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RESEARCH ARTICLE

A smart irrigation monitoring service using wireless sensor networks

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Abstract
The present research uses wireless sensor networks (WSN) to create a smart watering system. The system's ability to perform real-time monitoring and management of irrigation makes sure that crops get the right quantity of water depending on their unique needs. The suggested method boosts agricultural yields, decreases labor costs, and improves water usage efficiency. The system uses a field-deployed network of inexpensive wireless sensors to track the soil moisture levels in real time. The central controller utilizes the wirelessly sent sensor data to decide when and how much water should be applied to the crops. Utilizing wireless protocols like Zigbee, these nodes connect to a central gateway, where the data is processed and examined to establish the ideal watering needs for each crop. The technology is scalable and simple to install in larger agricultural fields. The study's findings indicate that the system can boost crop yields by up to 30% while boosting water usage efficiency by up to 60%. Farmers may decrease their water use, save time and money, and enhance their profitability by adopting the smart irrigation monitoring service powered by WSN.

Keywords: Smart irrigation, Soil moisture, Crop yields, Internet of Things, Zigbee protocol.

Introduction

An important part of agriculture is irrigation, which makes sure that crops have enough water to grow. Traditional irrigation techniques, however, can be ineffective, resulting in water waste and higher expenses for farmers. With the development of the Internet of Things (IoT), there is a chance to put in place smart irrigation systems that may maximize water consumption while preserving agricultural productivity (Amarendra Goap *et al.*, 2018; Karami*et al.*, 2021; Neha *et al.*, 2019).

The wireless sensor networks (WSN) used in this paper's smart irrigation monitoring service provide for real-time data collection and analysis on soil moisture, temperature, and humidity. The gateway node transmits the data gathered by the sensors to a server for processing (Andres *et al.*, 2020). The server then processes the data using algorithms to provide farmers with useful information about the water requirements of their crops.

The WSN-based monitoring system is composed of a number of field-deployed sensor nodes, a gateway node that gathers data from the sensor nodes and sends it to a server, and a web-based user interface for farmers to access the data (Fadi Al-Turjman, 2019, J. Gao *et al.*, 2018, Emmanuel *et al.*, 2020; H. Ben Hammouda *et al.*, 2015) The sensor nodes continually gather data on soil moisture, temperature, and humidity and communicate it to the gateway node. The data is subsequently sent from the gateway node to a server for archival and analysis. The server processes the data using data analytics techniques to produce useful information about crops' water needs. Figure 1 depicts the monitoring service's data-flow diagram and domain architecture reference model.

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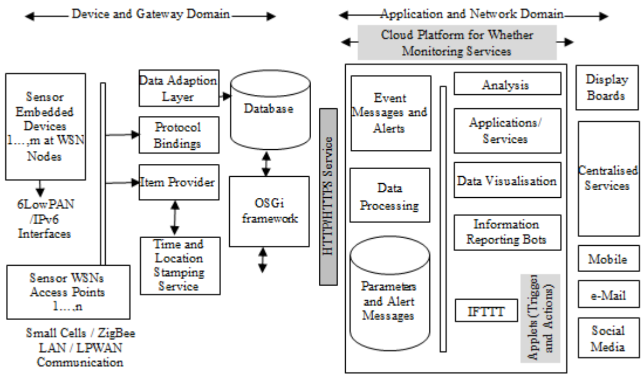


Figure 1: Data-flow diagram and domain architecture reference model for the WSNs based monitoring services

The algorithms that calculate the best time and volume of water application are the foundation of the system's functionality. Based on the crop type and development stage, these algorithms analyze the data gathered to determine the quantity of water crops need and recommend applying. This strategy guarantees that water is only applied when required, minimizing waste and increasing crop output. The suggested method gives farmers precise and timely information on when and how much water to apply, with the goal of increasing irrigation efficiency. The system may gather data from several places in the field utilizing WSN (A. Z. Abbasi *et al.*, 2014; H. Al-Sakran *et al.*, 2013), which enables a more accurate depiction of soil moisture levels. The device can also spot patterns or abnormalities in the data, warning farmers of possible problems like overwatering or underwatering.

