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Research Article

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A secure framework for IoT-based smart climate agriculture system: Toward blockchain and edge computing

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Abstract: An intelligent climate and watering agriculture system is presented that is controlled with Android application for smart water consumption considering small and medium ruler agricultural fields. Data privacy and security as a big challenge in current Internet of Things (IoT) applications, as with the increase in number of connecting devices, these devices are now more vulnerable to security threats. An intelligent fuzzy logic and blockchain technology is implemented for timely analysis and securing the network. The proposed design consists of various sensors that collect real-time data from environment and field such as temperature, soil moisture, light intensity, and humidity. The sensed field information is stored in IoT cloud platform, and after the analysis of entries, watering is scheduled by implementing the intelligent fuzzy logic and blockchain. The intelligent fuzzy logic based on different set of rules for making smart decisions to meet the watering requirements of plant and blockchain technology provides necessary security to the IoT-enabled system. The implementation of blockchain technology allows access only to the trusted devices and manages the network. From the experimentation, it is observed that the proposed system is highly scalable and secure. Multiple users at the same time can monitor and interact with the system remotely by using the proposed intelligent agricultural system. The decisions are taken by applying intelligent fuzzy logic based on input variables, and an alert is transmitted about watering requirements of a field to the user. The proposed system is capable of notifying users for turning water motor on and off. The experimental outcomes of the proposed system also reveal that it is an efficient and highly secure application, which is capable of handling the process of watering the plants.

Keywords: Internet of Things, sensors, data privacy and security, fuzzy logic, decision support

1 Introduction

Due to the modernization of farming, the climate monitoring in agriculture is essential for the growth of agricultural yields. With the monitoring of climate, efficient watering process is also very important because of shortage of sweet water resources across major parts of the world [1]. Therefore, there is a requirement for an automatic and intelligent agricultural system that can be adopted for providing essential amount of water to the plants and climate monitoring during the maximum farming time. The automatic process of

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climate monitoring and watering is essential in Asian region due to the limited resources of water and regularly changing environments. The major parts of Asian countries are under severe conditions of hot weather and drip system of irrigation, which is utilized for supporting small-scale farming. However, the system of drip irrigation is not efficient because of least control in the amount of walking during day and night times, various seasons of summer and winter [2]. For the efficient utilization of limited water resources, intelligent agricultural solution is required to be adopted for obtaining better farming yields considering severe conditions of weather. Moreover, many of common people do not have the idea and key knowledge for growing plants in an efficient manner. The irrigation of plants needs proper control on soil moisture level and monitoring of weather and watering quantity for its growth. Many such technologies have been designed for providing better water utility during irrigation [3–6]. However, each of these technologies has some limitations, and they are not efficient in providing better utilization of water resources and continuous monitoring of climate.

The prime focus of the proposed design is to present an automatic intelligent agricultural system that is capable of monitoring climate and providing an efficient utilization of water resources to feed plants during the maximum farming time [7]. Moreover, this study also contributes for providing a regular support through mobile application for regularly monitoring climate and watering process. The blockchain technology is adopted for securing the privacy of the proposed intelligent agriculture system [8]. The fuzzy rule is implemented for intelligent decision making along with the set of rules, which are applied on the collected data through deployed sensors along the field, and providing controls of watering amount in accordance with the plant's watering requirement [9]. The adopted blockchain technology provides secure information access among connected Internet of Things (IoT) devices [10]. The adopted blockchain technology enables the design by providing access only to the trusted devices and thereby controlling and managing the proposed intelligent climate and watering agriculture system (ICWAS). Multiple users at the same time are capable of monitoring and interacting remotely by using the proposed prototype of ICWAS. The prototype application is designed using an Android, and the fuzzy logic method is implemented for deciding the action depending upon the input values. The proposed ICWAS based on input values of climate and soil parameters further activates the actuator for making watering decisions such as turning on and off the water tunnels periodically.

The humidity, temperature, and soil moisture level varies across various parts throughout 24 h of the day. This is the reason behind the changes in requirements of watering across various parts in a day. The proposed ICWAS monitors climate, light intensity, temperature, humidity, and water content in soil through deployed sensors. The sensed information is then transferred on the server through Wi-Fi for providing the customized guidance of watering and continuously monitoring the plant's health on smart devices using a designed application [11]. Moreover, the varying species of plants requires different levels of water irrigation, and therefore, it is essential for effectively utilizing the water reservoirs for better plant growth [12]. The intelligent climate and pottering agriculture system requires quantifying the input variables collected from deployed sensors [13]. In this experimentation, limited amount of plants are considered for the modeling of the proposed system. The respective data set is collected at local field for accurately monitoring the health of plants and recommending the requirements such that the system can guide the farmer in an efficient way. The included set of plants in this study is mint, onion, cucumber, radish, chili, carrot, tomato, and garlic.

The Android application of ICWAS is also designed for an intelligent monitoring and smart management of water quantity through smart devices. The proposed prototype is tested for its effectiveness in laboratory and in field as well. The farmer can easily access the application for efficiently monitoring the climate and the level of soil moisture and compare the present moisture level with the required soil moisture for a specific plant [14]. The design also provides the remote interaction with plants, thereby a farmer can adjust the watering amount as per the requirement of specific plant. The proposed design provides a real-time monitoring of field from a distant place by simply accessing the smart devices across any part of the world with the support of IoT and blockchain techniques. The blockchain approach is implemented to secure the connection between the server and the IoT devices [15]. Because the proposed design of an ICWAS incorporates simple and reasonable mechanisms, the implementation of the proposed ICWAS at profitable level profile is a cost-effective result with a better efficiency, throughput, and accuracy. The proposed system is not only cost effective, but at the same time, it efficiently utilizes the sweet water resources and regularly tracks the health of plant by monitoring the climate in real time. The rest of the article is arranged as the most recent study in the implementation of blockchain and edge computing is discussed in Section 2. Section 3 represents the proposed architecture of the intelligent agriculture system. The results and analysis of the proposed architecture is discussed in Section 4. The concluding remarks and future direction are presented in Section 5.

