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Review on IoT Based Precision Irrigation System in Agriculture

S. Vinod Kumar[1*], C. D. Singh[1] and K. Upendar[1*]

[1]ICAR-Central Institute of Agricultural Engineering, Bhopal-462038, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author SVK managed conceptualization, reviews creation, writing- original draft preparation. Author CDS performed supervision, reviewing and editing, original draft preparation. Author KU managed conceptualization, methodology, reviews creation, visualization, reviewing and editing. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Precise irrigation plays an essential role in agricultural production and its management. Based on current conditions and historical records, profitability in the farming sector depends on making the right and timely operational decision. For the last two decades, especially in India, climate change, groundwater depletion, and erratic variation in rainfall have affected crop production significantly. Due to advancements in technologies and reduction in size, sensors are becoming involved in almost every field of life. Agriculture is one such domain where sensors and their networks are successfully used to get numerous benefits from them. In this paper, a review of the scope of smart irrigation using IoT has been discussed. The scarcity of agricultural workers in irrigation can be compensated by the Internet of Things (IoT) platform. The various parameters, such as soil moisture, soil temperature, humidity, and pH, have been collected using the Internet of Things (IoT) platform, equipped with sensors and wireless communication systems (WSN).

Keywords: Smart farming; precision irrigation; IoT; WSN; sensor; pressurized irrigation.

Corresponding author: E-mail: srinivasvinod1994@gmail.com;

1. INTRODUCTION

Agriculture is an imperative sector that contributes a sufficient diet to the growing population. The projected world's population will be more than 10 billion inhabitants by 2050 (United Nations, 2017). According to the UN Food and Agriculture Organization, with increasing population mouths, global food production must be increased substantially by 2050. To meet the demand, farmers and agricultural companies will have to push the innovations by suppressing their current practices. There is evidence from many researchers that agricultural areas and productivity decrease day by day.

Moreover, it is also reported that the coming years will see the increasing use of smart farming tools and technologies in the agriculture sector [1]. Present-day many developing countries, including India, are facing several issues. Extreme climate variability, scarcity of agricultural Labour, competition for water from the agriculture and industries sector, and groundwater depletion threaten the sustainability of irrigated agriculture. People are not showing their attention to agriculture, and they are migrating from village to urban cities for a better life. The irrigation industry must develop and adopt innovative technologies and follow acceptable management practices that optimize economic outcomes while minimizing environmental impact. The newly emerged sensor network (SN) technology has spread rapidly into various multidisciplinary fields. Agriculture and farming have recently diverted their attention to SN, seeking this cost-effective technology to improve its production and enhance agriculture yield standard [2].

Good agricultural practices must include knowledge of water usage by crop and techniques that permit efficient irrigation management [3] and [4]. The judicious application of irrigation water is one way to reduce water consumption and to improve water use efficiency. The wireless sensor network (WSN) serves as the backbone in modern precision agriculture. It is used for real-time automation irrigation in the field for delivering the precise and accurate amount of water for the crop at each stage of its growing period [5,6]. It may also be used to sense real-time field and environmental conditions such as temperature, relative humidity, leaf wetness, wind directions, and waterlogging conditions [7]. With this information, the users can adjust their strategies to achieve the desired objective of efficient management of all agricultural inputs like water and fertilizers [8]. Increasing competition with the other water users would limit the water availability for expanding the irrigated area [9].

Irrigation is one of the essential factors which regulate the level of crop production. The agricultural sector uses a maximum of 80% of global water [10]. Irrigation helps to maintain moisture in the soil and regulate soil temperature. It is vital for the proper crop nourishment and development of crop growth. Traditional irrigation methods include surface irrigation, sprinkler, Centre pivot, and drip irrigation, which are Labour intensive and cause waterlogging due to excessive seepage into the ground [11]. Over 70 percent of the farmers still use traditional methods and apply irrigation on an equal interval basis. Water is being a depleting resource; hence providing the right amount of water and at the right time to the crops depending on their water requirement is the need of the hour [12]. Precise irrigation is the only feasible solution for the current water shortage issues.

According to data from the U.S. Department of Agriculture Irrigation and Water Management Survey, the adoption rates of advanced irrigation scheduling technologies are less than 21 percent. Advanced irrigation scheduling refers to irrigation scheduling based on soil moisture sensors, evapotranspiration programs, plant-based sensors, and crop simulation models.