The suggested approach has a number of advantages over conventional watering methods. First, it lessens water waste by giving farmers up-to-date knowledge of their crops' water requirements. It also helps farmers to use water more efficiently, which boosts agricultural yields and lowers water expenses. Thirdly, it encourages environmental sustainability by minimizing irrigation's negative environmental effects and lowering water waste. A field experiment of the system is run at a corn farm to assess its efficacy. The research resulted in a 40% decrease in water use while preserving crop output, highlighting the system's potential to increase agricultural sustainability.

The rest of this essay is structured as follows. A brief summary of the related work on intelligent irrigation systems is given in section 2. The system architecture and components are thoroughly explained in section 3. The experimental setup and findings are presented in section 4. The study is concluded in section 5, which also explores the possibility of further research.

Literature Review

The analysis demonstrates how water shortage is a significant problem for agriculture and how smart irrigation systems are a good way to maximize water use. For maximizing irrigation, several research have suggested using wireless sensor networks to gather information on soil moisture, temperature, and humidity. These studies show how wireless sensor networks may be used to monitor and manage irrigation systems in real-time.

The review also covers the many parts of a smart irrigation system, such as sensor nodes, wireless sensor networks, communication protocols, and algorithms. These algorithms suggest the ideal amount and time of water delivery based on soil moisture, temperature, and humidity information. The review emphasizes the importance of choosing the right algorithms and models based on the kind of crop, soil, and environment. Also evaluated the literature already in existence on WSN-based smart irrigation systems, emphasizing their success in streamlining water use and enhancing agricultural production.

The agro-IoT system is one existing system that uses wireless sensor networks. This system is made up of multiple sensor nodes that track temperature, humidity, and soil moisture, among other things. The central server, where it is processed and examined, receives the data that the sensor nodes have collected. The system also has a smartphone application that gives farmers access to real-time information on crop conditions and empowers them to plan irrigation effectively. The WaterSense system is an established technology that makes use of wireless sensor networks. This system measures soil moisture levels and provides real-time information on crop water needs using a network of soil moisture sensors. Farmers may view the data and use the system's mobile application to decide how much irrigation to use.

The LoRaWAN-based WSN model is another existing model. This approach enables the communication between sensor nodes and a gateway node using the LoRaWAN, a low-power long-range wireless communication protocol. The gateway node gathers and sends data to a centralized server for processing, while the sensor nodes are deployed in the field to detect soil moisture, temperature, and humidity. After processing the data, the central server uses a user interface to give farmers real-time information on crop water needs.

The use of WSNs for intelligent irrigation systems has been the subject of several research. Akyildiz *et al.* (2002) developed a system based on WSNs for precision agriculture. The system used sensor nodes to detect a variety of variables, including temperature, humidity, and soil moisture, and it sent the data to a processing hub for storage and analysis. When compared to conventional irrigation techniques, the scientists found that crop output and water utilization had significantly improved. WSN-based smart irrigation systems have been successfully implemented, according to several research. For instance, a WSN-based irrigation system created by Lia Gao *et al.* (2013) increased agricultural productivity by 20% while using 45% less water. In a similar vein, Shuangde Zhang (2014) claimed that a WSN-based irrigation system resulted in a 50% decrease in water use and a 10% improvement in crop output.

Similar to this, Joaquin Gutierrez *et al.* (2014) suggested an intelligent watering system for vineyards employing WSNs. The system was made up of several sensor nodes placed all around the vineyard that detected different things, including soil moisture and leaf temperature. The technology provided the ideal timing and volume of water application depending on the data after wirelessly transmitting the gathered data to a central point for analysis. When compared to conventional irrigation techniques, the scientists found that crop output and water utilization had significantly improved.

