiency of the irrigation process with optimal use of water, while ensuring plant health and good growth [8].

Intelligent irrigation with sensing technology will water the crops based on the predictive model. The system uses sensors as inputs, and embedded controllers and drip valves as outputs. Currently, the intelligent irrigation technology identifies the amount of water needed by crops using weather-based or temperature and soil moisture sensor [9].

This paper describes in detail the design and development of RWH for intelligent irrigation systems for crop watering purposes. The process considers irrigation method based on environmental parameters through sensors, temperature and soil moisture. The system is capable of monitoring the crop irrigation process through a web server system in real time. Environmental and soil parameters are monitored through sensors and watering is performed through an embedded control irrigation system. The system uses the MATLAB-based Fuzzy Interface System (FIS). This will result in increased water resource efficiency, cost effective, less labor, sustainable and environmentally friendly.

2. SYSTEM ARCHITECTURE

The developed system architecture as shown in Figure 1 consists of a RWH, embedded controller, sensors and web server. The system uses embedded controller to obtain the temperature and soil moisture data from the farm. The RWH is used to irrigate crops and a web server monitors the process.

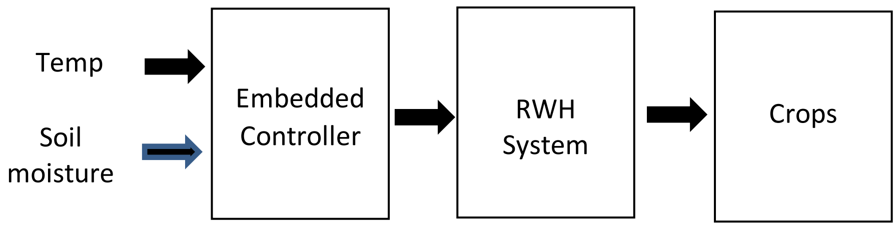


Figure 1. The system architecture

2.1 Rain Water Harvesting

The project is located at the Institute of Sustainable Agro Technology (INSAT), a university-owned agricultural research institute, in Padang Besar, Perlis. As shown in Table 1, the lowest rainfall was 51 mm in February while the highest was 325 mm in October. The highest average temperature was 27.1 °C in March and the coldest was 24.8°C in December. The humidity almost exceeds 70% throughout the year. The area also receives good sunlight, which has a minimum of 6.7 hours a day.

Table 1 Padang Besar weather report

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ave Temp (0C)	25.1	26.4	27.1	27	26,7	26.6	26.3	26.1	25.7	25.2	25	24.8
Ave Humidity (%)	79	71	73	80	85	85	85	85	87	90	89	86
Rain fall (mm)	74	51	136	186	210	166	176	199	236	325	276	174
Rainy days	8	6	11	16	18	17	18	18	19	21	19	14
Ave Solar (Hour)	7.9	8.9	8.7	8.2	8.0	8.1	8.0	7.7	7.4	6.9	6.7	7/1

The developed RWH system consists of three main parts, namely the building rooftop as a catchment area to collect rainwater, conveyance system and storage tank as illustrated in Figure 2. The catchment area where rainwater is collected is the roof of the INSAT office building. The amount of water collected is calculated using equation (1) as follows:

$$\text{Amount Collected} = Ar \times \mu \times P \tag{1}$$

Where, Ar is the rooftop area (m^2), μ is the Runoff coefficient and P is the Precipitation amount (mm). The roof area is 335 m^2, the rainfall is 200 mm and the roof runoff coefficient is 0.6, making the total collected is 40,200 liters for each month. A conveyor system is used to transfer the rainwater collected on the rooftop to a storage tank containing gutters, pipes and filters. This is done using PVC pipes connected to the gutters on the roof. The inert material of the pipe will maintain the pH of the rainwater and reduce the effects of corrosion.