2. DIFFERENT TYPES OF IRRIGATION METHODS

Artificial water application as an input to the agriculture field for crop growth and development is called irrigation. It is considered a crucial component and helps plants in absorbing micronutrients from the soil. The traditional irrigation practices such as boarder, furrow, and flood irrigation require plenty of water for crop production. The freshwater shortage issues made a motivational factor for developing pressurized irrigation techniques for precise irrigation management.

2.1 Surface Irrigation Methods

Traditional irrigation methods (border, basin, and furrow) apply water equal to the upper edges of banks/bunds considering the traditional plant-based indicators; that create ponds rather than irrigate them. Reported by [13], that irrigation water's imprudent application through traditional irrigation methods reduced crop intensities and yields. It was also found, that conventional water application practices had created water stagnation and soil salinity problem that substantially reduced the overall irrigation efficiency. Moreover, under such a situation, moisture distribution is uneven and deep percolation is unavoidable. Each surface irrigation system has unique advantages and disadvantages listed as follows: (1) initial cost; (2) size and shape of the fields; (3) soil characteristics; (4) nature and availability of water supply; (5) climate; (6) clipping patterns; (7) social preferences and structures; (8) historical experiences; and (9) influences external to the surface irrigation system.

2.2 Modern or Micro-Irrigation and Press urized Irrigation

Pressurized irrigation or micro-irrigation eliminates seepage and evaporation, water conveying losses by adopting pipes as a water transport medium. Due to these irrigation techniques, the entire area wetting problem is eliminated, and weed growth is diminished.

2.2.1 Drip irrigation

Drip irrigation uses drip emitters that apply water at the root zone drop by drop. Drip irrigation usually consists of a pressurized pipe (laterals) system that runs along crop rows. Emitters are placed on the lateral tubes at specific distances allowing water flow to the crop drop by drop. Revealed that drip irrigation techniques lowered the extreme application of irrigation water and saved a surplus amount of freshwater [14]. This technique saved freshwater by reducing the evaporation and water conveyance losses resulting in surface irrigation methods. The water application rate could be lessened by 50 to 100 percent through drip irrigation. It was found out that good drip irrigation management practices improved crop production, including squash, cowpea, faba bean, pea, sorghum sunflower beneath the Western Desert circumstances in Egypt [15]. The findings showed that yield components, all vegetative growth factors, and total yield were significantly enhanced by optimizing applied water.

2.2.2 Sprinkler irrigation

Water is sprinkled into the air and allowed to fall on the ground surface in the sprinkler irrigation method, somewhat resembling rainfall. This method is suitable in water-scarce areas and well suited for regions with an uneven ground level where irrigation is impossible using other irrigation techniques. The sprinkler irrigation method provides a humid environment for crops where crops might destroy due to high temperatures. Irrigation efficiency of surface, drip, and drip irrigation methods is presented in (Table 1).

2.3 Advanced or Automated Irrigation

Cultivation practices have been changed significantly since the start of agriculture. There is more technological advancement in recent days. In the present era, the internet of things (IoT) has become a part of each sector, and it is a boon for development in various sectors, one of which is the agriculture or farming sector. At present, water-saving and precise use of fresh water is a crucial issue in irrigation. The main aim of using the advanced or automated irrigation system is to supply the water required by crops. Precision irrigation means water application at the right time, in the right amount, and at the right place. Precision irrigation helps in improving crop productivity and water use efficiency (WUE).

Consequently, there is a reduction in energy cost per irrigation. Thereby, it allows for the management of variability within farmer's fields and experimental fields. The advantages and disadvantages of various irrigation systems as given in (Table 2).

Table 1. Irrigation efficiency of surface and pressurized irrigation methods [16]

Irrigation Efficiencies	Methods of Irrigation		
	Surface	Sprinkler	Drip
Conveyance efficiency	40-50 (Canal) 60-70 (Well)	100	100
Application efficiency	60-70	70-80	90
Water use efficiency	35-40	80-95	80-95
Surface water moisture evaporation	30-40	30-40	20-25
Overall efficiency	30-35	50-60	80-90