2 Related studies

During the exhaustive study of literature review, very few relevant research were identified, which intends to enhance the performance of agriculture in relation with various aspects such as soil power enhancement [16]. The suitable quantity of soil water includes certain obligatory conditions for the efficient growth of plant. Water is the most critical ingredient for the nourishment of life to efficiently use water resources. It is studied from one study that Indian farmers are facing issues such as electricity of low voltage and power cuts for the irrigation of agricultural land [17]. If the farmer does not irrigate agricultural land during the power cut time, then the probability of electricity and water wastage is very high during those hours, whereas the excessive watering also cause serious damages to the crops. Considering these issues, an integrated design was proposed of IoT and mobile application [18]. The design uses various sensors for measuring the temperature and soil moisture and the integration of Raspberry-Pi for automatically turning on and off water pumps. The authors have designed and automatic system for observing and irrigating the garden [19]. The design consists of watering the garden considering weather forecast and timer settings. The forecast API is used to access the forecast and integration of Raspberry-Pi for meeting the watering requirements. As per their study advanced sensors, user interface, time lapse and the form factor will be considered for the future directions. The authors proposed a design that considers recent and previous weather forecast for scheduling the watering of plants [20]. System also provides an application for their users where the weather conditions are forecasted for making plant watering schedule as per the weather conditions. The system also provides a facility for its users to select various services of weather forecasting such as underground weather, accessing private weather stations and dry sky conditions for the collection of different weather data. To access the private weather station, the proposed design is connected with Netatmo and Davis tools for accurate and highly localized weather information [21]. Depending on the outdoor weather conditions, the watering schedule is optimized. The design algorithm compensates inaccurate forecast of weather and utilizes water resource efficiently by managing the irrigation process considering parameters such as soil humidity, temperature, solar radiation, and speed of wind [22]. One study presents system for smart irrigation monitoring and controlling that uses wireless sensor networks and cloud computing technology [23]. The integration of wireless sensor networks and cloud computing helps monitoring and controlling the process of plant irrigation. The authors have utilized a set of census along with the actuators for measuring and evaluating water requirements of plants [24]. The design also consists of an Android application for remotely accessing the drips. The communication among sensor nodes and base station is carried out through ZigBee module. A web-based graphical user interface is utilized for handling the collected information on real-time basis. Another design based on an Android application is proposed, to facilitates farmers with full access for the ornamental treatment of plants remotely [25]. There is a requirement for optimizing and controlling the irrigation requirements. The meadowlands would never be overwatered and underwatered. The computer-based designs are adopted as these technologies provide efficient collection of data such as plant information and environmental factors with high accuracy and in fewer efforts.

Recently, with the evolution of technology, smartphones and web applications play a critical role in creating highly advanced and fully automated systems [26]. Such devices provide simple computing supply for all the people globally because of mobility factor. In daily life due to the intense incursion of smart devices, the development of secure Android applications is gaining more attention. A similar system was designed with the integration of IoT devices and Android application, where the design can be scaled up and rebuild [27]. Their system contains Arduino and a series of different sensing devices, which are connected in planter. The collected data from a real-time environment are deposited in cloud database, but this data can only be retrieved through the web application. Their scheme is capable of providing the learning of water conservation to the users through computerization and building a bridge between the computer system and the proposed centric system based on soil moisture sensor measurement. The senses become operational when the impedance factor changes among the electrodes, which are implanted in soil. The Arduino technology was implemented to design a system for controlling the irrigation and roofing procedure in greenhouse [28]. The input for the system is environmental data, such as humidity, temperature, soil moisture, and light intensity, through deployed sensors. The collected information is then compared with the weather forecast information for making the optimal decision. The Kalman filter was introduced to remove noise from the sensors [29]. In one more study, the authors propose the system based on census that measure the water level and water flow, which are connected with water pumps and irrigation canals, respectively [30]. They proposed a design, which utilizes wireless sensor networks for transmitting the sensed information to the server through gateway node periodically. In web server, the collected information are analyzed and kept in database for making comparison among recent and predefined values [31]. In their system, an alert is generated and transmitted to the farmers when the water requirement is needed. In one study, authors proposed an IoT design-based digital approach for handling the irrigation process [32]. The sensors are deployed in agricultural land for measuring the level of moisture and to check the water level in storage through smartphone network. To access the sensor information, an intelligent software is installed on the server for making effective decisions about irrigation. A design is proposed to improve the water management by using a global system for mobile communication module [33]. The design provides regular monitoring of water level in storage and capable of providing suggestions about the exact level of water, which is required for the plants' growth. This is also capable of measuring the humidity and temperature values to sustain the nutrients present in soil, which are essential for the plants' growth. Recently, the introduction of blockchain technology became very popular for securing the transmission in IoT-enabled smart systems [34]. The traceability of agricultural goods is becoming a critical challenge. To overcome this issue, a study was proposed that implemented blockchain technology for securing the tracing of agriculture products [35]. This study also incorporates various managerial operations such as irrigation and fertilization of plants. The blockchain technology is implemented for recording the information of dispersed farmers, sellers, growers, and users for providing the security to many such operational information through decentralized manner. In smart agriculture, a design was proposed by implementing the infrastructure of blockchain technology [36]. There proposed design provides the necessary safety for maintaining the data integrity in agricultural domain. The blockchain technology in smart agriculture facilitates users and various farmers, which ensures the immutability of high quality and worthy information [37]. The blockchain technology enhances the traceability along with the accessibility of watering control information spatially. In one study, a farmland irrigation system is developed, which contributes for the enhancement of agricultural products and livelihood of rural people by adopting modern agricultural process [38]. In their proposed system, the authors have implemented the blockchain technology for securing the information from compiling histories in irrigation canals, where the irrigation information is accessed through various farmland associations of irrigation. The role of artificial intelligence and IoT based for the application of health-care applications [39–41]. Furthermore, ant colony optimization is discussed for task offloading in fog computing in agriculture [42].