Water filter is used to filter large particles, leaves, branches and soil that carry from the rooftop to the water tank. The filters also help to flush out microorganisms to purify the rainwater, which will improve its quality. Before the rainwater flows through the filter, which is normally place on the top of the tank, the first flush of rainfall will be discharged. The filter components are gravel and sand that being hold with a mesh. The filter needs to be cleaned regularly to ensure that the rainwater flow smoothly. This will prevent the filter stuck with particles that block water flow into tank and overflow. Two 600-gallon PVC storage tanks are located on the ground near the building, which are used to collect the rainwater. Figure 2 illustrates the developed irrigation system. Proper installation, filtration and maintenance of the system will ensure good quality of harvested rainwater.

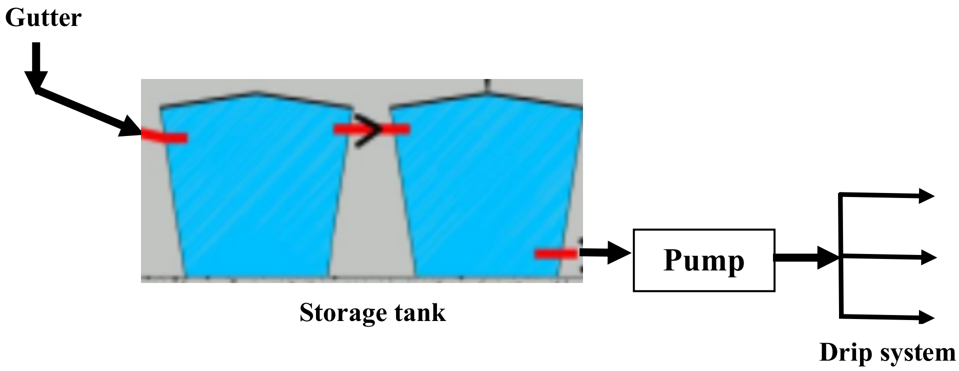


Figure 2. The developed irrigation system

2.2 Embedded Controller

The developed embedded controller comprises of ESP32 microcontroller as its embedded controller, sensors, water pump, electronic circuit, GSM/GPRS communication module and embedded control software for monitoring and controlling the intelligent irrigation system. The ESP32 is a series of low power and low-cost system on chip microcontroller with Wi-Fi and Bluetooth, and used as system embedded controller. It uses 3.3 volts DC power supply and operates at 240 MHz. It is equipped with 520 KB SRAM memory, 18 channels Analog to Digital Converter (ADC), as well as having four SPIs, two I^2Cs, three UARTs for communication interfaces and GPIOs for digital input / output [10]. It has the ability to acquire, store, process and send data wirelessly to cloud database for remote monitoring.

The sensors used to measure the parameters of the farm environment are temperature and soil moisture. The sensors will generate electrical signals related to the parameter being measured. The temperature sensor uses a thermistor to measure the temperature in the air and produces an output in a digital signal. Soil moisture sensor uses probes to measure water content in agricultural land using the principle of electrical resistance. It will determine the condition of the soil, whether dry, moist or wet depending on the texture of the soil and the ambient temperature.

The embedded controller will acquire the data from the sensor at a specified time and transmit it to the cloud database using the GSM / GPRS module. It can also use Wi-Fi network to transmit the acquired data to a cloud database. These data will be analysed and predictions made, which are used to operate DC water pumps to irrigate crops. Cloud databases are also used for remote monitoring operations. The embedded controller and sensor are placed in a weatherproof PVC casing for protection from the climate effects as shown in Figure 3.

