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An intelligent and secure smart watering system using fuzzy logic and blockchain ☆

M. Safdar Munir[a], Imran Sarwar Bajwa[b,*], Sehrish Munawar Cheema[a]

[a] *Department of Computer Science & IT, Islamia University of Bahawalpur, Bahawalpur, Pakistan*
[b] *Department of Software Engineering, University of Sialkot, Sialkot, Pakistan*

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ABSTRACT

An intelligent Smart Watering System (SWS) is presented in this paper that is assisted with an Android application for smart consumption of water in small are medium-scale garden and fields. The proposed system banks on a set of accessible and economical sensors that capture real-time data of plants and environment conditions such as Soil Moisture Level, Light Intensity, air humidity, air temperature, etc. Once the data is collected from sensors on a server, the proposed SWS processes the data to decide about the watering schedule using Block-chain and Fuzzy Logic approach. Here, Fuzzy Logic approach helps in taking smart decisions with respect to watering requirements and Block-chain provides the required security in IoT enabled system by allowing only the trusted devices to access and manage the proposed SWS. In our approach, Blockchain technology plays an important role by providing scalability, privacy, and reliability in the proposed IoT base smart system. The multiple users and devices can be involved in monitoring and interacting remotely with plants by using Smart Watering System (SWS) (prototype) application that is developed in Android. Once the Fuzzy Logic based system decides the action on the bases of values of the input variables, the SWS activates the actuators to take watering actions such as turning water tunnels ON/OFF in periodical manner. The results of the proposed system show that it is efficient and secure application to efficiently handle the watering process of plants.

1. Introduction

In modern farming, the watering process is one of the important and critical processes due to shortage of sweet water in most of the area of the world [1]. Hence, there is need of automatic, intelligent and smart systems that can make smart utilization of available amount of water to feed plants for maximum time of the farming [2]. The automatic watering becomes a necessity in areas like Pakistan, India, etc. that are seriously hit by severe hot weather and drip irrigation system is widely used to support small level and medium level farming. However, drip irrigation system has not been efficient due to minimal control of watering quantity in day and night times, winter and summer seasons, etc. For better utilization of little resources of water more efficient, intelligent and smart solutions are required for better farming in severe weather conditions. Additionally, common people do not have much knowledge that how to grow plants in appropriate way. Essen-

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* Corresponding author.
E-mail address: imran.sarwar@iub.edu.pk (I.S. Bajwa).

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tial requirements to irrigate plants include soil properties like required moisture for a plant to be grown and adjustment of watering quantity with respect to the environmental temperature. Many technologies have been developed for better use of water in irrigation process [3–5]. However, these technologies are not smart enough for efficient utilization of lesser resources of water.

This paper primarily focuses on design and application of an automatic, intelligent and smart systems that can make smart utilization of available amount of water to feed plants for maximum time of the farming. Additionally, there is need of a mobile application that provides support of human distant monitoring of the watering process that is not only intelligent abut also secure [5,6]. Here, the Fuzzy Logic approach is used for smart decision-making with the help of set of fuzzy rules applying on the data received by the sensors planted in the field and controls the watering quantity with respect to the watering requirements of the plants. Additionally, to make this application secure, the Blockchain technique is used to provides secure access in the Internet of Things (IoT) enabled system by allowing only the trusted devices to access and manage the proposed SWS. Multiple users can monitor and interact remotely with plants by using Smart Watering System (SWS) (prototype) application that is developed in Android. Once the Fuzzy Logic based system decides the action on the bases of values of the input variables, the SWS activates the actuators to take watering actions such as turning water tunnels ON/OFF in periodical manner.

Humidity level in air and soil moisture level tends to vary in different parts throughout 24 h of a day. That's why the watering requirements also change in various parts of a day [6]. The proposed Smart Watering System (SWS) tracks intensity of light, humidity, temperature, soil moisture or water content by sensors and then cross-references this information through Wi-Fi with plant databases on server to give customized gardening guidance about irrigation and plant's health on smart phone through application. Additionally, different species of plants need different quantity of water, an intelligent and smart system is required for efficient utilization of sweet water reservoirs and efficient growth of plants [7,8]. In the design of such intelligent and smart watering systems, there is a need to quantify the input data collected from a set of sensors. For the study discussed in this paper, a limited number of plants are selected for modeling a prototype system and the respective data is collected at local zone to accurately recommend plant's requirement so that system can guide a user in a more precise way. The selected set of plants includes green chili, cucumber, mint, coriander, onion, garlic, radish, carrot, and tomato.

To smartly monitor and manage the watering quantity and process of the plants, the an Android application of Smart Watering System for smart phone is also designed, developed and tested in lab as well in field. The users of this Android application can efficiently monitor the current soil moisture level in comparison to the required moisture level for a particular plant and can also interact remotely with their plants by adjusting the watering quantity as per need of a plant type. Such real-time monitoring from a distant place via smartphone from a distant location around the globe with the help of Internet of Things (IOT) [8–10] and Blockchain technology [6]. Here, Blockchain technology provides secure connection to Server and secure working of the designed Android application. Since, the design of proposed SWS involves simple, obtainable, and affordable components; the use of proposed SWS at commercial level will be a cost-effective solution with high accuracy, efficiency, and throughput. The proposed system will also help in not only decreasing the cost of irrigation but also help in saving the sweet water reservoirs and better and efficient utilization of limited quality of the sweet water in reservoirs.

The major focus this project is to make our ecosystem healthy through grabbing the intention of people towards efficient utilization of the sweet water in plantation and gardening by making it smarter as well as time and cost effective. The rest of the paper is organized as follows: Section 2 introduces literature survey. Section 3 deals with system design and implementation. Methodology, system components are presented in Section 4, results & discussion in Section 5 followed by conclusion and future work in Section 6 and 7 respectively.