Table 2. Advantages and drawbacks of various irrigation systems

Irrigation Method		Advantages	Drawbacks
Surface	Basin	Less investment and there is uniform application of irrigation water. Unlike micro-irrigation, the whole area is irrigated.	It is not useful for all crops, and there is a wastage of fresh water. Due to the entire area being irrigated, there is more chance to weed growth and, consequently, crop prone to severe diseases.
	Border	More areas can be irrigated with less expenditure, and it reduces soil erosion.	Not suitable for all crops and all soil types.
	Furrow	Plants get an optimum quantity of water, and it is a cheaper method of irrigation.	Wastage of water due to imbalance water flow, not suitable in all types of crops Due to the filling of excess water, there is a problem of salinity.
Micro or Modern	Drip	Water, chemical fertilizers, and pesticides saving are 30-70%, 30-60%, and 40-50% [17]. Plant growth and yield are enhanced by 20-40% [17]. And there is less chance of diseases and pest infestation.	The initial investment cost is high. It requires more maintenance, and skilled Labour is needed. Animals may cause damage to branch and dripper pipelines. It is not suitable for hilly areas.
	Sprinkler	An undulated field also can be irrigated. It is an ideal system when application rates are high.	Expensive; Requires technical knowledge; Water should be clean; Requires higher water pressure to improve the reach of water over the larger surface area and, therefore, not appropriate for smaller fields and windy conditions.
Advanced	Wireless Sensors	Potential applications towards automation in agriculture include precision agriculture, advanced irrigation scheduling, farmland monitoring, and greenhouse monitoring.	The system has low battery power, limited computation capability, and a small sensor node memory very high cost.

Anexperiment for evaluating a low-cost soil sensor for wireless network applications was conducted [18]. Irrigation was given based on a Time-domain reflectometer (TDR) and EC-5 sensors data installed horizontally at 5cm depth with an angle of 45^0 in a field to avoid ponding water on top of the sensors. They concluded that the application of irrigation based on the EC-5 sensor data with wireless networks showed good water-saving, profitable crop growth and reported the highest yield over TDR methods.

*A*new controller for water-based soil irrigation was designed [19]. The designed controller was tested on a plastic mulched tomato field in south Florida with drip irrigation. They have developed the controller by using readily available components and interface with a dielectric soil water probe. Further, they created a soil water-based control system with a custom circuit board and a commercially available soil water probe. Their study results indicated that the water saved up to 61% compared to the evapotranspiration-based water application.

An implementation of a temperature and soil moisture monitoring sensor network using GSM links was described by Ooi et al. [20] in permanent raised bed and flatbed wheat crops. He revealed that the wireless automated soil moisture and temperature monitoring system appears to maintain normal wheat plant growth while saving water. Compared to the traditional irrigation system, a study conducted by Prathyusha and Suman [21] on the impact of soil water monitoring on water saving and compared real-time sprinkler irrigation scheduling, sprinkler irrigation, and flood irrigation of winter wheat and their impact on vertisol yield and crop canopy. A significant increase in water-saving was achieved with irrigation methods in which soil water and rooting depth control were based on irrigation criteria. Compared with flood and sprinkler irrigation, using a real-time sprinkler system can increase yield and retain high irrigation efficiency. A real-time feedback automated irrigation system based on soil moisture was developed by Sanjukumar [22]. Soil moisture sensors, actuators, and wireless networks to build a closed-loop irrigation system. Soil moisture sensors, actuators, and wireless networks were the integral components of a closed-loop irrigation system. The system was tested at Pink Lady TM apple orchard, Dookie campus, University of Melbourne, Australia. The controller turns ON the motor and solenoid valve when the soil moisture level was below the lower limit and turns OFF when the soil moisture level reaches above the upper level. Their study concluded that real-time automated irrigation significantly improved water productivity, i.e., 73% than manual irrigation. So, the adoption of new technology leads to substantial water, labor, and time-saving. Hence, they revealed that real-time feedback based automation would dramatically improve economic efficiency with low water use efficiency.

An embedded system for drip irrigation automation was designed by [23] through which precise monitoring and control of plants' humidity and temperature were achieved. The system reduces runoff over watering saturated soils, avoids irrigating at the wrong time of the day, improves crop performance, and saves time. It also has been revealed that the design of microcontroller-based drip irrigation was a real-time feedback control system.

A soil moisture content-based automatic irrigation system for Motor Pumping and Agriculture Land Purpose was developed [24]. Based on moisture content in the soil, the pumping motor will automatically pump it into the field. The soil moisture sensor was used to obtain real-time information about soil moisture status inland, i.e., whether the soil is wet or dry, and continuously monitored by the microcontroller. The proposed technology was tested and validated numerically to monitor the soil moisture content in the cultivated field. The system saves the water while the plant can get the optimum water level, increasing crops' productivity.

