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Fuzzy Logic based Smart Irrigation System using Internet of Things

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A B S T R A C T

Traditional agricultural systems require huge amount of power for field watering. This paper proposes a smart irrigation system that helps farmers water their agricultural fields using Global System for Mobile Communication (GSM). This system provides acknowledgement messages about the job's statuses such as humidity level of soil, temperature of surrounding environment, and status of motor regarding main power supply or solar power. Fuzzy logic controller is used to compute input parameters (e.g. soil moisture, temperature and humidity) and to produce outputs of motor status. In addition, the system also switches off the motor to save the power when there is an availability of rain and also prevents the crop using panels from unconditional rain. The comparison is made between the proposed system, drip irrigation and manual flooding. The comparison results prove that water and power conservation are obtained through the proposed smart irrigation system.

1. Introduction

In agriculture, improving crop yield is crucial to meet up swiftly growing demand of food for population intensification. By predicting ecological circumstances, crop productivity can be increased (muthunpandian et al., 2017; GutiérrezJuan Francisco Villa-Medina et al., 2017; Mohanraj and AshokumarNaren, 2015; Williams, 2012; Harrington et al., 2011). In order to advance crop productivity, there is an urgent need to shift manual methods to automation (Gondchawar and Kawitkar, 2016). Besides, the power problem has become a major issue in most of the villages where still, an everlasting solution has not been found (Ahonen et al., 2008). Crop quality is ensured depending on the data received from agricultural field such as soil moisture level, surrounding crop temperature, etc. (Arivazhagan et al., 2013). Based on availability of sunlight, the system can be switched between the solar mode and the main power supply mode for reducing consumption of electricity (Kajale, 2015). The effective utilization of water is a successful agriculture process. Over several million liters of water are needed for the conventional irrigation methodology, whereas smart irrigation methodology needs few million liters of water (Kim et al., 2008). Whenever the groundwater level is minimized, **automation in irrigation methodology is necessary** for effective utilization of water resources (Lin, 2011).

A lot of researchers have been performed on irrigation systems. An integrated irrigation system was developed in (Narvekar et al., 2013) to assist and monitor irrigation using the Bluetooth

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technology. A microcontroller system like PIC 16F88 was designed to monitor the soil, temperature within the crop fields with suitable sensor devices (Narvekar et al., 2013). SMSs are sent to organize irrigation schedule whenever there is a possibility of rain based on environmental conditions in the agriculture field (Ross, 2009). Information regarding detection of diseases is also sent to users to monitor real-time activities. Weekly irrigation evaluation is performed using measurement of soil and environmental changes based on sensor nodes (Sigrimis et al., 2001). Machine learning methods are implemented in agricultural areas for getting precision data and positive yields (Barker et al., 2018).

Automation techniques were established to increase the quality and quantity of crop yield (Bing et al., 2015). However, production is reduced due to reduction in landscape and increasing of pest and plant diseases. Efficient water management is a major concern in many cropping systems. Plant disease causes major production and economic losses in agriculture (Borghetti et al., 2017). An important reason is because of unplanned use of water due to which a significant amount of water goes to waste (Giusti and Marsili-Libelli, 2015). Automating farm irrigation allows farmers to apply appropriate amount of water regardless of availability of labor to own valves on or off and to know the plant growth status. Nowadays, automation has been implemented in all fields like industries, home automation, agriculture, etc. (Papageorgiou et al., 2016). Distributed field sensor-based irrigation systems offer an eventual solution to support irrigation supervision that produces maximum yield with water saving systems.

Smart agricultural system is a superior technology for farmers to boost the productivity of the crops yield with low cost (Navarro-Hellín et al., 2016). A soil moisture detection system based on ZigBee wireless network was proposed to deal with monitoring soil moisture content and no control function for irrigation (Vellidis et al., 2016). The IEEE 802.15.4 standard defines the physical and MAC-layer interface and can operate in either master-slave or peer-to-peer networks arrangement (Tey et al., 2015). The soil moisture monitoring system, which is based on ZigBee, controls soil moisture rate in irrigation areas through solenoid valve, but it needs the support of electricity. A wireless sensing element network is connected to central node of Zigbee, which is successively connected to Central watching Station (CMS) through General Packet Radio Service (GPRS) or Global System for Mobile Communication (GSM) technologies. The system additionally obtains Global Positioning System (GPS) parameters associated with the sector and sends them to a central watching station (Tamirat et al., 2018). The framework examines the compelling path for performing recognition of grape sicknesses through leaf highlight assessment (Salemink et al., 2017), (Rose et al., 2016).

There are many **disadvantages of the existing traditional agricultural methods** namely costlier and manual monitoring of the agriculture field (Poushter, 2016). Specifically, small-scale smart irrigation systems are utilized to provide the solution for dissimilar variety of plants in spite of getting the solution for moisture related issues (AngelopoulosGabriel et al., 2020). Environmental conditions are analyzed using sensors where information is shared by web-based applications (Goapa et al., 2018). The climate-related smart agriculture is implemented to increase the efficient usage of water. It is also used to increase the ground water in the agriculture field with effective analysis (Imran et al., 2019). User friendly interfaces are used to simulate irrigation parameters to complete the decision whenever climate changes in the agricultural environment (Rowshona et al., 2019). Water utilization efficiency is extremely low, i.e. crops are over irrigated or less irrigated. Accuracy is also a major defect in the manual irrigation systems (Puspitasari and Ishii, 2016; Pongnumkul et al., 2015; Philip et al., 2017; García et al., 2018; Nikzad et al., 2019; Zhang et al., 2019; Singh, 2019).