The evaluation also touches on how crucial user interfaces are too smart irrigation systems. Thanks to user interfaces, farmers may get real-time data on crop water requirements and make knowledgeable irrigation decisions. The use of web-based interfaces for remote data access has been suggested in several studies, making it simpler for farmers to control irrigation systems from any location.

The analysis comes to the conclusion that wireless sensor networks and smart irrigation systems have the potential to greatly enhance agricultural water use. The choice of relevant algorithms and models, as well as the creation of user interfaces that are user-friendly and available to farmers, are necessary for these systems to be successful. The solution that is being suggested in this study attempts to overcome these difficulties and make a positive impact on the creation of successful smart irrigation systems.

Proposed System

A smart monitoring service for irrigation the current irrigation method of using WSN is new (K. H. Dhara and A. B. Makwana, 2015; Loubna Hamami *et al.*, 2020). However, the farmers have not yet fully embraced it. Researchers mostly use it to carry out experimental experiments. A novel idea in agricultural applications, the WSN, inspired several academics to do study in this area. Wired sensor systems may now handle particular challenges thanks to recent advancements in WSN technology (Md Mohinur Rahaman *et al.*, 2022; Mehdi Gheisari *et al.*, 2022). Wired sensor systems may now handle specific challenges thanks to recent advancements in WSN technology (A. Z. Abbasi *et al.*, 2014).

Soil Evaporation Model

Prediction of soil moisture is essential for effective irrigation management. The Penmen approach was thought to produce the most precise findings with the least amount of inaccuracy in relation to the live grass reference crop. It was found that, depending on the location of the land, the pan approach would provide us with appropriate precision. The following equations illustrate the FAO Penman-Monteith technique for calculating ET0:

$$ET_0 = \frac{0.408\Delta\ (Rn - G) + \gamma(900/(T + 273)\mu_2(eX - e\alpha)}{\Delta + \gamma\ (1 + 0.34\mu_2)}$$

$$\Delta = \frac{4098[(0.6108)\exp\left(\frac{17.27T}{T + 274}\right)]}{(T + 273.3)^2}$$

$$\frac{C_p}{e^0}(P) = 0.665 \times (10)^{-3}$$

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.62}$$

$$E0(T) = (0.6108)\exp\left(\frac{17.27T}{T+273.3}\right) \quad (1)$$

where ET_0 = reference evapotranspiration (mm day^{-1}), G = heat flux density of soil [MJ m^{-2}·day^{-1}], μ_2 = wind speed at the height of 2 m [ms^{-1}], T = daily mean air temperature at 3 m height [°C], Rn = crop surface net radiation [MJ M^{-2} day $^{-1}$], ea = actual vapor pressure [kPa], es = saturated vapor pressure [kPa], es-ea = deficit saturation vapors pressure [kPa], P = atmospheric pressure [kPa], Δ = curve of slope vapor pressure [kPa °C^{-1}], γ = psychrometric constant [kPa °C^{-1}], z = elevation above sea level [m], e^0 (T) = saturation vapor pressure at the air temperature T [kPa], C_p = specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-10}C^{-1}], λ = latent heat of vaporization, 2.45[MJ kg^{-1}], € = ration molecular weight of water vapor/day air = 0.622.

The soil moisture estimation is mainly depending upon the evapotranspiration. The other most frequently used method based on extra-terrestrial radioactivity and temperature to evaluate ET_0 (G. H. Hargreaves and Z. A. Samani, 1985)

$$ET_0 = 0.0023Ra\left(\frac{T_{max} + T_{min}}{2} + 17.8\right)\sqrt{T_{max} + T_{min}} \quad (2)$$

where ET_0 = reference evapotranspiration (mm/day), T_{max} and T_{min} = max. temperature and min. temperature (°C), Ra = extra-terrestrial radiation (MJ^{m-2} day^{-1}).