2. Literature review

During the detailed literature survey, a few related research works were identified that were focusing to improve the performance of agriculture with respect to different aspects as increasing soil power, etc. Suitable amount of soil water represents an obligatory term and condition for ideal growth of plant. As water is vital ingredient of life nourishment, so it is prerequisite to evade excessive use of water. A case study [5] of India where farmers are facing problems to irrigate agricultural lands because of power-cuts and low voltage of electricity supplied. If a farmer does not irrigate crops in that duration, probability is high of water and electricity wastage during that hours, also excessive watering can cause damage of crops. Keeping this view in consideration a system was developed using IOT integrated with mobile. System uses temperature and moisture sensors integrated with Raspberry-Pi to turn water pump in ON/OFF states automatically and remotely.

The GardenPi [7] monitoring and watering the garden automatically. The system had watering on the basis of weather forecast and timer. System looks up the forecast using the Forecast.io API and watered using Raspberry Pi by installing Raspbian, configuration with Wi-Fi access. Innovative sensors, form factor, time lapse, and user interface are all things that will be looking at for future versions. Similarly, GreenIQ Smart Garden Hub take into consideration about current, previous and forecasted weather conditions to make a watering schedule for plants. The system provides GreenIQ app to its users for selecting weather forecasting services from list like Dark sky, Weather UnderGround or some private weather stations to collect weather data. For private weather stations this system currently connected with Netatmo and Davis Instruments to get highly precise and localized weather data. So that according to outdoor conditions watering schedules would be optimized. The used algorithm compensates inaccurate weather forecasts and saves water by managing irrigation cycle duration taking considerations of variables like humidity, wind speed, solar radiation and temperature [8].

In another Smart Irrigation Monitoring and Controlling System [9] authors proposed a wireless sensor network is proposed based on cloud computing to monitor and control plants irrigation process. Smart Farm Irrigation System constitutes a set of sensors and actuators to measure and evaluate water needs of plants. System uses and android application to remotely access drips. Zigbee is used to make communication between sensors nodes and base station. To handle sensed data on real time, a web-based Java GUI is used.

In another system an Android mobile application facilitate users to provide full control in doing treatment of ornamental plants remotely like watering, fertilizing, refill water tank, changing the mode of UV glow light to ON/OFF states [10]. There is a need to optimize and control irrigation needs. Meadowlands would not be over-irrigated nor under-irrigated. Computer technologies have accepted because of efficient data gathering about plants environmental factors with high perseverance in less effort. In recent times, smart phones and mobile applications have a vital role in creating advanced and automated system [11]. These devices are also basic computing resource of all most all people worldwide because of its mobility. In our routine life due to immense incursion of smartphone use; Trend of developing of Android applications is becoming popular. A system called Smart resilient Garden Kit (SGK) was developed with IoT devices that could be rebuild and scale up. System consists of Arduino with a series of sensors installed with planter. Sensed data is stored in local database but can be accessed through a site and web app [12]. This system provides learning for gardeners (students) on water conservation by automation and conduct a bridge between computer study and this sustainability-centric system.

An automated irrigation system with low cost impedance-based moisture sensor system. Sensors come in operational form when a change in impedance occurs between electrodes implanted in soil [13]. A system to control irrigation and roofing process of greenhouse an Arduino technology was used. System inputs plant environmental data like temperature, humidity, water content in soil, light intensity using sensors and compare statistical results with weather forecast data to make an optimize decision. To remove noise from sensors Kalman filter was used. In [14] system is based on two sensors that are water-level sensor and flow sensor connected with irrigation canals and water pumps respectively. System uses WSN and sensors to send sensed data to wireless gateways which periodically forward data to server. IMS on web server analyze data stored in database to for making comparison between currents and predefined values. If water requirement needed IMS sends SMS alert to farmers. System [15] is an IoT enabled digital technique to handle irrigation system. Sensors are implanted in ground to measure moisture level and also checks water level in tank, well-water via smartphone network communication. On server, there are intelligent software [16] to assess sensed data to take effective decision about watering. For improved management of water, a system [17] was introduced that was using a GSM module for monitoring the water level tank and suggest exact amount of water need for crops. System also monitor humidity and temperature to sustain nutrient level in soil necessary for plants growth.

In the recent times, Blockchain is becoming ushering for secure data transmission in IoT based systems. Currently agricultural products traceability has becoming crucial issue [18]. In [19] a provenance system was proposed using block chain for agricultural products tracing and various agricultural managerial operations like plants irrigation, fertilizing etc. Use of block chain information is recorded of dispersed farmers, growers and sellers and many production operations data with great safety and in decentralized manner.

An ICT e-agriculture system was built using infrastructure of block chain. The system safeguarded the data integrity of environmental factors in agricultural perspective [20]. Block chain in e-agriculture facilitates farmers to get and ensure immutability of highly worthy and quality data. Block chain infrastructure enhances the accessibility and traceability of irrigation control data spatially.

In Taiwan, the farmland irrigation development has contributed to improve the agricultural products and rural livelihood by modernizing the agricultural procedures. When irrigation data accessed through different farmland irrigation associations is integrated using block chain mechanism it serves as an information source for compiling histories of irrigation canals. This data could be used for planning a maintenance process of these irrigation resources. And block chain infrastructure serves here as a bridge between society and irrigation association to support and save water for plants irrigation [23]. A comparison of the previous approaches is shown in Table 1.

The previous work in the domain is focusing on better utilization of irrigation water considering the soil moisture with the help of moisture sensor. However, there are some other very important parameters such as air humidity, temperature, light intensity, plant type, soil type, climate nature, etc. that play role in water consumption and growth of plants. Since, various plants types have various watering needs and similarly, same plant can have different watering needs considering the soil type and climate nature. The statistics shown in Table 1 clearly highlight that there is need of an intelligent system that measure real-time watering needs of plants considering all possible parameters mentioned above. The Smart Watering System (SWS) is an attempt to present a such solution that considers multiple parameters instead of considering only one parameter soil moisture. The architecture and working of the proposed SWS is given in the following section.