The **objective of the study** is to devise an integrated system in the form of plant growth monitoring and controlling irrigation to improve productivity in agriculture. To overcome the mentioned problems of the traditional agricultural methods, **the proposed method is implemented for automation in agricultural systems**. A plant disease monitoring system is developed to remotely monitor and control irrigation in the agricultural field, which saves water and labor cost. Increasing in accuracy is done using sensors to measure the farmland parameters like soil moisture, temperature, humidity and water flow by knowing water holding capacity of the soil in each field and water requirements and response of each crop grown. During the availability of sunlight, electricity can be utilized by energy stored using solar panel. Based on the data received from the soil moisture sensor, temperature sensor and rain sensor, water is supplied to the agricultural field. This helps in consumption of water. By using GSM technology, the full system is automated to reduce manual work drastically. Crop can also be protected from unconditional rain using a protection panel setup. This system provides a long-term sustainable solution for automatic irrigation control and plant disease monitoring. The **main contributions** of the paper are as follows:

- ✓ The proposed fuzzy-based smart irrigation system provides acknowledgement message about the job's statuses such as humidity level of soil, temperature of surrounding environment periodically.
- ✓ Based on the soil moisture sensor output, the motor is turned on or off automatically to prevent excessive usage of water and electricity.
- ✓ Based on the availability of rain, the motor is turned off automatically to save power.
- ✓ Usage of solar panel reduces the power consumption drastically.

The rests of the paper are organized as follows. Section 2 presents the proposed method, and Section 3 validates it by experiments. The last section draws the conclusions and further studies.

2. Proposed method

2.1. Principle

Agricultural fields of farmers may be located miles away from their residence. Sometimes, farmers need to travel to their agricultural field for quite a few times in a day to start and stop water pumps for irrigation. They cannot guard the crops from unconditional rain every time. In order to remove these practical difficulties, a system is designed to take care of all these problems automatically. The overall block diagram is demonstrated in Fig. 1.

The smart agriculture irrigation controlling and plant disease monitoring system has four major units: end device node, coordinator node, web server node and mobile (controlling unit). The end device node consists of Arduino controller, GSM, motor, plant leaf image soil moisture sensor, temperature sensor and humidity sensor. The microcontroller device is used as the end device as well as the coordinator device in the wireless sensor network. It is used for data communication in the network. Data are continuously collected from sensors and then transmitted to the coordinator node, which is connected to the web server system via RS232 serial data bus. The data acquirement is done in the web server for real-time monitoring of farmland parameters. From the server, data can be obtained and viewed in the Android phone. Then, the control signal is automatically sent to the coordinator node from the Android application.

Whenever the end device receives signal from the coordinator

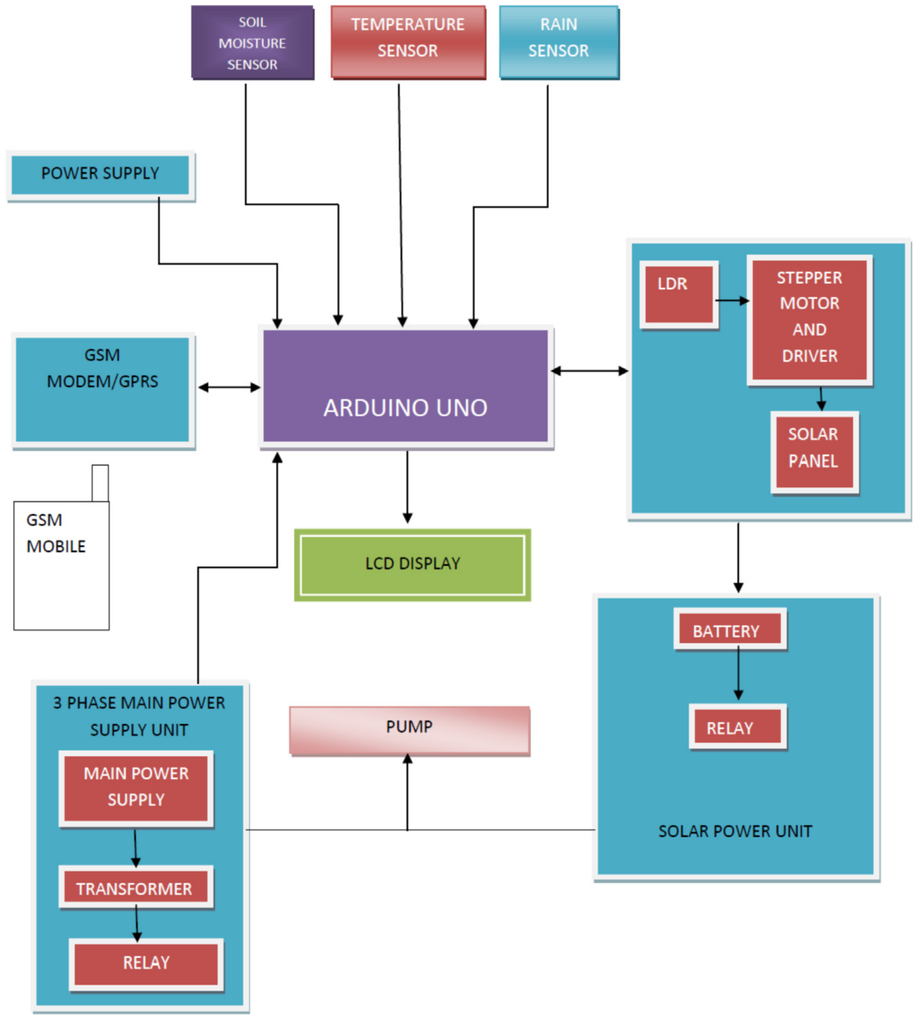

Fig. 1. Working principle.

node, it acts according to the received signal whether the motor is on or off. The motor on-and-off process for irrigation is framed using fuzzy logic. The controller is programmed based on fuzzy rules. Accordingly, the system helps farmers to control the motor and water usage according to farmland requirement even through remote monitoring of agricultural field. Arduino and GSM modem/GPRS get initialized as soon as the power supply is turned on. After initialization process, the system asks users to select either the manual mode or the automatic mode. When the automatic mode is selected, the Arduino initially verifies the availability of solar energy with the help of Light Dependent Resistor (LDR), which is used for sensing the sunlight. Here, the solar panel is mounted upon the stepper motor in order to expose the solar panel to the light according to movement of the sun. When there is no availability of solar energy, the system runs on battery.