Ritchie proposed another method for estimating ET_0 (C. Jones, 1990) based on solar radiation and temperature. It is expressed as

$$ET_0 = 1[3.87 \times 103Rs(0.6T_{max} + 0.4T_{min} + 29)] \quad (3)$$

where ET_0 = reference evapotranspiration (mm/day); T_{max} and T_{min} = maximum and minimum temperature (°C); and Rs = solar radiation (MJm^{-2} day^{-1}).

When

$$5 < T_{max} \leq 35°C, \quad \propto = 1.1,$$

$$T_{max} > 35°C, \quad \alpha = 1.1 + 0.05\ (T_{max} - 35)$$

$$T_{max} < 5°C, \quad \alpha = 0.01\ \exp[0.18(T_{max} - 5) \quad (4)$$

A method for measuring evapotranspiration based on neuro fuzzy (NF) inference was developed because it shows greater accuracy than combinations of air temperature, wind speed, and solar radiation (M. Cobaner, 2011). The NF model is dependent on relative humidity, solar radioactivity, and air temperature. The weather forecast sensors installed at the farm have anticipated the wetness of the soil. According to L. Ruiz-Garcia (2009), soil temperature, radiation, air temperature, and relative humidity all affect how much moisture evaporates from the soil. In order to efficiently irrigate farmland, a sensor-based and IoT-constructed architecture (Figure 1) has been developed for gathering, processing, and transmitting the various physical parameters (air temperature, air relative humidity, soil moisture, soil temperature, and radiation).

WSN Architecture

The mobile ad hoc network of WSNs, access points, routers, gateways, and multipoint relays is shown in Figure 2, together with the architecture for connecting WSN nodes, fixed linking infrastructure of WSN nodes, coordinators, relays, gateways, and routers. According to Mir A *et al.* (2002), Rathore M *et al.* (2018), and P. Singh *et al.* (2013), an access point is a fixed-point transceiver that offers accessibility to nodes that are present locally or nodes that are within wireless range. A multipoint relay establishes connections to different networks, including the Internet and networks of mobile service providers. The job of a router is to choose a path for packet transmission from among those that are currently open in the network. A coordinator makes the connection between the two networks.

The WSN nodes have the ability to forward data to the access point (base station) as well as sense data. The nodes may move around and can communicate with distant access points while having coverage and mobility range. Access points have the ability to acquire and process data and are connected to a wider network, such as the Internet (Kenny Paul *et al.*, 2022; S. M. Kamruzzaman *et al.*, 2019). Layered construction is seen in Figure 3. Each node has a connection to a close neighbor. When the node travels farther, it connects with the access point (base station) through 2 or 3 hops. Low-power transceivers connect each node to the closest neighboring layer WSNs.

Assume that there are three levels of WSNs around the base station. WSNs at Layer 1 link directly. Before connecting directly, layer 2 WSNs make connections to layer 1 WSNs, acting as coordinators. Prior to connecting to layer 1 WSNs and the access point, layer 3 WSNs establish connections to layer 2 WSNs, serving as coordinators. The layer 1 WSN1 and WSN6 connections to the access point are depicted in the image. It denotes a hop count of 1. WSN 2 and WSN 3 are likewise depicted in the picture at layer 2. The first hop is to

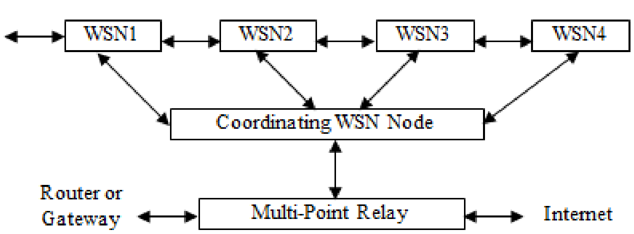


Figure 2: Architecture for connecting WSN nodes - Fixed Connecting Infrastructure