An automated irrigation system to optimize water use for crops was developed [25]. The system was tested in 2400 m^2 greenhouses, located near San Jose del Cabo, Baja California Sur (BCS), Mexico, for organic sage (Salvia officinalis) production. The system has a distributed wireless network of soil moisture and temperature sensors placed in the plants' root zone. The automated system was tested in a sage crop field for 136 days, and water savings of up to 90% was achieved compared with traditional irrigation practices. The automation irrigation system saves time, removes human error, and preservation of this natural resource.

An automated sensor network system for real time irrigation scheduling was developed [26]. The developed gypsum blocks sensors were interlinked with Global System for Mobile (GSM)

Module with a microcontroller unit. The sensor performed well in the range of 10–19% volumetric moisture content. These sensors were reliable in the range of 30–90 kPa. The sensors highly correlated with the coefficient of determination R^2 = 0.93 with slope 0.13 and small relative root mean square error (RRMSE) for given soil moisture potential at a depth of 30–45 cm. The microcontroller starts the pump when the soil moisture content reaches below the field capacity (FC) and stops when the field reaches FC of a given threshold range 15–18. The user receives the field information through mobile via transmitters and receivers using text messages. The system saves the water an average of up to 7%.

A low-power, cost-effective automatic irrigation system using the SHT1X soil moisture sensor was developed by Sivagami et al. [27], which gives soil temperature and humidity. The sensors were placed at a depth of 8 cm, and the power was given to 5V. The control unit received the signals through the Zig-bee end device, connected to the Arduino receiver, and values were compared with the predefined threshold value. If the value was higher than the threshold value, the control unit activated the solenoid valve. The status of the valve was sent to the authorized person through Gmail and SMS connected through GPRS. The control unit would display the solenoid valve stats on the display screen whenever the received data value was less than the threshold value. Thus, they concluded that the system was helpful to the farmers and could be extended by using the database to store the data at the field and the camera to monitor the plant's growth.

A low-cost automatic irrigation system was developed [28]. He tested the order at the Laboratory, and the Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. The programming required for controlling the valve and motor was done in the python language. Four sensors were placed in the field, two were placed at 5 cm, and the remaining two were set at 10 cm. Raspberry pi was used as a microcontroller for the system, solid-state relay, LCD screen, and membrane keys. He observed that any of the two sensors showed nearly 50 percent depletion of water than available water. The solid-state relay automatically opens the solenoid valve, and also the pump will start automatically. Even when any of the two sensors read moisture content near field capacity, the motor would be automatically closed OFF with solid-state relay. The solenoid valve will also get closed. He was found a water-saving of 7.99 m^3 for the entire crop period by adopting an automatic irrigation system. Therefore, he revealed that this system is cost-effective, working efficiently with 0-10% error, and user friendly.

An automatic irrigation system in greenhouse management was developed by [29]. The developed system controls the microclimatic parameters of the greenhouse. They applied the LCD for alerting the user about the condition inside the greenhouse. In this study, soil moisture sensors, temperature sensors, and LDR were used. This system was tested in about 82 sq. Ft in the land area. In their studies, the estimated 27% of water-saving by using drip irrigation and 39% by using sprinkler irrigation separately. Hence, they revealed that using an automatic irrigation system with drip or sprinkler water saving came up to 48.78%.

2.4 Wireless Sensor Technology and Networks

Sensors are used for collecting information about physical and environmental characteristics, whereas actuators are employed to react to the feedback to have control over the situations. The sensors' accumulated information that characterized the object or environment and used to detect the various parameters viz., locality, objectives, and states [30,31]. The context acquisition provides a valuable contribution to modeling situations of domains with a variety of time-variant attributes. Agriculture is one such domain.

The agriculture domain possesses several requirements that are the following:

1. Collection of weather, crop, and soil information
2. Monitoring of distributed land
3. Multiple crops on a single piece of land
4. Different fertilizer and water requirement for various parts of uneven land
5. Diverse needs of crops for different weather and soil conditions
6. Proactive solutions rather than reactive solutions.