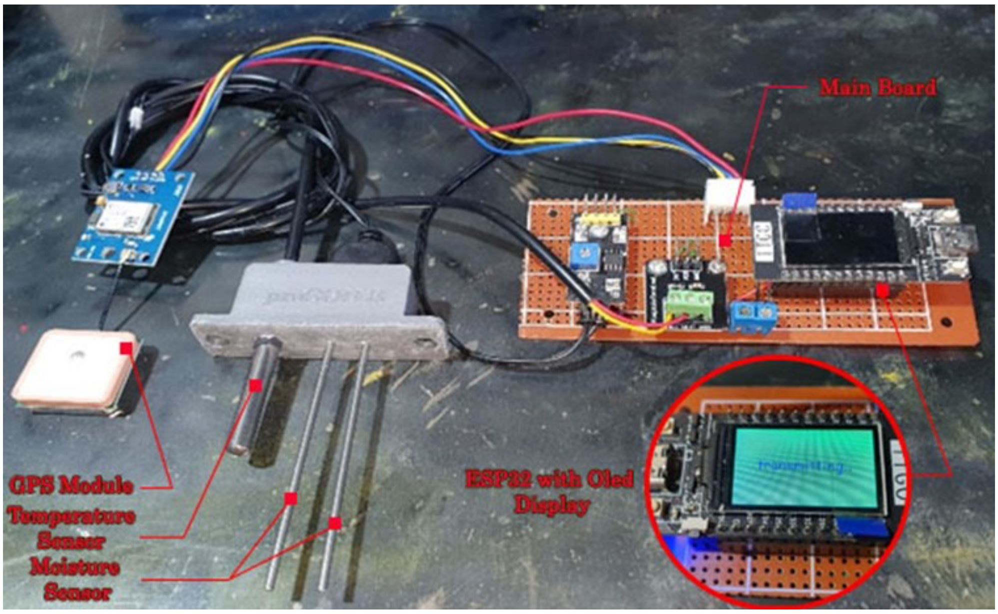


Figure 3. The Embedded Controller

3. FUZZY INFERENCE SYSTEM (FIS)

Fuzzy Inference System (FIS) has been widely used in various fields such as data classification, automation control, pattern recognition and prediction [11]. FIS also known as fuzzy expert system, fuzzy associative memory, fuzzy model and fuzzy logic controller is the mapping process from given input to output using fuzzy logic technique. FIS completes the nonlinear mapping from its sharp input to output by mastering some fuzzy if-then rules. The FIS is structured with four main functional blocks as shown in Figure 4.

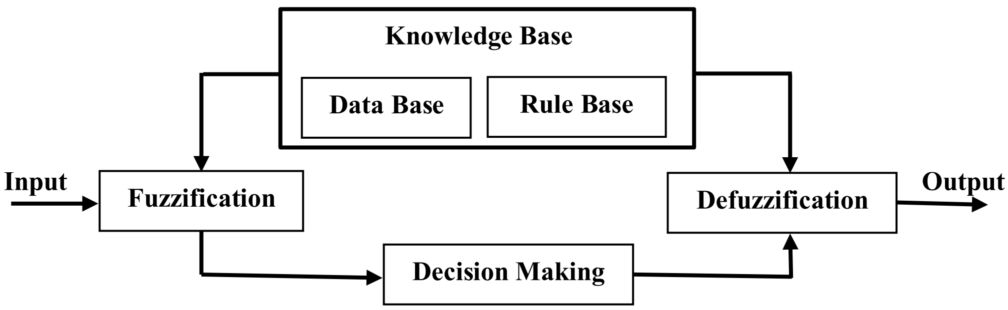
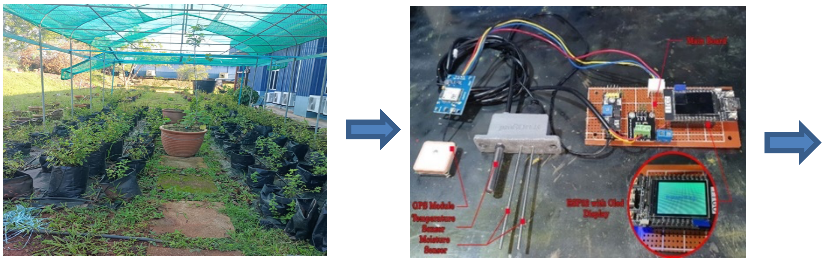


Figure 4. Structure of FIS.