The sensed information can be utilized for making a maintenance process of irrigation resources. The blockchain technology serves as an integrated bridge between irrigation association and farmers for supporting plant irrigation and efficiently using water resources. The comparison of various designed approaches that can be used for smart agriculture is tabulated in Table 1. The earlier designed system in agricultural domain is focused on efficient utilization of water irrigation by measuring the soil moisture [43]. However, essential parameters for controlling the water consumption and improved growth of plants are soil type, light intensity, humidity, and temperature. Because different plants need different watering

Table 1: Parameters comparison of proposed model with existing technologies

Previous technologies	Parameters				
	Precision soil irrigation	Decision support watering	Optimized consumption of energy	Decentralized network	Secure data communication
[8]	Yes	No	No	No	No
[13]	No	No	No	No	Semi implementation
[18]	Yes	No	Yes	No	No
[22]	Yes	Yes (not implemented fuzzy logic)	No	Yes	No
[27]	No	No	Yes	No	No
[32]	Yes	No	No	No	No
Proposed model	Yes	Yes	Yes	Yes	Yes

requirements, and accordingly similar plants can have various irrigation needs consisting of suitable environment and soil type [44]. The comparison tabulated in Table 1 clearly highlights that there is a strong requirement for designing an intelligent system that can accurately measure the climate and irrigation needs on a real-time basis, considering all of the possible parameters. The ICWAS is an effort for providing a key that considers various constraints instead of only measuring soil moisture. The proposed design and its working along with the experimental analysis are discussed in the third section.

3 Architecture design of intelligent agriculture system

The proposed ICWAS is designed considering security and integrity of data implementing the blockchain technology. The blockchain is applied for tracking and tracing the transactions through device, which are performed during the operation of the proposed ICWAS. The blockchain technology does not only secure the transaction but also enables seamless availability and connectivity of various features provided by the proposed system. The proposed architecture of integrated IoT and blockchain-based ICWAS is depicted in Figure 1.

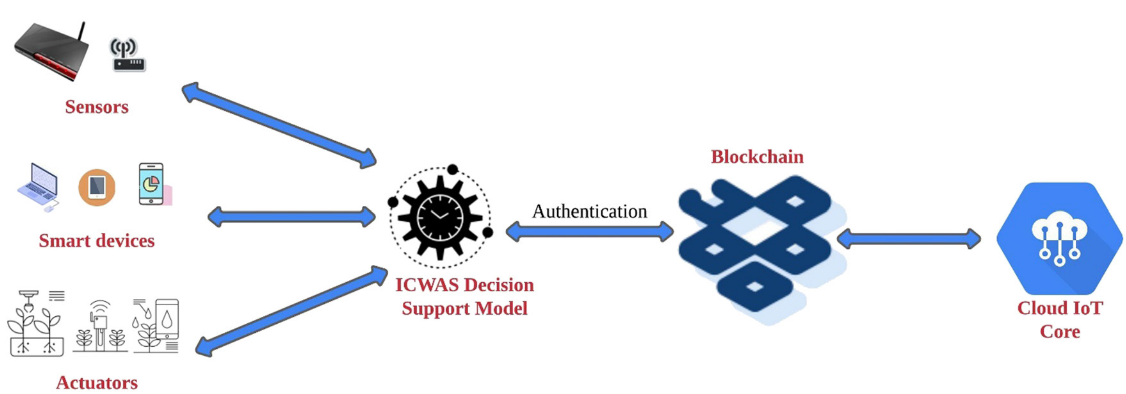

Figure 1: Proposed model for IoT-based ICWAS.

The central storage concept may be vulnerable from various security threats but to tackle these threats we have implemented a decentralized storage approach. In decentralized approach, the climate, watering, and plants database are stored using the blockchain technology. The communication channels among sensors, actuators, smart devices, and IoT cloud platform of the proposed system is depicted in Figure 1. Smart devices are represented as nodes where each node contains blockchain copy, and their copies are transmitted to each node for their further use. At every 15 minutes, each family in block is updated, and this is the reason why the proposed system presents a secure communication procedure, and it is nearly impossible to track or trace the security of system. Therefore, by implementing the blockchain technology, a secure transmission in terms of receiving data from devices, delivering data to users and its storage is achieved.

In the proposed system, the blockchain module is designed using Java, and the blocks contents is defined as hash, which acts as a unique identifier. Each of the block is capable for computing block hash, and then secure hash algorithm hash is evaluated based on it. A block is designed when threshold level meets the requirement, and the connectivity is, therefore, achieved by managing the blockchain. The blockchains are then looped over to verify the validation of entire blockchain system that whether the blocks hash is matching with previous block hash or not.