3. Architecture of smart watering system

The proposed Smart Watering System is designed with the ability of Blockchain security support [26] to track and trace the device transactions performed during the processing of the Smart Watering System (SWS). Such ability to trace blockchain based transaction does not only enable the proposed system to provide security and privacy features but also

Table 1
Comparison with the previous approaches.

Previous systems	Features				
	Precision irrigation (PA)	Secure communication	Decision support irrigation	Optimize energy consumption	Decentralized database
Rao, R.N. and Sridhar, B., 2018 [2]	Yes	NO	NO	NO	NO
Garcia Paucar, Luis, et al. 2015 [21]	Yes	NO	NO	Yes	NO
de Ocampo, A. L. P., & Dadios, E. P. 2017 [22]	Yes	NO	NO	Yes	NO
Carlos Kamienski et al., 2018 [23]	NO	Yes (Semi implementation)	NO	NO	NO
Goap, Amarendra, et al. 2018 [24]	Yes	NO	Yes (No fuzzy decision logic)	NO	NO
Banđur, Đoko, et al. 2019 [25]	Yes	NO	NO	Yes	NO
Hamouda, Y. E. 2017 [26]	Yes	NO	Yes (using fuzzy logic)	NO	Yes
Proposed approach	Yes	Yes	Yes	Yes	Yes

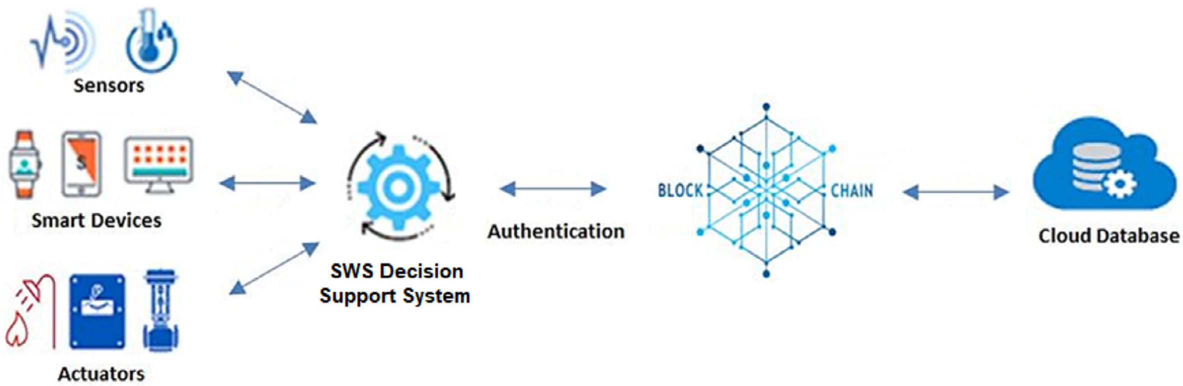

Fig. 1. Blockchain based IoT model for smart watering system.

provides seamless connectivity and availability of the features proposed smart system. The architecture of the proposed system is shown in Fig. 1. The concept of central storage may cause security threats but in our system we implanted the decentralized storage of irrigation and plants database by implementing the concept of blockchain. Here, Fig. 1 of proposed SWS shows the communication channels between smart devices, sensors, actuators and cloud storage, users and network. The smart devices act as nodes and each node contains a copy of blockchain (a family of blocks). If user needs to irrigate plants; each node must verify the transaction; a type of electronic voting. If majority of nodes validate the transaction it is permitted to occur and recorded with a hash code in blockchain and its copy is sent to each node for further use. As each family of block will be updated every ten minutes that's why it's a secure way of communication that is impossible to forge the system security. Thus the requests to receive data from devices and secure storage and delivery to users is achieved with the help of Blockchain based IoT model.

The Blockchain module was implemented in Java by defining a block's contents in hash that is a unique identifier. Each block can compute a block-hash and then a SHA-256 hash is computed from it. A block is created when a threshold is achieved, and connectivity requests are accepted by managing blockchain. The chain of blocks is looped-over to verify a block's hash is matched to the previous block's hash for the sake of validity of the entire blockchain.

The proposed system has four layers as shown in Fig. 2. These four layers of proposed Smart Watering System are Application layer, Management layer, Network and Connectivity layer and Device and Perception layer. All these layers interact with each other to provide a secure communication in devices and sensors for seamless working of the proposed smart watering system.

The Device and Perception layer includes all the hardware devices such as sensors, actuators, microcontrollers that connected and communicate with each other using Wi-Fi modules. The upcoming layer is the Network and Connectivity layer that contains networking components, WiFi and Bluetooth modules. This layer supports the transmission of information between gardeners and hardware. It provides access to cloud server. It handles resources remotely and cause high level processing. The Management layer handles device management, cloud storage and the Block chain based security module. Block chain provides safe channels for transmission of data between users (gardeners) and hardware devices [18]. The cloud

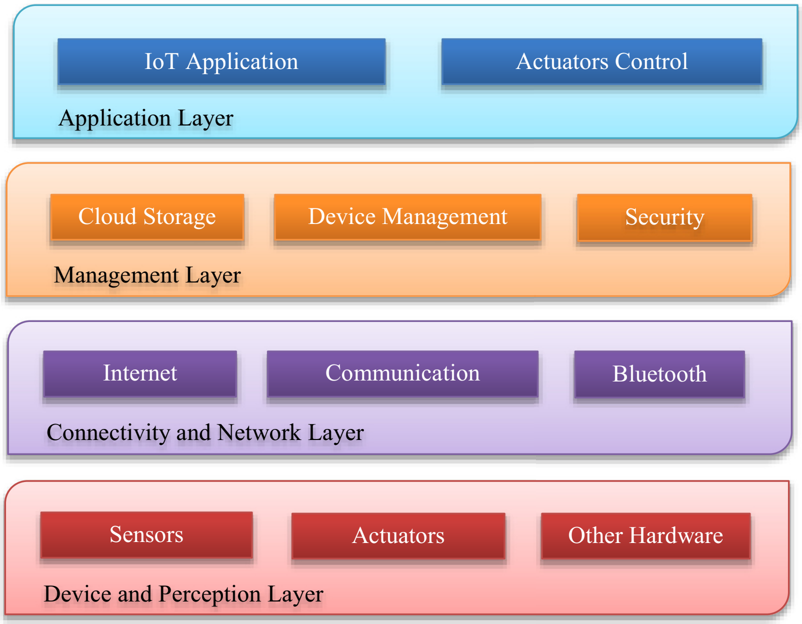

Fig. 2. Smart watering system architecture.