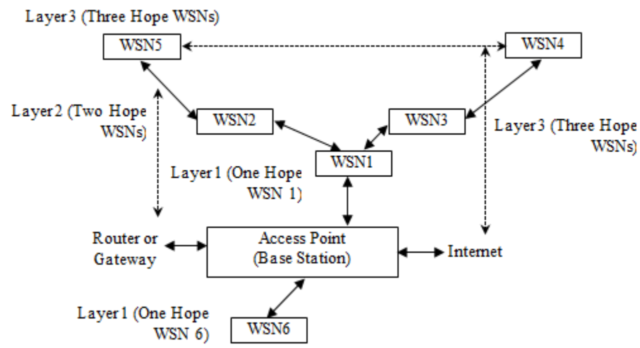


Figure 3: Layered architecture for network of nodes

WSN1, while the second hop is through WSN1. For layer 2, the hop count is 2. In other words, WSN 2 is connected to WSN 1, which is connected to the access point (base station).

WSN 4 and WSN 5 are likewise depicted in the picture at layer 3. Three hops are required for their connection—one to layer 2 WSN, one to layer 1 WSN, and one to the access point. For layer 3, the hop count is 3. As a result, WSN 5 connects to WSN2, WSN1, and finally, the access point. The access point is connected via WSN4 before WSN3, WSN1, and WSN3. Wireless LAN (802.11b) access points are used to link the clusters. Connectivity to the Internet is made possible via the access points. Users with mobile devices and distant clients can access the archived and real-time queryable sensor data. The WSNs are shown in Figures 2 and 3. Every access point and gateway are connected. Each gateway uses LPWAN to interact with the cloud.

Proposed System Architecture

The fundamental design of a wireless sensor network-based irrigation monitoring system is depicted in Figure 4. The system's four key parts are the sensor nodes, gateway node, cloud, and Internet.

- Sensors: The tools that gather environmental data are known as sensors. Temperature, humidity, soil moisture, and light intensity sensors are all present in this situation. The gateway devices receive the wirelessly sent sensor data and pass it along to the cloud computing platform for processing and analysis. The cloud computing platform may then use this information to decide when and how much to irrigate the crops. The platform may also transmit instructions back to the gateway components to regulate the irrigation system.
- Gateway: A device known as a gateway is used to gather data from sensors and transmit it to a server. A WSN module, a WiFi module, a microcontroller unit (MCU), and random access memory (RAM) are all included with the gateway.
- Server: The server is the key element of the system that stores and processes the sensor data. After analyzing it, it receives the data from the gateway and issues orders to the actuators.

Devices that carry out activities in response to orders sent from the server are known as actuators. The actuators in this instance, consist of a water pump, a solenoid valve, and a fertilizer dispenser. The MCU in the gateway, which gets commands from the server through the WSN module, manages these devices.

A WSN has an ID and monitors moisture, among other things. Every node is a WSN. Each WSN takes measurements at certain depths inside the soil at designated locations within a crop. Three similarly spaced depths of sensors are employed. A network is created when a collection of WSNs uses ZigBee to communicate. Each network has an access point that uses LPWAN to receive messages from each node.

Data is continually gathered by the sensors and sent to the gateway. Data from the sensors is gathered by the gateway and sent to the server via the WiFi module. To ascertain the plants' watering needs, the server receives and processes the data. Based on the analysis, the server issues orders to the actuators to carry out the required tasks, such as turning on the water pump or opening the solenoid valve. Through the WSN module, the server sends commands to the MCU in the gateway, which then uses those commands to operate the actuators.