The water level sensor attached to this system is used to indicate the water level in the tank of the agricultural field. Relay is linked to the pump, which starts pumping water to the agricultural field as soon as the moisture sensor identifies the land is dry. Moisture sensor is used to sense soil moisture of crop land. The temperature sensor detects surrounding temperature of agricultural field. When it starts raining, the pump automatically stops pumping water to the field to save electricity and updates information to the user using GSM/GPRS. The protection panels are automatically closed to protect the crop getting affected by rain. Data collected from sensors are displayed using Alpha Numeric Display. When a manual mode is selected, details about the agricultural field are updated to the user only when calling to a given authenticated number. Fig. 1 demonstrates the working principle for the proposed system, and Fig. 2 illustrates the flowchart of the proposed system.

2.2. Working steps

1. The GSM modem gets initialized as soon as the power supply is switched on.
2. Using AT commands, the GSM modem communicates Arduino.
3. The LCD display is linked to Arduino so that data monitored by sensors are displayed correctly.

4. Initially, the processor verifies availability of solar energy with the help of Light Dependent Resistor (LDR) for sensing the sunlight. Solar panel is interfaced to the stepper motor, which in turn is linked with the stepper motor driver.

5. The solar panel rotates in both clockwise and counter clockwise and brings to a halt where the maximum sun's intensity is obtained and stores the energy in battery.

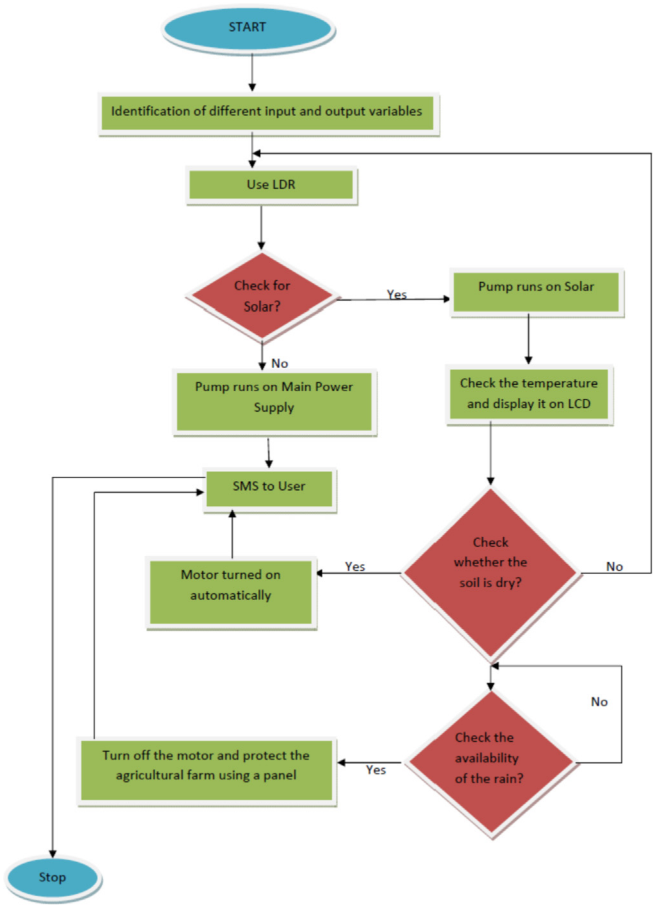

Fig. 2. Main flow of the proposed system.

6. In case of availability of solar power, water is pumped to agricultural field with the help of solar or with the help of mains (3 phase lines).
7. The soil moisture sensor checks for the soil moisture content whose maximum threshold is kept at 850 (indicating dry) and minimum of 500. When the soil moisture content is greater than 700, the motor will pump water to the agricultural filed.
8. The temperature sensor measures surrounding temperature of agricultural farm.
9. The rain sensor senses heavy rain and switches off the motor to save electricity. It also closes the panel to protect the crop.
10. All the information gathered from sensors will be transferred to the user using GSM technology.

2.3. Mathematical modeling

The fuzzy logic-based methodology focuses on the decision-making purpose. It is mainly utilized to get incomplete data to take decision with the concepts called degrees of truth and true or false. The fuzzy set fully contains the classical set. The membership function property is used for implementing the fuzziness of elements in the set that will have the solution based on the experience in spite of knowledge. The weighted average methodology is utilized to implement the membership function with the fuzzy interference system. More details about fuzzy and deep learning techniques can be found in (Jha et al., 2020; Son et al., 2020a; Abdel-Basset et al., 2020; Dey et al., 2020a; Son et al., 2020b; Son et al., 2020c; Son et al., 2020d; Giang et al., 2020; Dey et al., 2020b; Koo et al., 2020; Ngan et al., 2020; Jha et al., 2019a; Nguyen et al., 2019a; Jha et al., 2019b; Son and Fujita, 2019; Tuan et al., 2019; Long et al., 2019a; Kaur et al., 2019; ThongLuu QuocDat et al., 2019; Son et al., 2019; Dat et al., 2019; Popa et al., 2019; Long et al., 2019b; Harold Robinson et al., 2019; Tey et al., 2019; Gai Quek et al., 2019; Nguyen et al., 2019b; Vo et al., 2019a; Vo et al., 2019b; Long et al., 2019c; Le et al., 2019; Le et al., 2018).