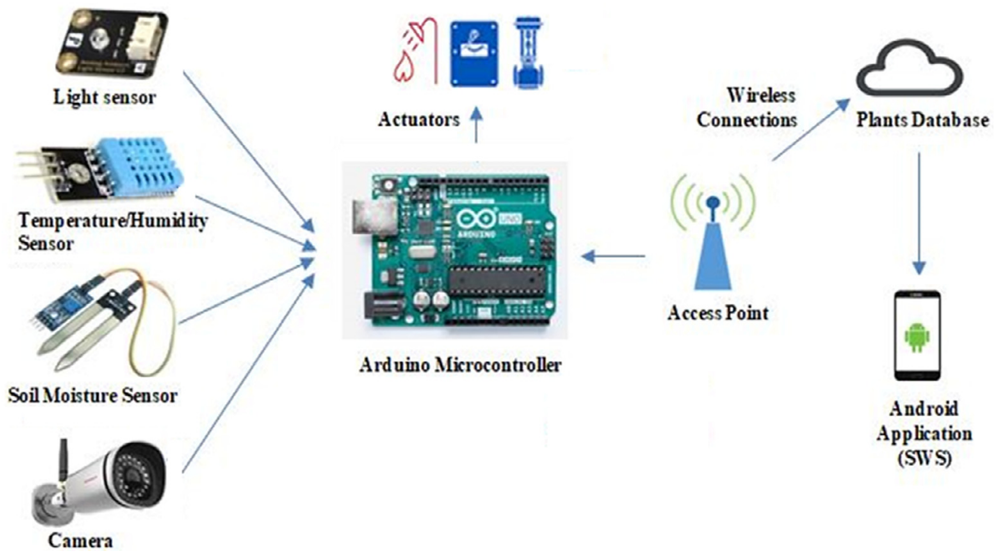

Fig. 3. Design of hardware integration of the proposed system.

database for plants provide through remote server resources used for decision making in irrigation. Device management component handles smart devices connected remotely to our system by using an interface provided by top level layer that is application layer. On application layer end user interfaces will be available that is an android application named Smart Watering System (SWS). By login to that application gardener can monitor and control the irrigation process and set a schedule to control the actuators for some specific type of plants.

The Fig. 3 represents the architectural design to view of physical components of system. It contains all the hardware devices and architecture of smart vegetable garden system as deployed in real world environment. As shown in Fig. 3 on the leftmost side, there are light and moisture sensors which are connected through analog input with microcontroller same as humidity, camera and temperature sensors are connected through digital input. On the other hand, actuators (water pump and lights) are connected to serial output of microcontroller, here microcontroller work as a centralized device which takes input from sensors and transmit this information towards server through internet. The server sends the sensor's data such as light intensity value, change rate of temperature, change rate of humidity, soil moisture, etc. to the proposed fuzzy logic module that assesses and decides the current water needs of the plant considering the type of plant with the help of the plant database. Once the decision is taken regarding watering needs of the plant the decision is communicated on a mobile application (SWS) for further necessary action. A user can automatically set the reaction to manual or automatic handling of the actuators available in the system.

4. A decision-support system for smart watering

The decision support system based on fuzzy logic is the main component of the proposed Smart Watering System (SWS) gets helps in taking decisions on the basis of data achieved from the sensors. The used fuzzy logic module is supported by a plant knowledgebase that helps in taking plant specific decisions. The fuzzy logic is used in this module due to its bi-fold significance. First, fuzzy logic is a better approach for decision making problems. Secondly, fuzzy logic is simple and easy tom implement in IoT applications. Once the fuzzy logic module takes a decision regarding watering needs of the plant, the decision is communicated on a mobile application developed in Android.

The Fig. 4 shows the main components (such as fuzzification module, a set of fuzzy rules, an inference engine, and a defuzzification module) of the proposed Fuzzy Logic based decision support system. In a typical, fuzzy logic system, a universe of discourse U is implied in a fuzzy set *S* is a pair (*U, m*) [5], whereas a fuzzy set is an ordered pair of an variables *v* and a membership function *mS(v)*. The Eq. (1) shows the composition of set *S*:

$$S = \{(v,\ ms(v),\ v \in U)\} \tag{1}$$

Following steps are followed in implementation of the Fuzzy Logic module:

Step-1. A set of variables are defined (see Eqs. (1) and (2))
Step-2. A set of membership functions are defined
Step-3. For each variable, a set of rules are defined
Step-4. A set of inputs (crisp inputs) such as x_1, x_2, x_3, ... $x_{|n|}$ are given.
Step-5. A membership function is defined and used for each input crisp value to map it to a fuzzy value.
Step-6. Inference for each rule the set of fuzzy rules is achieved.
Step-7. An aggregation of inference each rule is achieved.
Step-8. The resultant inference value is converted to crisp output value Y.

As described in Step-1, the used Fuzzy Logic decision support system is designed to handle five variables such as change rate of temperature, change rate of humidity, intensity of light, and change rate of moisture and type of plant. These five variables are defined as five subsets of set *S* (*A, B, C, D*, and *E*) is define. As shown in Eqs. (1) and (2), change rate of temperature is represented by variable A, change rate of humidity is represented by variable B, light intensity is represented by variable C, change rate of moisture is represented by variable D and the time is represented by variable E.