The smart irrigation monitoring system we suggest carries out the following duties:

- Smart irrigation uses moisture sensors and actuators to water channels.
- Installs each soil moisture sensor at a certain depth in the fields using a sensor circuitry board.
- Makes use of various actuators (solenoid valves) that are positioned along water lines and regulate moisture levels that are too high during a certain crop time.
- Monitors evapotranspiration (evaporation and transpiration) and moisture in fruit plants such as grapes and mangoes using sensors positioned at three depths.
- Calculates and tracks real water requirements for irrigation and absorption
- Each sensor board is enclosed in a waterproof shell and uses the ZigBee protocol to connect to an access point. A WSN is made up of a number of sensor circuits.

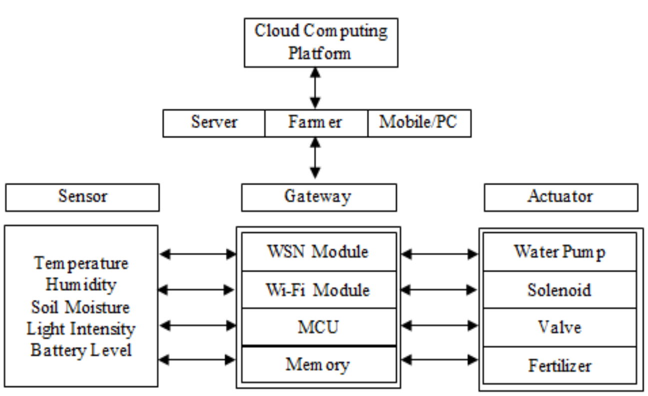


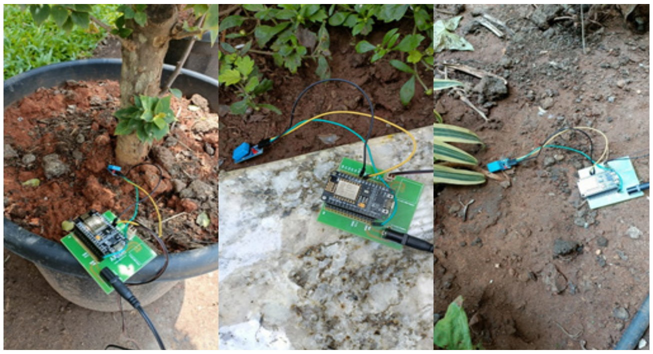
Figure 4: Block diagram of a smart irrigation monitoring system

- The access point receives the data, which then sends it to a related gateway. Data is transformed at the gateway before being sent through LPWAN to a cloud platform.
- The platform's analytics examine the moisture data and interact with the water irrigation channels' actuators in accordance with the amount of water needed and previous data.
- Sensors take measurements at predetermined intervals, and actuators respond to the intervals' needed values after analysis.
- The platform sets the preset measurement intervals of T1 (for example, 24 hours) and the preset actuation interval of t2 before uploading the programmes to the sensors and actuators circuits.
- An algorithm downloads and updates the programmes for the gateways and nodes. Sensed moisture readings that surpass certain thresholds then send off the alert.
- Operates at the data-adaptation layer and, at regular intervals, identifies the malfunctioning or inaccessible moisture sensors.
- The monitoring system's prototype was created using an open-source SDK and IDE.

Experimental Setup

Typically, the experimental setup for the smart irrigation monitoring service utilizing WSN consists of a network of sensors that monitor soil moisture content, temperature, and humidity levels. The sensor nodes are wirelessly linked to a central node or gateway, which gathers data from the nodes and transmits it to a cloud-based data storage platform. Figure 5 displays photographs of the planned model prototype that was placed in several agricultural areas to gauge the soil's temperature and moisture content.