Table 1
The fuzzy rule table with various categories of the input and output parameters.

Rules	Soil Moisture	Temperature	Humidity	Motor status
1	Dry	Cold	Low	On
2	Dry	Warm	Low	On
3	Dry	Hot	Low	On
4	Dry	Cold	Medium	On
5	Dry	Warm	Medium	On
6	Dry	Hot	Medium	On
7	Dry	Cold	High	On
8	Dry	Warm	High	On
9	Dry	Hot	High	On
10	Medium	Cold	Low	Off
11	Medium	Warm	Low	Off
12	Medium	Hot	Low	On
13	Medium	Cold	Medium	Off
14	Medium	Warm	Medium	Off
15	Medium	Hot	Medium	Off
16	Medium	Cold	High	Off
17	Medium	Warm	High	Off
18	Medium	Hot	High	Off
19	Wet	Cold	Low	Off
20	Wet	Warm	Low	Off
21	Wet	Hot	Low	Off
22	Wet	Cold	Medium	Off
23	Wet	Warm	Medium	Off
24	Wet	Hot	Medium	Off
25	Wet	Cold	High	Off
26	Wet	Warm	High	Off
27	Wet	Hot	High	Off

The fuzzy rule base system is used to produce the outputs according to the given input for the system. In this study, 3 input parameters are considered and each parameter consists of 3 membership functions as shown in the below equations. The number of rules is calculated based on each input parameter's membership function. Hence, each parameter consists of 3 membership function. The total number of rules framed is 27 (Table 1). The membership function values and the fuzzy rules are framed by researcher's assumption based on the fuzzy inference concept.

Fig. 3 demonstrates the Fuzzy Inference System in which the soil moisture, temperature and humidity are the input values. After completing Fuzzification, Defuzzification methodology is used for producing the output for generating status of the motor. The input membership functions are formulated using the trapezoidal function, and the output membership function is formulated using the triangular membership function. Fig. 4 demonstrates the membership function for humidity whose parameters for analyzing humidity are low, medium and high. Fig. 5 illustrates the membership function for soil moisture whose parameters for analyzing soil moisture are dry, medium and wet. Fig. 6 illustrates the membership function for temperature whose parameters for analyzing temperature are cold, worm and hot. Fig. 7 demonstrates fuzzy rule settings for the fuzzy inference system that are the conditions for the membership functions. The fuzzy rules are framed based on if-then conditions of the soil moisture, humidity and temperature. Fig. 8 illustrates fuzzy rule viewer in MATLAB. The

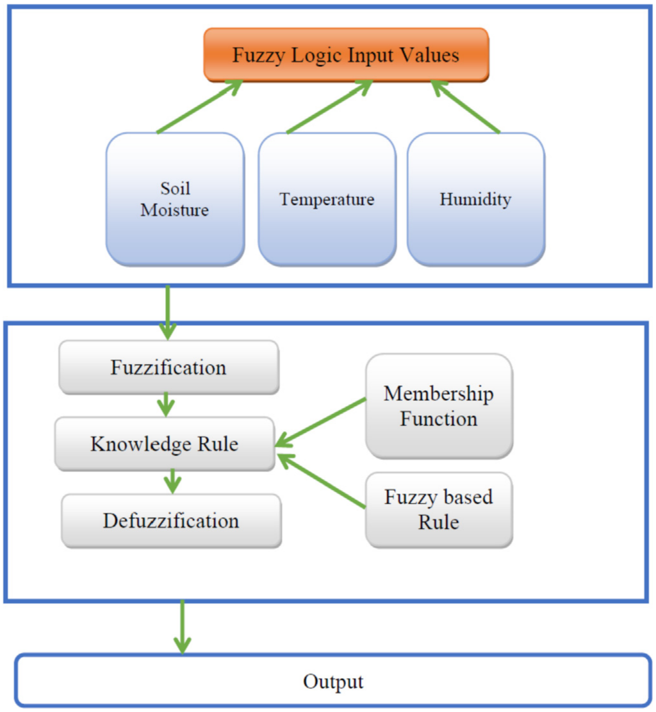

Fig. 3. Fuzzy inference system.

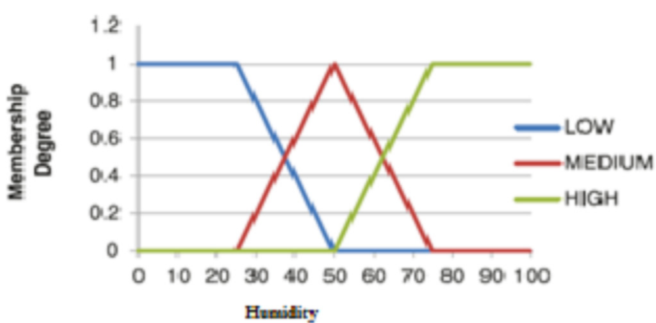

Fig. 4. Membership function for humidity.

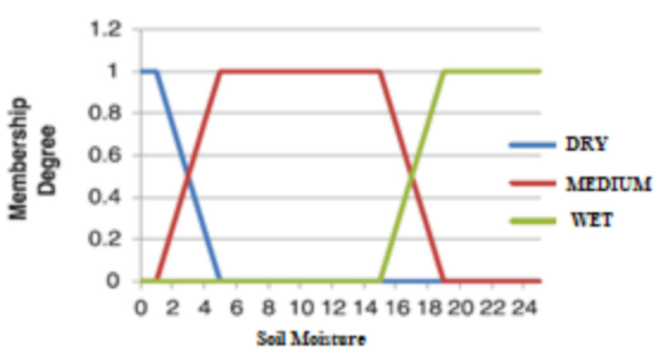

Fig. 5. Membership function for soil moisture.

fuzzy table represents the various categories of the input and output parameters.