As described in Step-2, a set of membership functions are defined for each input crisp variable such as $m_A(x)$, m_B (x), $m_C(x)$, $m_D(x)$, $m_E(x)$ are the membership functions of variables A, B, C, D, and E, respectively. These membership functions denote the degree of membership of variable x in variables A, B, C, D, E. as defined in Eqs. (2) and (3), given below:

$$\mathrm{A} \cup \mathrm{B} \cup \mathrm{C} \cup \mathrm{D} \cup \mathrm{E} = \{\mathrm{x},\ \max(m_A(\mathrm{x}),\ m_B(\mathrm{x}),\ m_C(\mathrm{x}),\ m_D(\mathrm{x}),\ m_E(\mathrm{x}))\ |\ \mathrm{x} \text{ is an element of } S\} \tag{2}$$

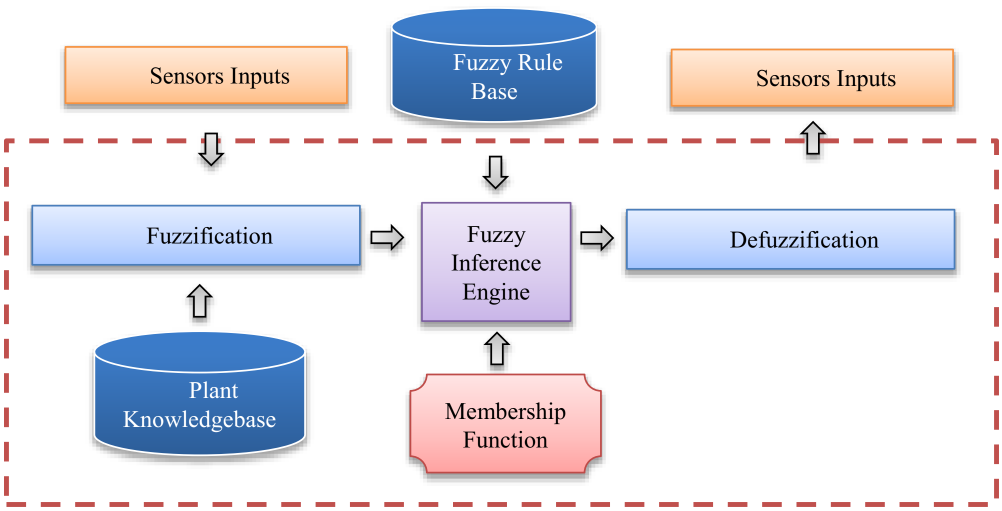

Fig. 4. Fuzzy logic controller for smart watering system.

$$\mathrm{A \cup B \cup C \cup D \cup E} = \{\mathrm{x},\ \min(m_A(\mathrm{x}),\ m_B(\mathrm{x}),\ m_C(\mathrm{x}),\ m_D(\mathrm{x}),\ m_E(\mathrm{x}))\ |\ \mathrm{x\ is\ an\ element\ of}\ S\} \tag{3}$$

As described in Step-3, in the implementation of fuzzy logic based decision support system, the if-then rules are used to implement the set of fuzzy rules. Each of the three components of the proposed fuzzy logic systems mentioned in Algorithm I are implemented into a module and working of each module is discussed in the following text:

As given in Step-4, the membership functions for variables A, B, C, and D are defined as C*hange_rate_of_Temperature, Change_rate_of_Humidity, Change_rate_of_Moisture, Light* and are valued as "Low", "Mid", and "High". Whereas, and membership function for variable E is defined as *Time* and is valued as "Day" and "Night". Eq. (4) shows that the fuzzy set $\mathrm{K(x_i)}$ is kernel of fuzzification and is implemented using mapping μ_i and x_i to a fuzzy set $\mathrm{K(x_i)}$.

$$\sim A = \mu_1 K(x_1) + \ \mu_2 K(x_2) + \ \mu_3 K(x_3) + \ldots + \ \mu_n K(x_n) \tag{4}$$

As described in Step-5, the process of fuzzification is implemented using the Eq. (4). In our implementation, a triangular membership function [15] is as given in Eq. (5).

$$\mu_A(\mathrm{x}) = \begin{cases} 0, & x \le \mathrm{a} \\ \frac{x-a}{c-a} & a < x \le \mathrm{c} \\ \frac{b-x}{b-c} & c < \mathrm{x} < \mathrm{b} \\ 0, & \mathrm{x} \ge \mathrm{b} \end{cases} \tag{5}$$

The min and max operations are used to find the fuzzy values from the crisp input values as shown in the Eq. (6):

$$triangle(x; a, b, c) = max\left(min\left(\frac{x-a}{b-c}, \ \frac{c-x}{c-b}\right)\right) \tag{6}$$

As show in Eq. (6), the **x** coordinates of the three corners of the targeted triangular membership function are defined as three parameters such as **a, b, c** where **a < b < c**. As given in Eqs. (5) and (6), the membership functions are defined for all five variables (four inputs and one output) of the used fuzzy logic system. The output linguistic variable "water_need". These membership functions are defined using MATLAB Fuzzy Logic toolbox.

As described in Step-6, a fuzzy inference system is a main component of proposed SWS for decision making used that is based on a set of if-then rules, a set of membership functions and fuzzy logic operators such as "and", "or". In the proposed approach, the fuzzy inference is mapped from an input to an output using fuzzy logic using Mamdani fuzzy inference system [23] is used that was originally introduced by WeEbrahim Mamdani in 1975. The used Mamdani fuzzy inference system is implemented in the following six steps:

1 Fuzzification of input using membership function.
2 According to fuzzy set theory the fuzzified inputs are combines.
3 Built fuzzy rules.
4 Finding outcomes of the rules by combining rule strength and output membership function.
5 Get an output distribution by combining the outcomes.
6 Defuzzification of the output membership function.