The knowledge based on FIS structure is developed by combining a rule base consisting of several fuzzy if-then rules and database that defines the fuzzy set membership functions used in fuzzy rules. A fuzzification performs an inputs transformation process from crisp into degrees of matches with linguistic value while a defuzzification performs fuzzy results into a crisp output. In the decision-making block, the FIS performs an inference operation on a pre-defined rule. A fuzzy conditional statement or known as if-then rules can be expressed as; If x is A, then y is B, where x and y are input and output linguistic variable. The A and B are input and output label that have been set in membership function. The FIS uses two types of fuzzy reasoning, namely Mamdani and Sugeno. Nevetheless, the Mamdani type was chosen because of its defuzzification technique in generating a sharper output compared to Sugeno, which uses a weighted average [8].

4. METHODOLOGY

An experiment was conducted to test the developed system operational and functionality as illustrated in Figure 5. The samples were collected from INSAT. The temperature and soil moisture sensor are placed at a predetermined location at a fixed depth where data will be obtained at the same time every morning. After three days, the sensor will be relocated to another location where the process is repeated. The embedded controller would acquire data through the sensor periodically at certain intervals. The acquisition process was repeated five times to ensure its repeatability. Then, the embedded controller will send the average measured data wirelessly via the GPRS/GSM module to the web server.



Date	Time	Moisture	Temperature
4/6/2020	9:00:05	462	29.55
4/6/2020	10:00:05	486	29.68
4/6/2020	11:00:05	504	29.71
4/6/2020	12:00:05	511	29.85
4/6/2020	13:00:05	522	29.88
4/6/2020	14:00:05	533	29.91
4/6/2020	15:00:05	534	29.92
4/6/2020	16:00:05	542	29.95
4/6/2020	17:00:05	556	29.97
4/6/2020	18:00:05	568	29.99

Figure 5. The sampling processes.

5. RESULTS AND DISCUSSION

5.1 FIS Model

Temperature and soil moisture were used as input variables for the FIS model. Figure 6 shows that the input variables are used to control the dripper and DC water pump duty cycle. The model was developed using Mamdani type, which is based on multiple input and multiple output (MIMO). This input will go through the fuzzification and defuzzification process before producing output.

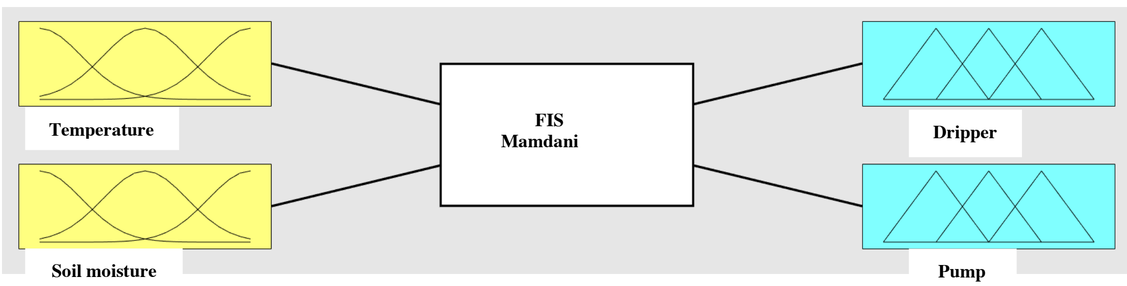


Figure 6. Fuzzy Inference System Model.

As illustrated in Table 2, the optimal control conditions using the FIS model developed based on nine Fuzzy Interface Rules designed using appropriate indices. The resulting rule involves Dripper (D) and Pump (P) output control simultaneously. It will be used to maintain optimal soil moisture and ambient temperature. The pattern of the FIS surface view relationship between input and output indicates that high temperature and low soil moisture in hot weather will result in maximum duty cycle for dripper and pump.