Input membership function:

Membership functions for moisture measurement:

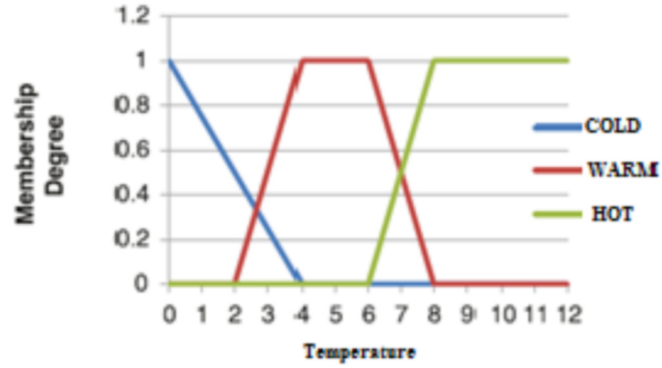

Fig. 6. Membership function for temperature.

$$Moist_{dry}(x) = \begin{cases} 1, x \le 20 \\ \frac{40 - x}{20}, 20 < x \end{cases} \tag{1}$$

$$Moist_{medium}(x) = \begin{cases} \frac{x - 40}{15}, 40 < x \le 55 \\ 1, 55 \le x \le 65 \\ \frac{80 - x}{15}, \quad 65 \le x < 80 \end{cases} \tag{2}$$

$$Moist_{wet}(x) = \begin{cases} \frac{x - 80}{10}, \quad 80 < x < 90 \\ 1, 90 \le x \le 100 \end{cases} \tag{3}$$

Membership functions for temperature measurement:

$$Temp_{cold}(x) = \begin{cases} 1, 0 \le \ x \le 10 \\ \frac{20 - x}{10}, 10 < x \le 20 \end{cases} \tag{4}$$

$$Temp_{warm}(x) = \begin{cases} \frac{x - 20}{3}, 20 < x < 23 \\ 1, 23 \le x \le 27 \\ \frac{30 - x}{3}, \quad 27 \le x < 30 \end{cases} \tag{5}$$

$$Temp_{hot}(x) = \begin{cases} \frac{x - 30}{7}, \quad 30 < x < 40 \\ 1, 40 \le x \le 49 \end{cases} \tag{6}$$

Membership functions for humidity measurement:

$$Hum_{low}(x) = \begin{cases} \frac{x}{15}, 0 \le x < 15 \\ 1, 15 \le x \le 25 \\ \frac{40 - x}{15}, \quad 25 < x < 40 \end{cases} \tag{7}$$

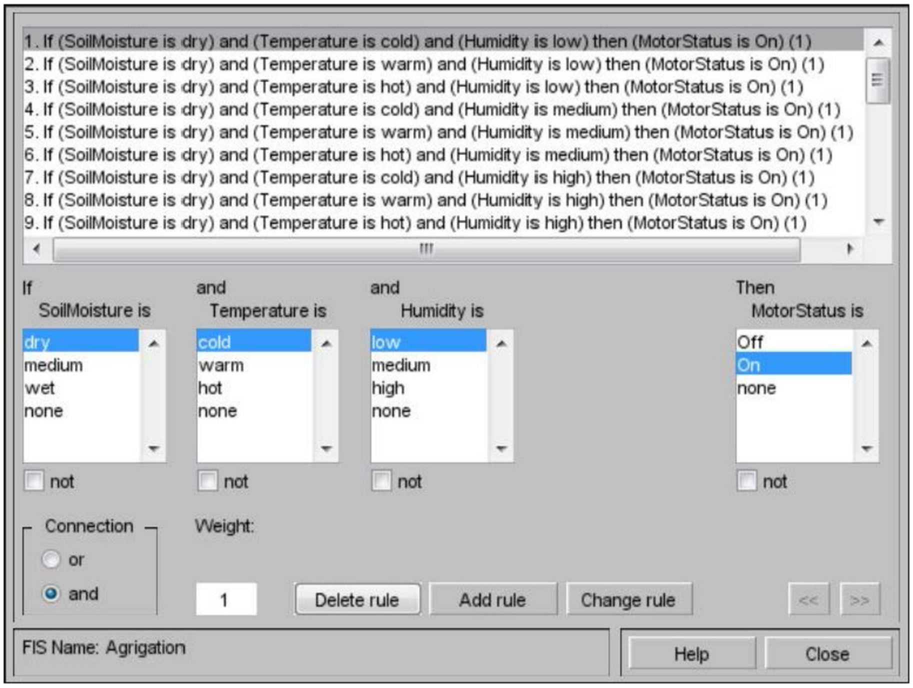

Fig. 7. Window for fuzzy role settings.

$$Hum_{medium}(x) = \begin{cases} \frac{x-40}{10}, 40 \le x < 50 \\ 1, 50 \le x \le 60 \\ \frac{70-x}{10}, \quad 60 < x \le 70 \end{cases} \tag{8}$$

$$Hum_{high}(x) = \begin{cases} \frac{x-70}{10}, 70 \le x < 80 \\ 1, 80 \le x \le 90 \\ \frac{100-x}{10}, \quad 90 < x \le 100 \end{cases} \tag{9}$$

Output membership function:
Membership functions for water valve operation:

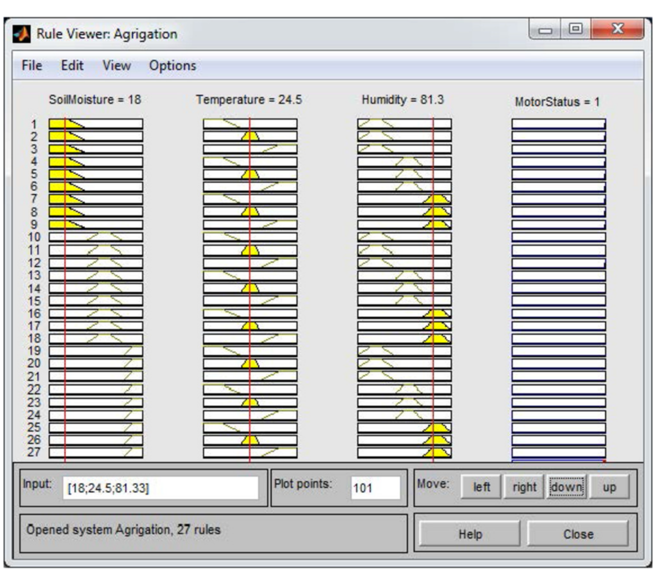

Fig. 8. Window for Fuzzy rule viewer.

$$Motor_{status}(x) = \begin{cases} off, x = 0 \\ on, x = 1 \end{cases} \tag{10}$$

3. Performance evaluation

The proposed work has been programmed using MATLAB simulation tool and Arduino programming. DHT11 sensor is used to collect the information about the humidity and temperature. It is used because of cost effectiveness and fast response while

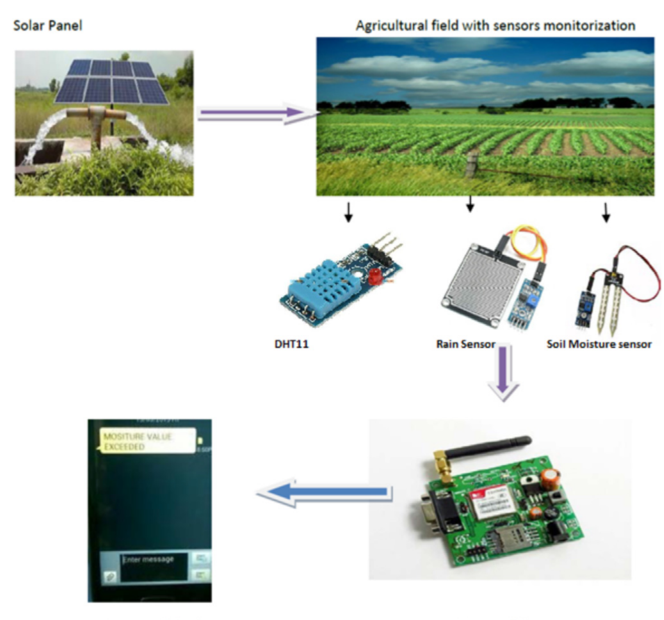

Fig. 9. Overall description of the proposed system.

Fig. 10. Agricultural Field monitoring System.

Fig. 11. Agricultural Field monitoring System with LCD is gathering the data.

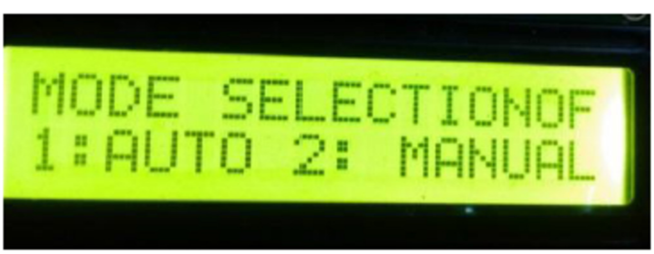

Fig. 12. Mode selection.

Fig. 13. Temperature sensor.

monitoring the temperature and humidity data. Correspondingly, the soil moisture sensor is used to collect the data regarding the humidity content of soil in the agricultural field.

Fig. 9 demonstrates the overall demonstration of the proposed system. The solar panel is used to generate energy. Sensors are used to monitor the agriculture field in real-time scenario. The sensors (i.e. rain sensor, humidity sensor, temperature sensor, soil moisture sensor) are connected with the GSM module. This module is directly connected with the mobile phones for further communication. Fig. 10 demonstrates the LCD Display which displays the agricultural field monitoring system. Fig. 11 illustrates data fetching from the sensors. Fig. 12 demonstrates the LCD Display with Automatic mode or Manual mode.

After getting results from the temperature sensor, the LCD displays the current temperature values (Fig. 13). Fig. 14 demonstrates the Moisture sensor.

The results are obtained in the Android phone application (Fig. 15). Fig. 16 shows the message from GSM to the farmer's mobile, when there is no response from the Android application. The

Fig. 14. Moisture sensor.

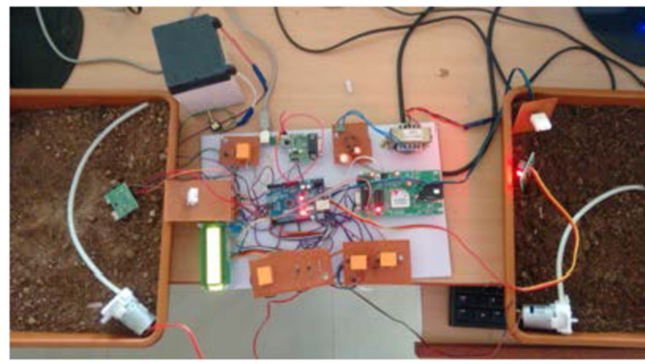

Fig. 15. Transmitter section.

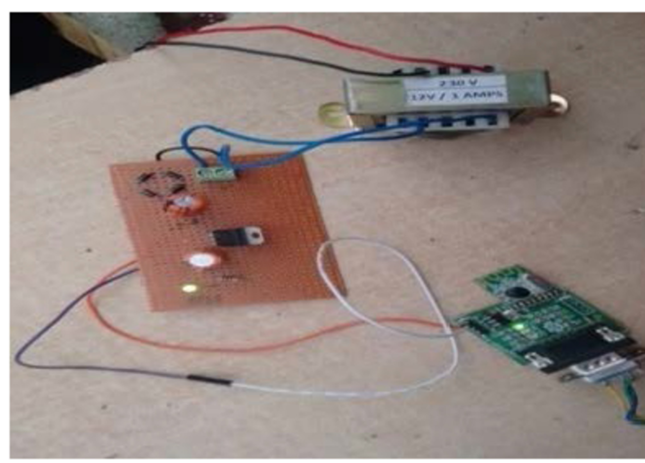

Fig. 16. Receiver section.