A detailed process of Mamdani FIS [27] using four inputs and two rules is illustrated and defined in Eqs. (7) and (8) where the input x_1, y_1 and z_1 is fuzzy, not crisp.

$$\mathrm{IF\ (U_1\ is\ A1_1\ AND\ W_1\ is\ A1_2\ AND\ X_1\ is\ A1_3\ AND\ Y_1\ is\ A1_4\ AND\ Z_1\ is\ A1_5)THEN(w\ is\ B1)} \tag{7}$$

$$\mathrm{IF\ (U_2\ is\ A2_1\ AND\ W_2\ is\ A2_2\ AND\ X_2\ is\ A2_3\ AND\ Y_2\ is\ A2_4\ AND\ Z_2\ is\ A2_5)THEN}\left(\mathrm{w\ is\ B^2}\right) \tag{8}$$

The three inputs are fuzzified by applying intersection on crisp input value with the input membership function. For combining, the three fuzzified inputs to obtain rule strength by using operator "and". The used Mamdani inference system uses a membership function for each rule and then according to the condition of the rule reaches to a conclusion.

This is a last step in the implementation of FMWS whereas the output is evaluated from a rule set that is written in the form of if-then statements and saved in a knowledge base of the system. Here, a scalar value of fuzzy system is fuzzified, rules are applied, and each rule generates a fuzzy output and converts it to a scalar quantity. In this approach centroid defuzzification method is used because it gives an accurate result which is originally developed by Sugeno in 1985. This technique is expressed mathematically in Eq. (9) as

$$x^* = \frac{\int \mu_i\ (\mathrm{x}).xdx}{\int \mu_i(\mathrm{x}).dx} \tag{9}$$

Where **x*** is the defuzzified output, $\mu_i(\mathbf{x})$ aggregated membership function and **x** is the output variable in Eq. (9), where x-axis represents the output variable x, y-axis represents $\mu_i(\mathbf{x})$ aggregated membership function and x* is the defuzzified output. The shape of output is obtained by applying fuzzy operator "and" by clipping the output membership function according to the rule strength.

5. Implementation of smart watering system

Following is the list of the hardware devices and sensors that are used in the implementation of the proposed Smart Watering System (SWS):

- Arduino-UNO R3(Arduino Nightly)
- Bread Board
- 12v Water Pump
- 5v Relay
- Wi-Fi Module ESP 8266–01
- Standard wires and jumpers
- Ambient Light sensor
- DHT-11 Temperature & Humidity sensor
- YL-69 Soil Moisture Sensor

5.1. Server side of smart watering system

A server-side application was designed to handle the proposed Smart Watering System, with the help of a web-based interface. The interface of the management provide different options to control the Smart Watering System. This page also includes the option for administrator to be login into system and also shows description of system working.

To manage plants data at admin panel, system provides a dash-board to manage plants data on server side. Admin can add news plant with its details regarding to planting period, fertilizer to be used, required water level and other details; in the plant list that will be available and visible to gardener according to preference. Administrator can delete plants details irrelevant and unneeded from repository. Admin manage users by allowing them to create his accounts to SWS to avail functionalities of system.

5.2. Mobile application for smart watering system

An android application for Smart Watering System (SWS) is also designed that allow the user to remotely control the system. Tabbed menu shows basic controls of application to user. It provides access to user for the main features of the system as monitoring garden, controlling actuators and recommendations tab. Number of stars shown under the name of each vegetable; represent the suitable season and time for planting that vegetable according to an area's climate e.g. coriander, mint and spinach are planted in same season thus their probability to grow is approximately the same. Behind this will be an artificial agent provided with data then it will match between plant's currents and predefined state to provide customized gardening guidance such as when to grow a plant, which fertilizer to be use, when to trim, estimated time to harvest, is the season is appropriate to germinate desired plant and appropriate schedules for irrigation.

The Mobile app uses system's calendar to set a schedule for watering plants. Real time values of sensors are processed on server and list of plants with their feasibility rating is sent to user's mobile. Users can schedule watering of plants. When specific date & time of schedule arrives or water level get lower in garden it notifies to user to set water pump in ON state by just clicking on a button in application from anywhere in the world. Ultimately when water content in ground increases to predefined limit water pump get state OFF.

6. Results and discussion

The real time sensed data that are facts received by master node is shown in table. 1(a) which is stored at the cloud for further decision making. The web server is used to monitor and store real time sensed data from master node. Our expert system on server consists of a knowledgebase with predefined rules shown in Tables 2–4 and a database of facts received by plant sensors. A rule-base inference engine matches fact with knowledgebase entries. Evaluating the real time sensed values of four parameters temperature, humidity, moisture, light; recommendations about which plant should be planted in garden in current season, are put to gardener. Table 5 shows the sensed data from temperature, humidity, soil moisture and light sensors transmitted by microcontroller from sensors, received at the server side. We categorized soil moisture data received by sensors as shown in following Tables.

Table 2
Moisture categorizations.

Moisture	Category
0 – 449	High/Dry
450–600	Normal
601–1000 or above	Low/Wet

Table 3
Humidity categorizations.

Humidity	Category
80 or above	High
60–79	Normal
< 60	Low

Table 4
Soil moisture categorizations.

Light	Category
High	Dry
Low	Wet

Table 5
Collected input data from sensors.

Chip ID	Temperature (°C)	Humidity	Light	created_at	Moisture
Pot1	10	12	12	2018-07-11T14:27:38.9900000	13
Sp2	10	12	12	2018-07-12T10:26:49.7000000	13
Mi3	10	12	12	2018-07-12T20:47:27.9600000	19
Co4	29.2	97.7	1023	2018-07-13T20:23:41.6200000	42
R5	25.7	71.7	49	2017-10-13T08:23:17.3530000	982
Cap6	6	9	9	2018-07-14T20:12:54.9570000	6
To7	12	12	12	2018-07-16T18:19:11.0630000	12
Pot8	1	3	3	2018-07-16T19:07:05.0900000	3
Cor9	25.7	73.2	48	2017-10-13T08:21:55.8730000	1011
Oni10	31.5	77.7	34	2017-10-12T15:27:19.0570000	343

Table 6
Table of the SWS results of 12 experiments.