Figure 2 depicts the four-layer operation of the proposed ICWAS. These four layers are perception layer, network layer, transport and management layer, and application layer. In perception layer where the sensors, actuators, and other hardwares are deployed. The second layer is the network layer, which is responsible for the connection establishment by using Bluetooth and Internet technology. The third layer is the transport and management layer, which is responsible for processing the sensed information, its security, management, and storage. The fourth layer is the application layer; the stored data and regular entries are analyzed using smart devices and transferred to the user through Android application. All of these four layers continuously interact among each other for providing secure transmission in smart devices and sensors for their efficient working of the proposed ICWAS. By simply logging-in into the application, a

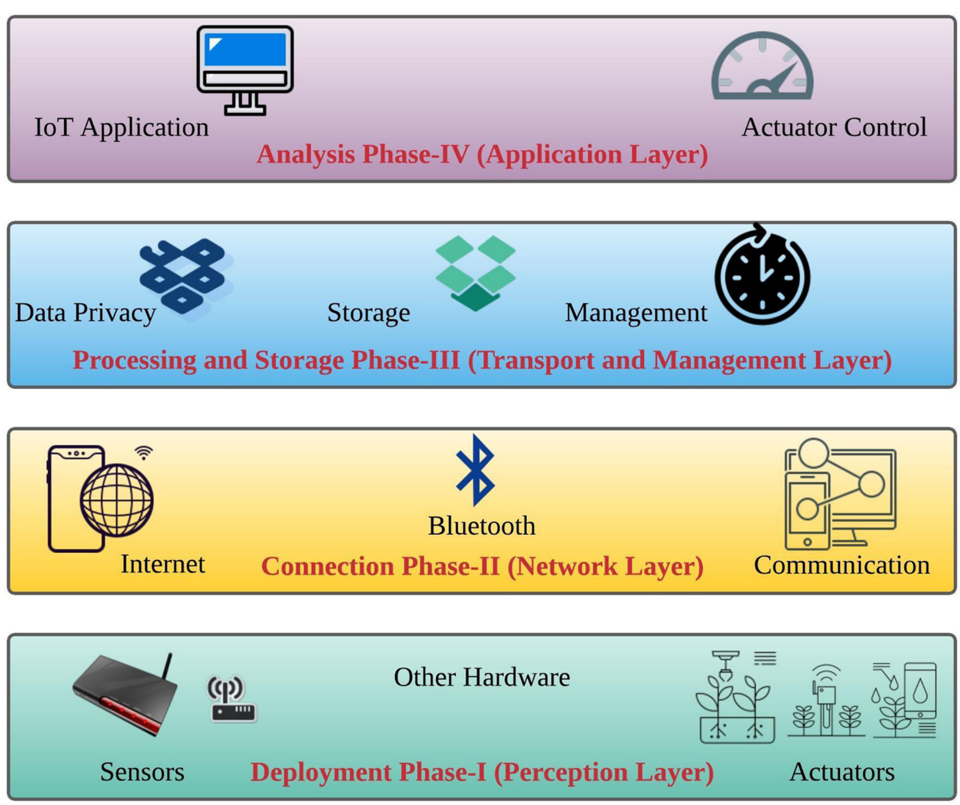

Figure 2: Architecture of ICWAS.

farmer can monitor climate and control the process of watering and can schedule actuators for specific plants.

Figure 3 depicts the architectural design of the proposed ICWAS, which represents the physical components of the design. It consists of the architecture of all the hardware utilized in the intelligent agriculture system, which is deployed in a real-time environment. As depicted in Figure 3, different sensor nodes such as temperature, soil moisture, humidity, light intensity, and camera sensors are deployed in the area of interest, which are connected with the microcontroller through analog inputs. The actuators, which consist of water pumps and lights, are connected with microcontroller in the serial output port. The microcontroller acts as a centralized system, which gathers data from deployed sensors and transmits sensed information toward the server through access points. The server is responsible for transmitting the sensed information such as light intensity, temperature, soil moisture, and humidity to the proposed module of fuzzy logic. This module analyses the entries and provides the decision whether there is a requirement of watering to the plant considering different plant types through the database of plants. Once the watering decision is taken to fulfill requirements of plant irrigation then alert is transferred to the user via SMS for taking necessary action. The user is capable of changing the operation of the system and can set the operation automatically and manually for handling the actuators of the system.

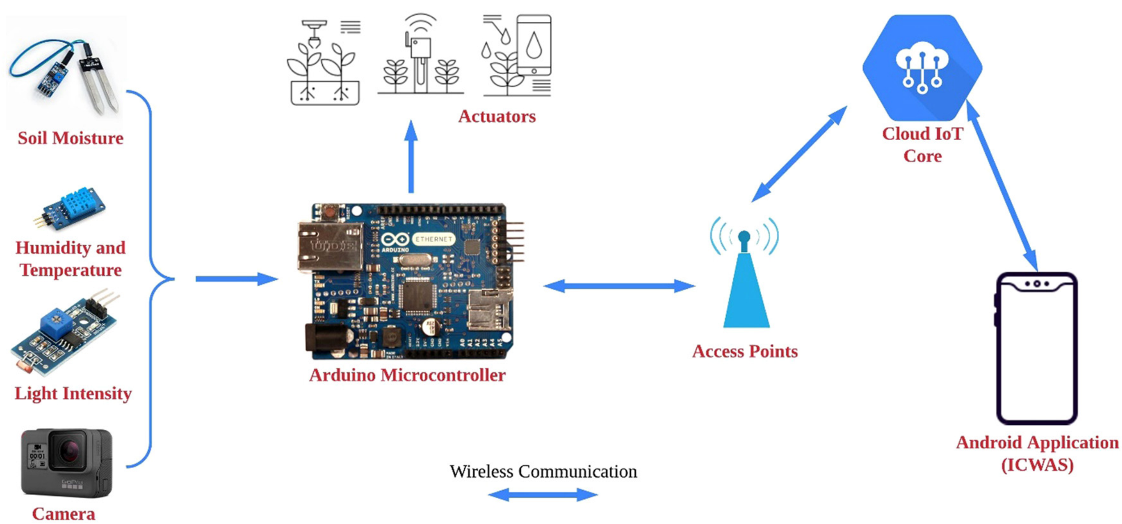

Figure 3: Hardware implementation of proposed system (ICWAS).