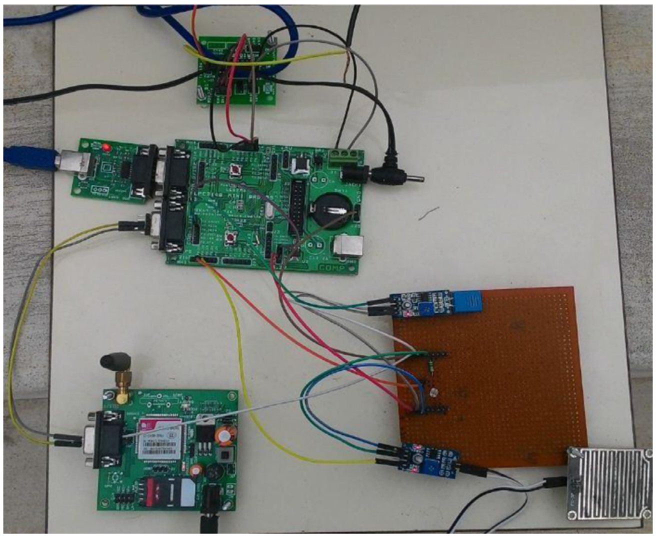

Fig. 17. Hardware setup.

hardware setup is shown in Fig. 17.

The proposed smart irrigation system is tested by recording the temperature during 15 days with maximum and minimum temperatures (Fig. 18).

The humidity percentage recorded within 15 days is demonstrated in Fig. 19. Fig. 20 demonstrates the water level for different irrigation methodologies. The results show that the proposed system has the less amount of water level compared to the manual irrigation and drip irrigation.

Fig. 21 describes the water consumption level of all the three methods in the period of three days. In this comparison, the proposed smart irrigation system pumps water in the period of 7 h, while the drip irrigation method and the manual flood irrigation method pumps water in 12 h and 20 h, respectively.

Fig. 22 demonstrates the cumulative percentage of time when the motor is in use for the period of three days. The proposed smart irrigation system uses the motor for 9.72% of the total time for watering, while the drip irrigation and the manual flood irrigation method use 16.67% and 27.78% of the total time for watering, respectively.

4. Conclusion

The agriculture irrigation control is one of the most significant interests in agriculture. This study mainly focused on fuzzy logic control to obtain higher level of accuracy to expertly use water for irrigation. The simulation result defines the water usage according to the field parameters in the agricultural field. The hardware implementation and irrigation control through Android phone

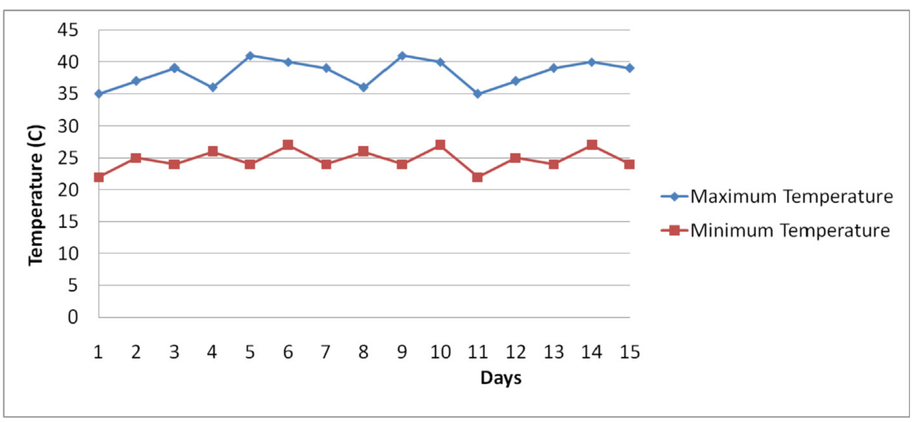

Fig. 18. Temperature.

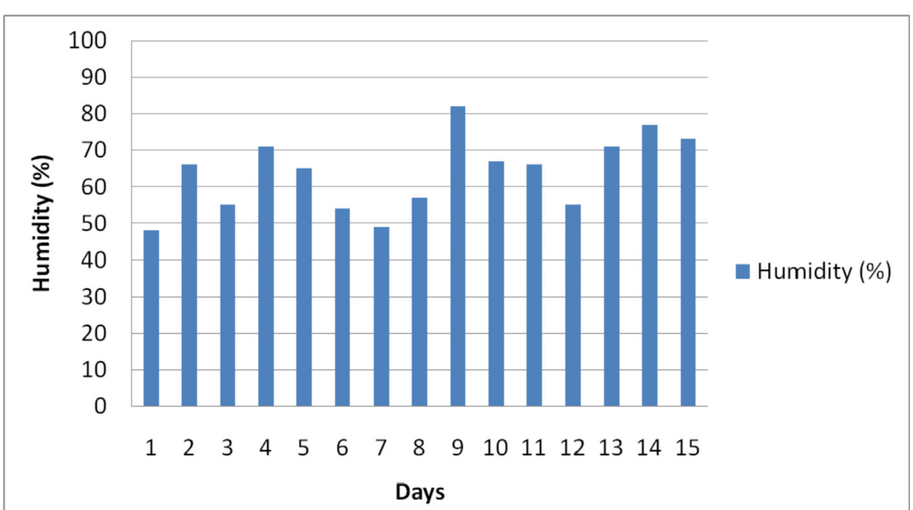

Fig. 19. Humidity.