Due to the advancement of technology, size reduction, and versatility, sensors' use is becoming possible in virtually every area of life. A sensor is a system with the ability to calculate and translate physical attributes into signals for the observer. Sensors are part of nature, and in the case of bio-sensors, many of the sensing capabilities are available in a living organism. There are multiple components called nodes in the wireless sensor network (WSN). Sensor network performs three main functions (i) Sensing (ii) Communication (iii) Computation by using hardware, software & algorithms. The nodes play different roles. The distributed nodes which gather the information are called the source node.

Various communication protocols have been introduced in the last few decades due to the rapid increase in IoT devices and WSN technologies. Each protocol has its specifications depending on the bandwidth, the number of free channels, data rate, battery timing, price, and other factors [32]. The most commonly-used protocols for wireless communication in IoT-based applications in agriculture, as shown in the following (Table 3).

3. SYSTEM ARCHITECTURE AND IOT ENVIRONMENT

Irrigation can be automated using sensors, microcontroller, Bluetooth, and Android application, as shown in Fig. 2. (a). The low-cost soil moisture sensor and temperature and humidity sensor are used. They continuously monitor the field. The sensors are connected to the Arduino board. The sensor data obtained are transmitted through wireless transmission and are reached to the user to control irrigation. The mobile application can be designed in such a way to analyze the data received and to check with the threshold values of moisture, humidity, and temperature. The decision can be made either by the application automatically without interruption or manually through the application with user interruption. If soil moisture is less than the threshold value, the motor is switched ON, and if the soil moisture exceeds the threshold value, the motor is switched OFF. The whole IoT environment set up is shown in Fig. 2. (b).

3.1 Working Procedures

The system's central hypothesis is to apply the right amount of water at the right time to fulfill the water requirement of the crop and maintain the soil always at field capacity with allowable 50% available soil moisture depletion. For achieving this condition, sensors could be installed at the effective root zone of a specific crop in undisturbed soil. After installing the sensors, set a lower set point (LSP) and a higher set point (HSP). When the available soil moisture content is below the LSP, the sensor sends signals to the controller to start the irrigation system to deliver water up to the field capacity (HSP). At the same time, it sends a text message to the user's mobile about the pump's on and off.

Once the soil has reached HSP, the sensors send a signal to the microcontroller. The microcontroller stops the pump, and at the same time, text messages are sent to the user. The solenoid valve and pump operation's detail is sent to the user's mobile in text SMS. The controller hourly saves the soil moisture content in the memory card over the entire crop period, so one can quickly get information about the entire crop period's field condition. The controller has the capacity and facility to store the data of soil moisture content in the field for two years, and it can be increased. This algorithm is programmed in a microcontroller, as shown in Fig. 3.

4. CALIBRATION OF THE SENSOR

The gravimetric method for determining soil moisture content on a volumetric basis was used to know the accurate soil moisture content. Then in the same soil, the sensors were inserted and kept for a particular period to stabilize voltage reading, which then converted and calibrated as soil moisture content on a volumetric basis. [33] gave a detailed method of calibration of the sensor, in which; the voltage is recorded for known percent of moisture. Using the regression equation, other values of voltage for respective moisture content were estimated. The regression equation is inserted in the system's program, so this will directly give the amount of moisture content in the soil when the sensor is truly inserted in the soil.

Calibration is done by the standard procedure as suggested by cobos and chambers [34];

Step 1: 1 kg oven-dry soil has been taken. 5% water was added to it and mixed properly.
Step 2: The sensor is inserted correctly in the soil and recorded the reading of voltage.
Step 3: Added 5% more water and mixed it thoroughly. The respected soil moisture sensor reading is recorded in voltage.
Step 4: Follow the step-3 for 15%, 20%, 25%and 30% water content. Record the respective moisture content in voltage, scale, or unit.

Table 3. Wireless communication protocols are used in precision agriculture (PA) [34]

	ZigBee	Bluetooth	Bluetooth Wibree	WiFi
Frequency band Range	2.4 GHz Range 30 m–1.6 km.	2.4 GHz 30–300 ft.	2.4 GHz Up to 10 ft.	2.4 GHz 100–150 ft.
Data rate	250 kbps	1 Mbps	1 Mbps	11–54 Mbps
Power consumption	Low	Medium	Low	High
Cost	Low	Low	Low	Low
Modulation/protocol	DSSS, CSMA/CA	FHSS	FHSS	DSSS/CCK, OFDM
Security	128 bit	64 or 128 bit	128 bit	128 bit