4 Intelligent watering decision support system

Intelligent decision support scheme based on fuzzy rule is a major constituent of the proposed ICWAS. The proposed decision support system helps in making decisions based on the analysis of collected data from sensors. The fuzzy logic is implemented in this study because of its high two implications. The first significance is that the fuzzy logic provides highly accurate decision-making. The other significance of implementing fuzzy rule is its simple and easy implementation for IoT applications. The fuzzy logic analyzes the climate and makes decisions about watering requirements of plants. The decision is transferred to the mobile application, which is developed in Android.

Figure 4, depicts the major components of the proposed intelligent decision support system such as fuzzy inference procedure, fuzzification, and defuzzification module, set of fuzzy rules, database, and sensor data. Typically, in any fuzzy logic design, the universal discourse D is inferred in any fuzzy set F in pair as (D, m). The fuzzy set consists of an ordered pair of i variables along with the membership function $mf(i)$. The comparison of fuzzy set F is shown in equation (1).

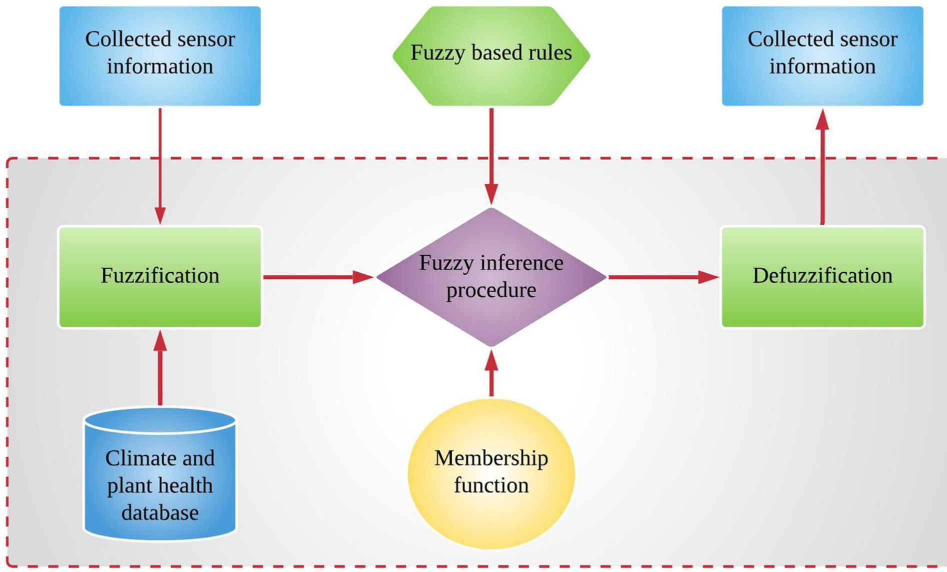

Figure 4: Proposed fuzzy logic controller for ICWAS.

$$F = \{ i,\ mf(i),\ i \in D\} \tag{1}$$

Equation (1) is used for computing fuzzy sets and below are the steps, which are followed for the implementation of fuzzy logic.

Step (i): Equations (1) and (2) are used for defining initial set of variables

Step (ii): In second stage, the membership function are declared

Step (iii): Rules are formulated for each defined variable

Step (iv): Input a_1, a_2, a_3,..., a_n are given in the fourth step

Step (v): In fifth step, the membership functions are declared and utilized for each of the input value for their mapping with fuzzy value

Step (vi): In sixth step, the fuzzy rules are achieved for inferencing each rule

Step (vii): In this step, the aggregation is achieved for inferencing each rule

Step (viii): In the last step, the final inference value is further converted to output value Y

As shown in step (i), the designed fuzzy logic-based intelligent decision support system is used for handling five different variables such as temperature, humidity, light intensity, soil moisture, and plant type. These five different variables are declared as the subset of set $F(P,\ Q, R, S$ and $T)$.

As described in equations (1) and (2), the temperature change is represented with variable P, humidity change is represented with variable Q, intensity of light is represented with variable R, soil moisture is represented with variable S, and variable T represents time.

In step (ii), membership function set is computed for each input value of variables, such as $m_P(a)$, $m_Q(a)$, $m_R(a)$, $m_S(a)$, $m_T(a)$, which represent the membership function of different input variables P, Q, R, S and T. These computed membership functions represent the membership degree of variable a for set of variables P, Q, R, S and Tas represented in equations (2) and (3).

$$P \cup Q \cup R \cup S \cup T = \{a, \max(m_P(a), m_Q(a), m_R(a), m_S(a), m_T(a))\} \tag{2}$$

where a is an element of F.

$$P \cup Q \cup R \cup S \cup T = \{a, \min(m_P(a), m_Q(a), m_R(a), m_S(a), m_T(a))\} \tag{3}$$

Step (ii) is followed by step (iii) where if then rules are applied for the implementation of fuzzy set rules. Every component of the proposed fuzzy logic-based intelligent decision support system as mentioned in algorithm above are implemented for each module where the working of modules are described in section 5.