Sr. no.	C-R-temp (°C)	C-R-moisture (Voltage)	C-R-humidity (%age)	Time (Minutes)	Chances of dry soil (%age)	Test case	Actual case	Accuracy (%age)
1	1.51	High	8.83	2.53	23.1	Low	Low	100%
2	5	High	10	4	45	Mid	Mid	100%
3	3.67	High	9.28	2.53	40	Mid	Mid	100%
4	7.41	High	12.9	1.99	61.2	High	High	100%
5	6.69	High	16.3	2.35	83.4	High	High	100%
6	1.27	High	15.8	2.35	45	Mid	Low	50%
7	5.48	High	11	1.39	65.9	High	High	100%
8	9.1	High	15.3	4.04	83.9	High	High	100%
9	7.89	High	14.3	8.3	82.9	High	High	100%
10	1.87	High	3.01	1.39	14.3	Low	Low	100%
11	2.71	High	5.18	2.47	45	Mid	Mid	100%
12	7.29	High	7.35	1.39	67.7	High	High	100%

The statistics shown in Tables 2–4 are the key limits that are associated with the designed fuzzy logic module to decide the current watering needs of the plants. Table 5 shows the results of the sensor's used in the experiments. System's rule-base engine compares sensed values of plant parameters stored in facts database with threshold values stored in knowledge base. It computes percentage of number of rules that match with input parameters as a score of some specific plant i.e. "gain". And transmit this value of score to recommender tab on android application of gardener in the form of rating stars. These ratings show suitability of that specific plant to grow in current environmental conditions.

For irrigation control of garden, three to four times a day sensed data is transmitted to server where these values are compared with threshold values of temperature, humidity, moisture and light to check whether to irrigate plants or not. If conditions to water the plants fulfill then user is notified about it [26–35]. When soil moisture or water content level is maintained, water pump is turned off. After experiments, all results are collected, now in this section results are discussed, and all experiment results are illustrated in Table 6.

Results of the experiments shown in Table 6. In experiment 6 to 12 few of them are High and few are Mid chances of fire. As it can be observed from Table 6. The accuracy of proposed SWS in most of experiments is 100% which means the system is working according to our defined rules for SWS. The overall SWS is calculated below:

$$\text{SWS accuracy} = \sum \frac{\mu(\text{aj})}{\text{n}} \tag{10}$$

Table 7
Sensors data to control actuator's response.

Sr.	Temperature	Humidity	Light intensity	Soil moister level	Water pump status
1	31.5	78.2	35	358	ON
2	31.5	79.7	42	1019	OFF
3	25.2	67.2	50	1013	ON
4	12	13	13	4	ON

In Eq. (10), we calculated SWS accuracy where $\mu(a_i)$ represents the accuracy percentage of each experiment and n represents the total number of experiments. And according to experiments we achieved accuracy 95.83%. Table 6 shows the sensor's data and effect on actuators after the fuzzy logic based decision is taken.

Table 7 highlights the statistics of sensor' data that instigated the action taken by the fuzzy logic module to turn actuators (such as water pump) turn ON or OFF with respect to the current soil moisture and air humidity and temperature.

The proposed system is designed to detect dry-soil cases at early stage, it is very effective for this purpose which is found in some previous solution and it also has many advantages as well as few disadvantages. As we have provided the initial framework to use IOT in agriculture, so this project has the flexibility of future extension as well, currently system is working for only ten selective plants it can be extended to more plants by implanting more sensors, more attributes can be added in data set and use advanced algorithm such as genetic algorithm, multi-agents and neural networks to generate more precise recommendations & predictions and system would be in mature state. Developed system irrigate plants by getting response commands by gardener (manual intervention of user) but in future irrigation process could be autonomous if user do not bother a threshold of notifications due to busyness to water the plants.

7. Conclusion and future work

In this era where everything is emerged with the technology so there is a huge need to advance the agriculture especially in our country 'Pakistan' which is an agricultural country. We have to use the computer technology to increase efficiency and productivity of crops. Our project is an expert system based on the Internet of Things (IOT) used to monitor and control garden from anywhere using smartphone. System use the input data collected in real time through sensors & guide farmers/gardeners through smart recommendations. Mobile app displays a list of suggested plants according a region's climate and season; that user can select along with general information like plants description, types of plants, standard humidity level and temperature of plant's environment, water content required or fertilizer, suitable time to water and fertilize plants. Users of application only press "add" button for preferred plants available in suggested list and microcontroller in collaboration with application take automatically set best care of those selected plants. Furthermore, android application provides users live monitoring of garden in the form of video feed. It helps to take hands-on reduction of irrigation cost and increase in yield.

In future, more water save solution could be found by using Fuzzy Decision Support System (FDSS). Water leakage can be monitored if water pipeline would be leak or in disorder remotely. By performing root analysis and measuring the parameters: leaf temperature, leaf humidity probability of specific diseases could be predicted like fungus moisture due to over moisture of soil. As a result, system will provide more precise recommendations about fertilizers for plants. Furthermore, the mobile app will facilitate users to perform live monitoring in the form of a video feed. In future system would be enhanced for outdoor utilization. Current scope is Punjab and we are very confident to expand it to whole Pakistan as well as the whole world.

Conflicts of interest

The authors declare no conflict of interest.

References

[1] Burton L, Dave N, Fernandez RE, Jayachandran K, Bhansali S. Smart gardening IoT soil sheets for real-time nutrient analysis. J Electrochem Soc 2018;165(8):B3157–62.
[2] Rao RN, Sridhar B. IoT based smart crop-field monitoring and automation irrigation system. 2018 2nd International Conference on Inventive Systems and Control (ICISC). IEEE; 2018. January.
[3] Munir MS, Bajwa IS, Naeem MA, Ramzan B. Design and implementation of an IoT system for smart energy consumption and smart irrigation in tunnel farming. Energies 2018;11:3427.
[4] Dorri A, Kanhere SS, Jurdak R, Gauravaram P. Blockchain for IoT security and privacy: the case study of a smart home. In: Pervasive Computing and Communications Workshops (PerCom Workshops), 2017 IEEE International Conference on. IEEE; 2017. p. 618–23. March.
[5] Azhar FC, Irawan B, Saputra RE. Controlling and monitoring ornamental plants care remotely using android application. In: Wireless and Mobile (APWiMob), 2017 IEEE Asia Pacific Conference on. IEEE; 2017. p. 12–18. November.
[6] Khan MA, Salah K. IoT security: review, blockchain solutions, and open challenges. Future Gener Comput Syst 2018;82:395–411.
[7] "GardenPi," 2014. [Online]. Available: https://spin.atomicobject.com/2014/06/28/raspberry-pi-gardening/. [Accessed 2018].
[8] Kolias C, Stavrou A, Voas J, Bojanova I, Kuhn R. Learning internet-of-things security "hands-on". IEEE Security Privacy 2016;14(1):37–46.
[9] Gubbi Jayavardhana, Buyya Rajkumar, Marusic Slaven, Palaniswami Marimuthu. Internet of Things (IoT): a vision, architectural elements, and future directions. Future Gener Comput Syst 2013;29:1645–60 ELSEVIER.