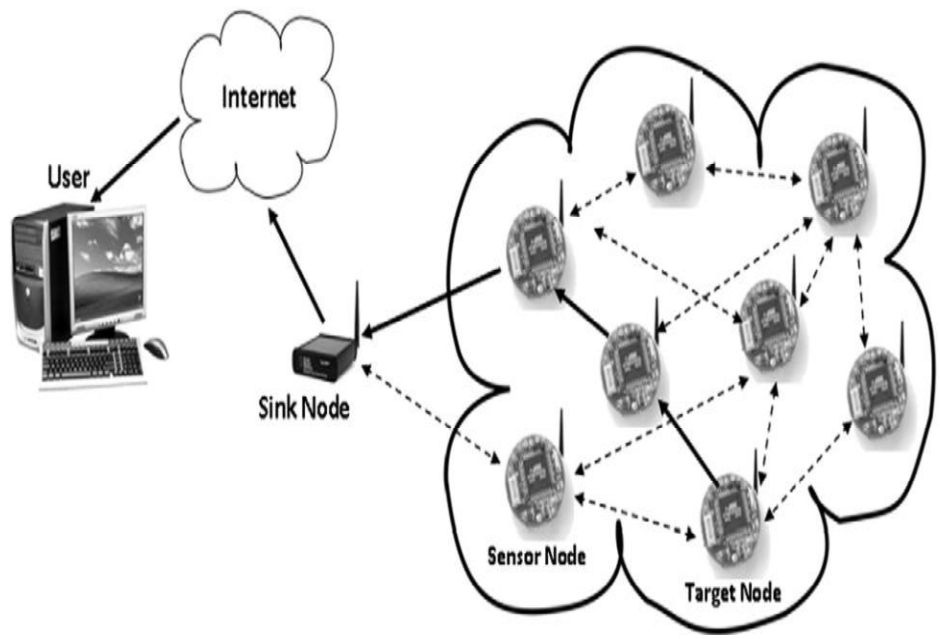

Fig 1. Wireless sensor network (WSN) [32]

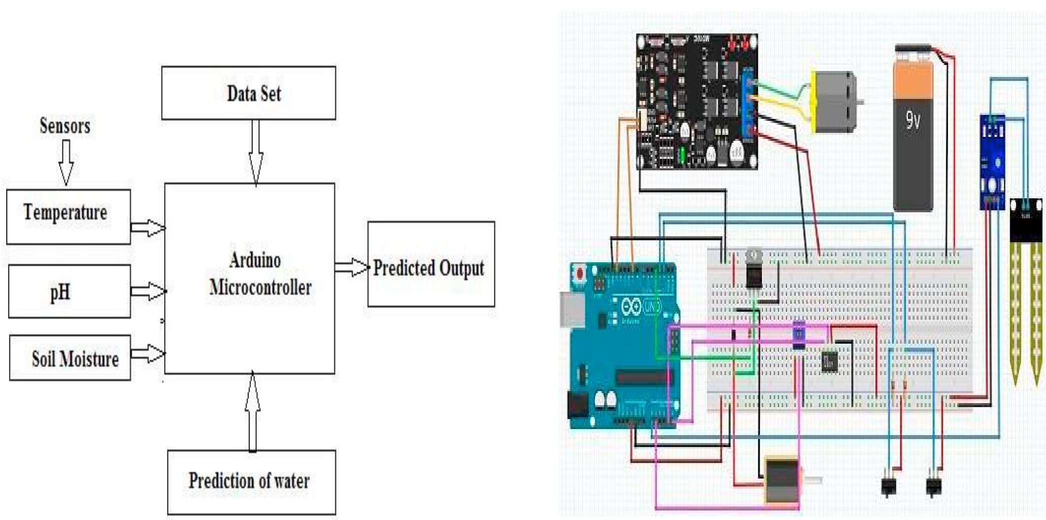

Fig. 2. (a) Block diagram of system architecture; (b) Complete set of arduino UNO