In step (iv), the membership functions are defined for each variable P, Q, R and S as temperature change, humidity change, moisture change, and light intensity as "lower," "medium," and "high." However, the membership function for input variable T is computed as time such as "day" and "night." Equation (4) represents the fuzzy set $F(a_i)$, which is fuzzification kernel and further implemented utilizing mapping of μ_i and a_i for a fuzzy set $F(a_i)$.

$$\sim P = \mu_1 F(a_1) + \mu_2 F(a_2) + \mu_3 F(a_3) + \ldots + \mu_n F(a_n) \tag{4}$$

As mentioned in step (v), the fuzzification process is computed using equation (4). Equation (5) represents the triangular membership function of the proposed implementation.

$$\mu_P(a) = \begin{cases} 0, \ a \le X \\ \dfrac{a - X}{Z - X} & X < a \le Z \\ \dfrac{Y - a}{Y - Z} & Z < a < Y \\ 0, \ a \ge Y \end{cases} \tag{5}$$

The operations of minimum and maximum are utilized for evaluating the fuzzy values through crisp input values as represented in equation (6).

$$\Delta(a; X, \ Y, \ Z) = \max\left(\min\left(\frac{a - X}{Y - Z}, \frac{Z - a}{Z - Y} \right) \right) \tag{6}$$

As represented in equation (6), the three corner coordinates of a for the considered triangular membership function, which are declared as $X, \ Y, \ Z$ where $X < \ Y < \ Z$. As represented in equations (5) and (6), the membership functions are declared for each of five variables of the utilized fuzzy logic design. The MATLAB toolbox of fuzzy logic is utilized for defining these membership functions.

As represented in step (vi), the main component of the proposed ICWAS is fuzzy inference procedure, which is responsible for effective decision making based on set of if-then rules, membership function set and "or," "and" operators of fuzzy logic. In our proposed scheme, the fuzzy inference procedure is mapped with input to the respective output by utilizing fuzzy logic. The implemented fuzzy inference procedure consist of following steps, which are mentioned below.

(i) The fuzzification of input variable through membership function.
(ii) In the next step, fuzzified inputs are combined as per fuzzy theory.
(iii) Making of fuzzy rules.
(iv) Rules outcome evaluation with the combination of output membership function and rule strength.
(v) The outcomes are combined for obtaining the output distribution.
(vi) In last step, defuzzification of observed membership function is followed.

The detailed procedure of fuzzy inference through four inputs along with two rules is represented in equations (7) and (8) where $W_1, \ Y_1$, and Z_1 represent fuzzy and not a crisp value.

$$\text{If}\,(U_1 = E1_1, \ V_1 = E1_2, \ W_1 = E1_3, \ Y_1 = E1_4, \ Z_1 = E1_5) \ \text{Then}\,(w = D1) \tag{7}$$

$$\text{If}\,(U_2 = E2_1, \ V_2 = E2_2, \ W_2 = E2_3, \ Y_2 = E2_4, \ Z_2 = E2_5)\,\text{Then}\,(w = D^2) \tag{8}$$

Thereafter, the intersection over crisp input value with the membership function of input is applied for the occasion of three input values. The "and" operator is used for merging three fuzzified inputs to obtain the rule strength. The implementation of fuzzy inference procedure utilizes a membership function for every rule and then depending upon the complaint of each rule a conclusion is drawn. In the last step of the proposed implementation, the output is evaluated through fuzzy set of rules, which is written using if then statements, and then stored in knowledge database. In this step the scalar value is fuzzified, then rules are applied where is rule provides fuzzy output and then its conversion to a scalar measure. In the proposed scheme, defuzzification approach is utilized as it provides accurate outcomes as express in equation (9).

$$a^* = \frac{\int \mu_i(W) \cdot x\mathrm{d}x}{\int \mu_i(W) \cdot \mathrm{d}x} \tag{9}$$

where a^* represents the defuzzified outcome, $\mu_i(W)$ represents the membership function aggregation, and x represents the output variable. In equation (9), the output variable x is represented by x-axis, the aggregated membership function $\mu_i(W)$ is represented by y-axis and defuzzified outcome is expressed as a^*. At last the output shape is observed by the implementation of fuzzy "and" operator with clipping of observed membership function as per the rule strength.

5 Implementation of intelligent agriculture system

The hardware devices used for implementing the proposed ICWAS are mentioned below.

(i) Arduino-Uno
(ii) Wi-Fi module ESP8266
(iii) Water motor – 15 V
(iv) Soil moisture sensor node – EC1258
(v) Temperature and humidity sensor – DHT 11
(vi) Light intensity sensor – BH1750
(vii) Relay node – 6 V

5.1 Process of intelligent agriculture system at server end

The application is designed at server end for handling ICWAS. A web-based interface is introduced for handling the system. The management interface provides various options for controlling the proposed intelligent agriculture system. The web application requires an administrator level login for the secure access and also provides the working description of system.

A dashboard is provided by the system through application for the management of plants data at the administrator level. The administrator after logging into the application may add new information about plant such as planting period details, fertilizers, watering, and other required details of the specific plant. This provided information is visible to the farmers and users as per the preference. At the same time, the administrator can also delete the details from its repository, which are irrelevant and not necessary. The administrator can control or manage users for allowing them to access the functionalities of the system by creating accounts.