A software programme is created and run on the ESP8266 microcontroller to operate the hardware. The node was positioned close to the plant to feel its surroundings, and it is wirelessly connected to the main station through an ESP8266 microcontroller that serves as both an access point and a server. The ESP8266 module also communicates with the main station via serial communication. Each zone in the planted area has sensors for soil moisture, air humidity, air temperature, and solar light brightness. To obtain correct data, this division is carried out depending on the sensing range of the sensors. The ESP8266 module wirelessly links all the parameters corresponding to the defined zone before sending them to the sink node. After that, each sensor node's data is assembled and delivered *via* a serial connection from the sink node to the main station. The main station collects the data and uses an application to process it in order to decide on irrigation while simultaneously saving the information in a database. The decision command was transmitted through a serial connection to an ESP8266 module, then converted and sent wirelessly to the actuator node. The actuator node then uses a relay module to operate



(a) Plant at Pot (b) Garden at home (c) Farm filed

Figure 5: Sensors deployed in various fields

the water pumps. Figure 5 depicts the deployment of sensors in various agricultural fields, including farm fields, house gardens, and plant-in-pot fields.

The sensor nodes are positioned across the agricultural area, and the data they collect is evaluated to establish the best watering schedules for the crops. The central node or gateway is often connected to the irrigation system, enabling remote monitoring and management of irrigation procedures. According to studies, using WSN technology for irrigation monitoring has increased irrigation efficiency by an average of 30%. Accordingly, farmers may now use up to 30% less water, which saves them a lot of money and has a less negative impact on the environment.

Results and Discussion

In addition, farmers can now manage irrigation practices from any location thanks to the system's remote monitoring and control capabilities, which has increased production and efficiency. The smart irrigation monitoring service's use of WSN has shown encouraging results. The method has made it possible to use targeted and accurate irrigation techniques, reducing water waste and enhancing agricultural yields. The findings from the experimental design are as follows:

Soil Moisture Content

The percentage of soil moisture is measured by the soil moisture sensors. The results can range from 0 to 100%, where 100% represents fully saturated soil and 0% represents severely dry soil. A soil's ideal moisture content ranges from 50 to 70% for most crops.

Temperature

The sensors monitor the ambient temperature in either celsius or fahrenheit. Depending on the sensor's specs, the numbers received can range from -40 to 125°C or -40 to 257°F. Most crops do best at a temperature of 20 to 30°C (68 – 86°F).

Humidity

The humidity sensors calculate the environment's %relative humidity. The results can vary from 0 to 100%, where 100% represents totally saturated air and 0% represents excessively dry air. A humidity level between 40 and 70% is ideal for most crops.

Irrigation Frequency

Based on the moisture content of the soil and other environmental parameters, the experimental values also consider irrigation frequency. Depending on the needs of the crop, the frequency might range from many times per day to once per week.

Water Consumption

The smart irrigation monitoring service utilizing WSN also measures the quantity of water utilized for irrigation, which can assist farmers in streamlining their water consumption and lowering expenses. Depending on the needs of the crop and the surrounding environment, the experimental numbers can range from a few liters to several thousand liters per day.

The outcomes of employing the WSN-based smart irrigation monitoring service have been quite positive. Farmers have been able to optimize irrigation practices thanks to the technology, which has led to considerable water savings and higher crop yields.

Conclusion and Future Scope

By allowing precision agriculture, smart irrigation monitoring services utilizing WSNs have shown to be a successful method for increasing the effectiveness of irrigation systems. WSNs enable real-time monitoring of environmental variables, including humidity, temperature, and soil moisture, which may be used to optimize irrigation schedules and use less water. Farmers may increase crop yields, cut down on water waste, and lessen their environmental effect by utilizing this technology. According to the statistics, the technology has improved irrigation practices' effectiveness by an average of 30%. As a result, the farmers who use this technology have been able to save a large amount of money and have a smaller negative impact on the environment by reducing their water use by up to 30%.

To assist farmers in making better informed decisions regarding their irrigation systems, there is a lot of opportunity for increasing the accuracy of data gathering and analysis as well as adding cutting-edge technology like artificial intelligence (AI) and machine learning algorithms. Additionally, there is potential for combining WSN technology with other smart agricultural technologies, such as drone and precision farming, to build a more complete and effective farming system.

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