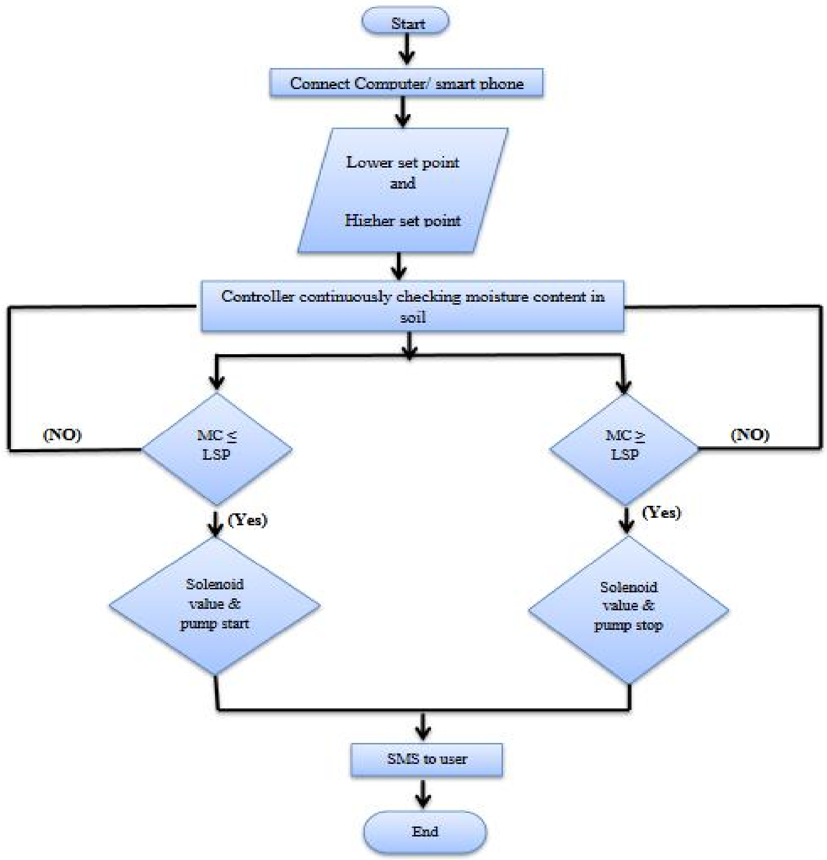

Fig. 3. Flow chart of working of an automated irrigation system

4.1 Finding the Calibration Function

The calibration function is calculated quite easily after performing the standard procedure as suggested by Soulis et al. [33]. Simply made a scatter plot with the sensor output on the X-axis and the soil moisture content on Y-axis. Then by using the trend line or curve fitting function, a mathematical model of the relationship is developed.

5. INSTALLATION OF SENSORS

5.1 Field Location

Select the location for each sensor accessible, yet at least 5 feet away from the edge of the field [35]. Find the areas or spots with the lowest water holding capacity or dry earlier than the other field area and areas with the most sun exposure. Therefore, it is best to manage the irrigation of the whole field so that the area doesn't experience water stress, and the rest of the field should be fine. This often means irrigating more frequently but in smaller amounts.

5.2 Placement of Sensor

The placement of the sensor at the respective depth plays a crucial role in achieving higher irrigation efficiency. [36] reported that nearly the same finding, i.e., soil moisture sensors positing considerably affect irrigation efficacy. The respective sensor readings were crucial factors to provide more precise information about the average soil water content at the root zone [37]. The depth of placement of the sensor is the area where most of the active root occurs. [38] reported that most active roots are nearer to the surface where there is evaporation loss. Hence it is necessary to fix soil moisture sensors at a particular depth to sense available soil moisture content by considering the depth of soil and effective root zone depth. Several researchers found the sensor's depth of placement during their studies, as shown in the following (Table 4).

Table 4. Depth of sensor used by researchers in their studies

Sr. No.	References	Year	Depth of placement of the sensor
1	[37]	2003	Sensors at 5 cm and 15 cm respond quick
2	[27]	2015	8 cm
3	[35]	2015	The most suitable was 10 cm
4	[29]	2017	Two sensors used at 5 cm and 10 cm

6. CONCLUSION

The micro-irrigation practices saved an ample amount of freshwater, and this method recorded the highest water use efficiency. Now, it is time for the elimination of the need of humankind and bringing automation in agriculture. To keep in view the present and future needs of the IoT application in agriculture, a comprehensive view of different moisture and RH sensors used in irrigation, depth of placement of moisture sensors, and list of wireless communication device reported in the document. In addition to it, the calibration procedure of the soil moisture sensor was also reported. The case studies listed in the article expressed a positive opinion on IoT based smart irrigation and suggested future use of it. The IoT based precision irrigation system can give an optimal solution for autonomous agricultural operations for precision, economics, reduced human struggle, and environment protection. Though many benefits are using IoT in agriculture, proper working of sensors and internet connectivity limit their adaptability at the field level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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