5.2 Analysis of intelligent agriculture system through mobile application

An Android-based application for intelligent agriculture system is also designed. This application allows user for farmers to control the system remotely. The basic control of the system are provided to the user, which are available in the menu. This application provides the necessary access to farmers such that they can access main features of the proposed system. The user can monitor the field, control actuators, and access the necessary alerts. In the user application, the information is available about each plant, which represents the suitable time and season for its planting and watering. At the backend, the fuzzy logic base intelligent system makes decisions by matching the previous and current state of the plant. This process provides the guidance to farmer about planting such as where and when to plant a seed, details about suitable fertilizers, estimated harvesting time, and environmental conditions.

The user can their self-schedule watering process through their mobile application, are synchronized with a system calendar. The sensed information are processed in server on a real-time basis, and plant list along with their feasibility rating is transmitted to the farmers' mobile. An alert is transmitted to the user mobile whenever the watering schedule meet specific date and time or the water level of field decreases. As per the regular schedule of watering or with the decrease in level of water, farmer can control the state of water motor to on and off by just accessing the application from anywhere across the world. When the water level of the field increases or meets the level of plant water requirement, again alert is transmitted to the user mobile to change the state of water motor to turn it off.

6 Experimental analysis and discussion

The sensed information from the field received to sink node on a real-time basis and installed in IoT cloud platform for its analysis and decision-making. The web-server is introduced for monitoring and storing the real-time sensor information from sink node. A proposed system consists of knowledge base at server and along with predefined rules as tabulated in Tables 2–4. This database is obtained by the regular training of sensor nodes for or observing their threshold values. To match the observed values with knowledgebase data, rule base inference procedure is followed. The collected real-time information of temperature, humidity, soil moisture, and light is evaluated to give recommendations about the health of plants, and to convey which plant can be planted in particular season. Table 5 represents the sensed information about temperature, soil moisture, intensity of light, and humidity change. This sensed information from the field is further transmitted using microcontroller and received by the server.

The statistics presented in Tables 2–4 auditors hold points, which are observed through the training of sensors. Table 5 represents the sensor outcomes, which are used in this experiment. The fuzzy rule

Table 2: Training of moisture values

Moisture level	Training
0–500	Higher/dry condition
501–700	Average
701 and above	Lower/wet condition

Table 3: Training of humidity values

Percentage humidity	Classification
70% or above	Higher
50–69%	Average
Less than 50%	Lower

Table 4: Soil moisture classification

Light intensity	Classification
Higher	Dry condition
Lower	Wet condition

Table 5: Collected entries of sensed data

Time created at (Instances)	Entry	Hum (%)	Moisture (g/m^3)	Temp (°C)	Light (lux)
2021-02-12 14:25:23 + 0530	211	23.35	18	15.36	143
2021-02-12 14:28:00 + 0530	212	20.12	19	16.32	165
2021-02-12 14:34:41 + 0530	213	21.33	22	15.36	183.3
2021-02-12 14:38:10 + 0530	214	27.35	125	19.22	184
2021-02-12 14:45:30 + 0530	215	27.22	628	18.17	146.3
2021-02-12 14:52:20 + 0530	216	22.45	13	18.35	145.2
2021-02-12 14:58:03 + 0530	217	21.37	19	12.35	122
2021-02-12 15:05:28 + 0530	219	19.13	389	13.22	132.6

inference procedure compare the sensor values from plants, which are stored in IoT, cloud database with the threshold values stored in knowledgebase. The fuzzy logic computes percentage of set of rules, which matches with input variable as a score of particular plant. This observed score value is then transmitted to the Android application and highlighted in the menu bar. This information helps farmer to know the suitability of particular plant for its growth and health in different environmental conditions. For controlling the watering process of a field, sensed information is transmitted toward server five to six times in a day. These transmitted values are compared with the computed thresholds of temperature, humidity, soil moisture, and light intensity for checking whether to schedule watering process or not. The user is regularly notified with the current condition of water level in soil. During watering process, when the moisture of soil all the content of water is maintained above the threshold value, the water motor is turned off.

The collected entries of the field data in stored in IoT cloud for analysis and decision making where few sample entries are depicted in Figure 5. Table 6 represents the experimental outcomes of the proposed system. From the experimentation of 5–10, there are few chances where the value is high, and for some cases, the valley is observed medium. Accuracy of the proposed ICWAS for most of the experiments is above 98%. The accuracy of the proposed system signifies that the system accurately working as per defined fuzzy rules for ICWAS. The overall accuracy of the proposed ICWAS is calculated using equation (10).

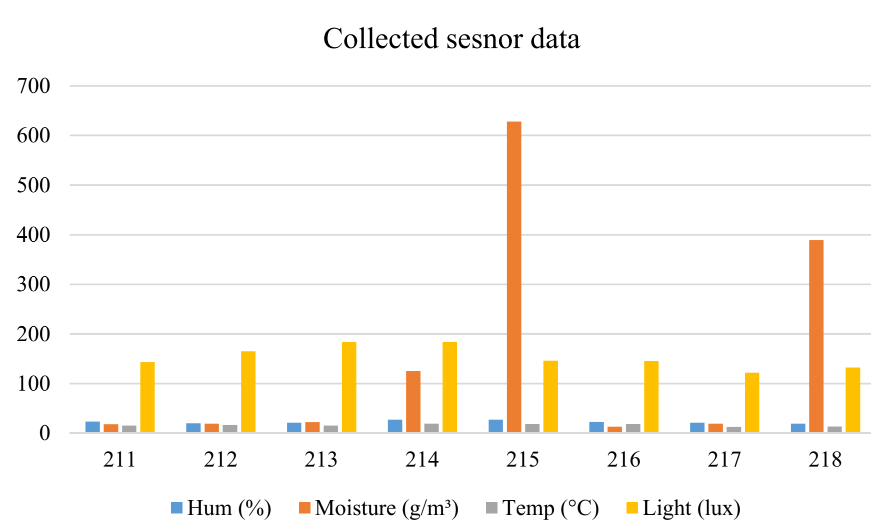

Figure 5: Collected sensor information in IoT cloud during experimentation.