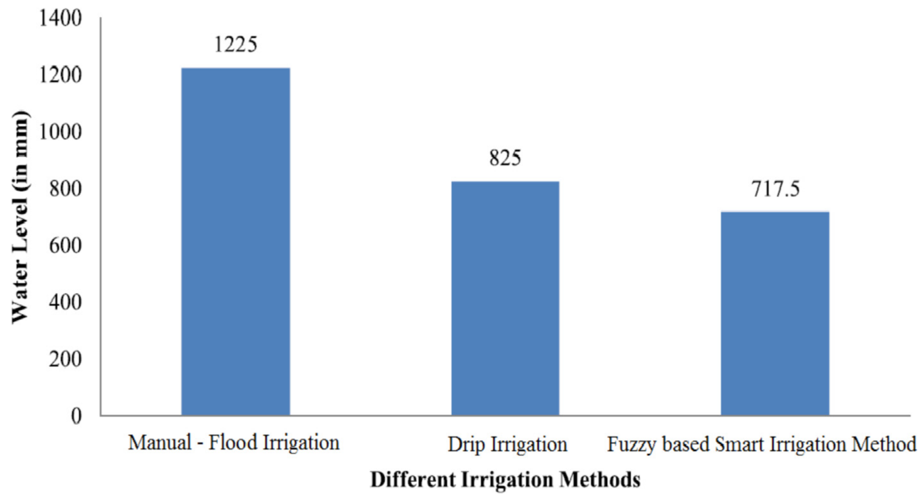

Fig. 20. Water level for the different kinds of irrigation methodologies.

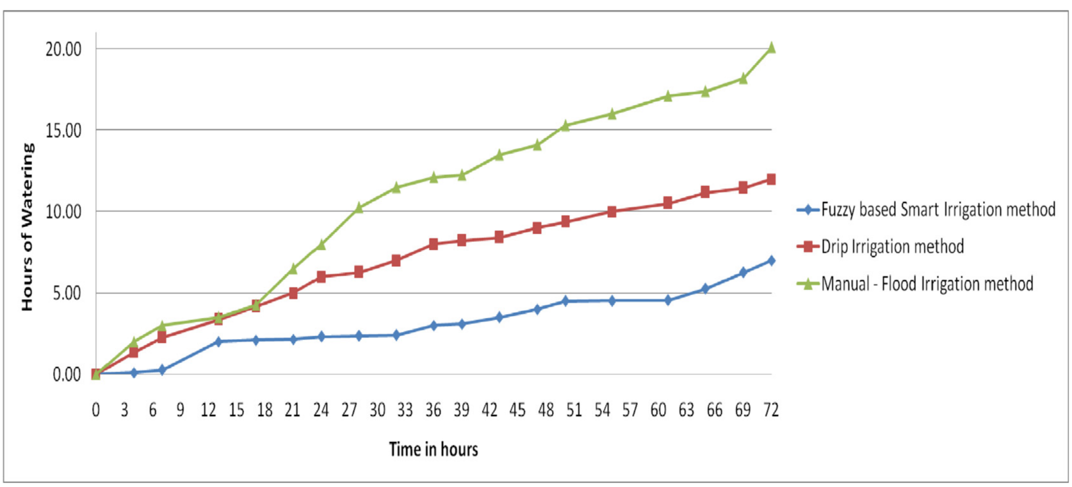

Fig. 21. Water consumption for the time period of three days.

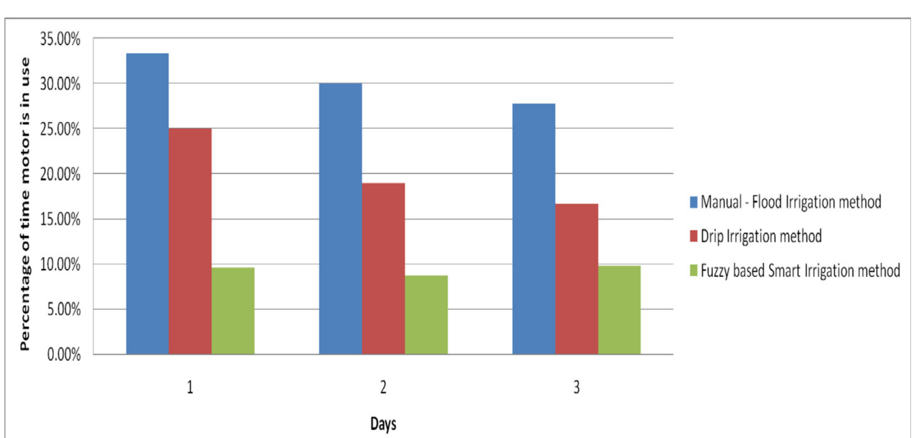

Fig. 22. Percentage of time when motor is in use.

application were implemented. It has been verified from the experiments that we can achieve excellent results such as low manual labor cost and effective usage of water for irrigation through the proposed smart irrigation system. Future studies may embed smart farming technologies using IoT, which will facilitate both growers and farmers to minimize waste and to enrich the productivity ranging from quality of fertilizers used to the amount of harvest made.

Author contributions

R. Santhana Krishnan is responsible for system implementation. E. Golden Julie is responsible for data collection and analysis. Y. Harold Robinson is responsible for first draft manuscript writing. S. Raja is responsible for system verification. Raghvendra Kumar is responsible for data processing. Pham Huy Thong is responsible for revising the manuscript and algorithm development. Le Hoang Son is responsible for algorithm verification and manuscript writing.

Declaration of competing interest

The authors declare that they do not have any conflict of interests. This research does not involve any human or animal participation. All authors have checked and agreed the submission.

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