Table 2 Fuzzy Inference Rules

		Soil Moisture		
		Wet	Medium	Dry
Temperature	Low	D: OFF P: OFF	D: OFF P: LOW	D: LOW P: MEDIUM
	Optimum	D: OFF P: OFF	D: OFF P: LOW	D: LOW P: MEDIUM
	High	D: MEDIUM P: OFF	D: MEDIUM P: MEDIUM	D: HIGH P: HIGH

Figure 7 shows a simulation of the output crisps values, in which the dripper and pump duty cycles function according to the design rules. In addition, Table 3 provides an example for a singleton output control from a variable data input.

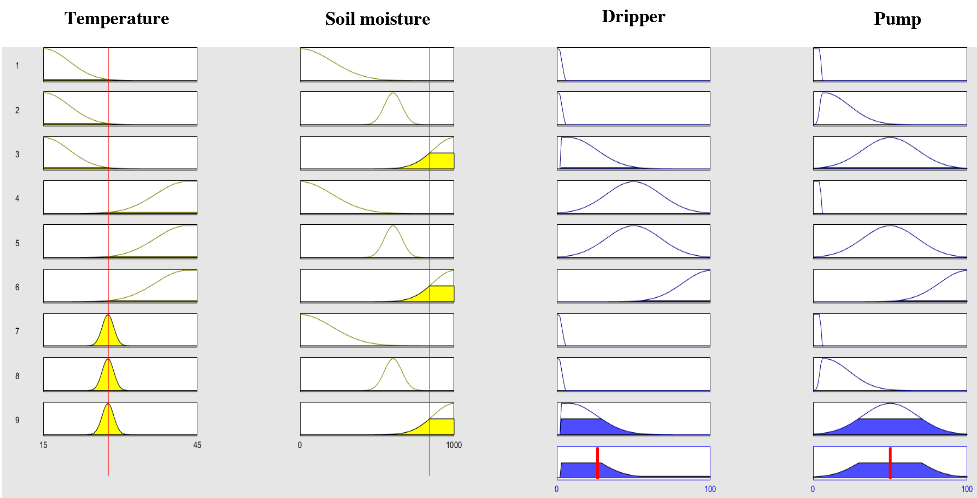


Figure 7. FIS Input and Output rules crisp value simulation

Table 3 Singleton values for FIS output

Rules	Temperature	Soil Moisture	Dripper	Pump
R_0(2)	Low (18)	Medium (591)	Off (7.59)	Low (19.9)
R_1(4)	High (40.8)	Wet (168)	Medium (50)	Off (2.48)
R_2(7)	Optimum (27.8)	Wet (168)	Off (28.7)	Off (2.48)
R_3(9)	Optimum (27.8)	Dry (899)	Low (24)	Medium (50.1)

5.2 Result in Web server

The web server is created as a dashboard to display the result based on the input or sensor data obtain from microcontroller. An open-source platform called Thingspeak is used to store the data from the microcontroller. Thingspeak is an IoT, a platform that allows collect and store sensor data in the cloud system [9]. Figure 8 shows the moisture and temperature monitoring graphs shown on the web server depending on the data obtained. There are several details where the level, day, date and time will appear when the user clicks on any data point in the monitoring graph.

Figure 8. Temperature and soil moisture sensor data

The overall data will be stored on the web server, which consists of date, time, entry number, moisture level, temperature level and water pump status, and hence, users can monitor the system effectively. In wet conditions, the range of soil moisture level is 350Ω to 600Ω, while in dry conditions; the range is 601Ω to 999Ω [10]. The water pump will turn on when the soil moisture sensor measurement reaches the dry level and will turn off when in the wet state.

6. CONCLUSIONS

Intelligent Irrigation System using RWH and FIS were successfully developed and tested. Data acquisition and analysis system can be created using web server. The embedded system sensor successfully obtains the temperature and soil moisture of the farm, and sends it wirelessly to a web server. The easy-to-use systems advantages would be efficient, cost effective, reduce labor and sustainability. Workers and farmers can monitor their crops soil moisture, ambient temperature and water pump status remotely. As a result, the system is able to monitor and control the farm watering process efficiently. Future work will focus on applying an embedded fuzzy and adding other environmental parameters such as humidity and light intensity to the system.

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