[10] h Ram VV, Vishal H, Dhanalakshmi S, Vidya PM. Regulation of water in agriculture field using Internet of Things. In: 2015 IEEE Technological Innovation in ICT for Agriculture and Rural Development (TIAR); 2015. p. 112–15.
[11] Saraf SB, Gawali DH. IoT based smart irrigation monitoring and controlling system. In: Recent Trends in Electronics, Information & Communication Technology (RTEICT), 2017 2nd IEEE International Conference on. IEEE; 2017. p. 815–19. May.
[12] Halweil B, Nierenberg D. Farming the cities. In: State of the world 2007. Routledge; 2013. p. 80–97.
[13] Pienaar JP, Fisher RM, Hancke GP. Smartphone: the key to your connected smart home. Department of Electrical, Electronic and Computer Engineering, University of Pretoria and university of Hong Kong; 2015.
[14] Santosh KG, Sudarshan Ghuge G. A modern farming techniques using android application. Int J Innov Res Sci Eng Tech (IJIRSET) 2015;4(issue 10):1–8.
[15] Angal S. Raspberry pi and Arduino based automated irrigation system International Journal of Science and Research (IJSR) ISSN (Online): 2319–7064.
[16] Sensor based automated irrigation system with IOT. Int J Comput Sci Inform Tech 2015;6(6):5331–3 ISSN: 0975-9646.
[17] Pavithra DMS, Srinath. GSM based automatic irrigation control system for efficient use of resources and crop planning by using an android mobile. IOSR J Mech Civ Eng (IOSR-JMCE) 2014;11(4):49–55 e-ISSN: 2278-1684,p-ISSN: 2320-334XVer. I (Jul-Aug).
[18] Hua J, Wang X, Kang M, Wang H, Wang FY. Blockchain based provenance for agricultural products: a distributed platform with duplicated and shared bookkeeping. In: 2018 IEEE Intelligent Vehicles Symposium (IV). IEEE; 2018. p. 97–101. June.
[19] Sarwar B, Bajwa IS, Ramzan S, Ramzan B, Kausar M. Design and application of fuzzy logic based fire monitoring and warning systems for smart buildings. Symmetry 2018;10:615.
[20] Lin YP, Petway JR, Anthony J, Mukhtar H, Liao SW, Chou CF, Ho YF. Blockchain: the evolutionary next step for ICT e-agriculture. Environments 2017;4(3):50.
[21] Garcia Paucar Luis, Ana Ramirez Diaz, Federico Viani, Fabrizio Robol, Alessandro Polo, Andrea Massa. Decision support for smart irrigation by means of wireless distributed sensors. Inst Elect Electron Eng 2015.
[22] de Ocampo ALP, Dadios EP. Energy cost optimization in irrigation system of smart farm by using genetic algorithm. In: Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM), 2017 IEEE 9th International Conference on. IEEE; 2017. p. 1–7. December.
[23] Kamienski C, Kleinschmidt J, Soininen JP, Kolehmainen K, Roffia L, Visoli M, Fernandes S. SWAMP: smart water management platform overview and security challenges. In: 2018 48th Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W). IEEE; 2018. p. 49–50. June.
[24] Goap A, Sharma D, Shukla AK, Krishna CR. An IoT based smart irrigation management system using Machine learning and open source technologies. Comput Electron Agric 2018;155:41–9 June.
[25] Banđur Đ, Jakšić B, Banđur M, Jović S. An analysis of energy efficiency in wireless sensor networks (WSNs) applied in smart agriculture. Comput Electron Agric 2019;156:500–7.
[26] Hamouda YE. Smart irrigation decision support based on fuzzy logic using wireless sensor network. In: Promising Electronic Technologies (ICPET), 2017 International Conference on. IEEE; 2017. p. 109–13. October.
[27] Mamdani EH. Application of fuzzy algorithms for control of simple dynamic plant. Proc. Inst. Electr. Eng. 1947;121:1585–8.

M. Safdar Munir received the MCS degree from Islamia University Bahawalpur, Pakistan in 2006 and the MS degree in computer science from the Islamia University of Bahawalpur, Pakistan in 2014. He is currently pursuing his PhD degree from the Islamia University of Bahawalpur. His current research interests include IoT, and Intelligent systems.

Imran Sarwar Bajwa is Associate Professor in Department of Computer Science & IT, The Islamia University of Bahawalpur. He received his PhD degree in Computer Science from the University of Birmingham, UK. He has published more than 150+ papers in well-reputed peer-refereed conferences and journals. He has 970+ citations in Google Scholar. Additionally, he has 50+ articles in ISI Web of Science and 90+ articles in Scopus and 300+ citations of his work in Scopus. Bajwa has more than 15 years of teaching research experience at various universities of Pakistan, Portugal, and United Kingdom. He has very good programming skills in Java and C#. He was chair of ACM Bahawalpur Chapter in 2016–17.

Sehrish Munawar Cheema currently works at the Department of Software Engineering, University of Sialkot. She does research in Software Engineering, Data Mining and Programming Languages. Her current project is 'irrigation control and monitoring using IoT'.