Table 6: ICWAS outcomes for ten experiments

Experiments	Humidity (%)	Temperature (°C)	Time (min)	Moisture (voltage)	Test result	Real result	Accuracy (%)
S1	9	2.68	2.9	High	Lower	Lower	99
S2	11.2	6.3	4.3	High	Medium	Medium	98
S3	9.4	4.58	2.8	High	Medium	Medium	99
S4	13.6	8.6	2.1	High	Higher	Higher	99
S5	15.9	2.34	2.6	High	Medium	Lower	55
S6	17.6	7.5	2.7	High	Higher	Higher	98
S7	16.2	6.3	1.9	High	Higher	Higher	99
S8	15.3	6.9	4.4	High	Higher	Higher	100
S9	4.2	10.5	7.6	High	Higher	Higher	100
S10	6.9	8.9	1.9	High	Lower	Lower	100

$$\text{ICWAS accuracy} = \sum \frac{\mu(A_j)}{N} \tag{10}$$

By implementing equation (10), we have calculated the overall accuracy of ICWAS where the percentage accuracy for each experiment is represented as $\mu(A_j)$, and total number of experiments is represented as N. The overall accuracy of the proposed system through the experimentation is observed as 96.7%. Different sensor information and actuators effect after the decision is taken using intelligent fuzzy logic is tabulated in Table 7. The actuator response for five experiments of the proposed system is depicted in Figure 6.

Table 7: Controlling actuator response through sensed data

Entry	Soil moisture	Temperature	Intensity of light	Humidity	Status of water motor
E1	387	26.5	38	79.3	On
E2	1,028	26.3	45	77.8	Off
E3	1,041	23.2	54	68.7	Off
E4	341	19.3	53	67.5	On
E5	283	16.7	16	26	On

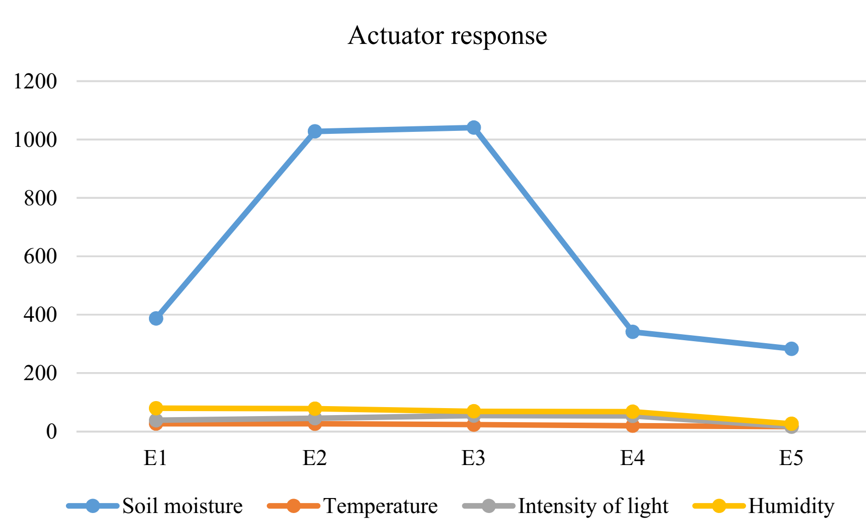

Figure 6: Actuator response for different experimentation.

Table 7 represents the observed statistics of sensor information, which instigates the decision taken by intelligent fuzzy logic module for changing the state of motor by turning on and off with respect to temperature, humidity, and soil moisture values. The proposed intelligent agricultural system is designed for monitoring climate and early detection of soil dryness. From the experimentation, it is analyzed that the proposed system is an effective solution for detecting the dryness in soil at early stage. The proposed system offers a secure transmission of information from field to the server through decentralized network. The proposed integrated IoT and blockchain-based intelligent agricultural system has the flexibility of future directions as well. The current system is only considered for eight type of plants, whereas the proposed study can be extended by implementing genetic algorithm for neural networks for obtaining more precise recommendations and accurate predictions at its initial stage.

7 Conclusion

In the modern era, technology is playing a critical role for the growth of a nation and an individual. With the modernization in various sectors, the agricultural sector also requires huge advancement especially in a country such as India. The modern technologies should be utilized for increasing the efficiency and productivity of the agricultural products. This project is aimed to design an intelligent agricultural system, which is capable for monitoring the climate and other important parameters such as temperature, humidity, soil moisture, and light intensity for enhancing the health of plant and increasing the productivity. The proposed intelligent agricultural system is an integration of IoT and blockchain technology for providing efficient and secure decision system. The system collects the field data in real time through deployed sensors and recommends usage with necessary precautions and decisions. The decisions are taken by applying intelligent fuzzy logic based on input variables, and an alert is transmitted about watering requirements of a field to the user. The proposed system is capable of notifying users for turning water motor on and off. The current system is only considered for eight type of plants, whereas the proposed study can be extended considering future directions by implementing the genetic algorithm for neural networks for obtaining recommendations that are more precise and accurate predictions at its initial stage.

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