© 2025 IJRTI | Volume 10, Issue 9 September 2025 | ISSN: 2456-3315

Automated Irrigation System Using Wireless Sensors

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***Abstract*—Effective water management is an essential issue in modern agriculture, especially in water-limited areas. This paper introduces the design and deployment of an automated irrigation system using wireless sensor networks (WSNs) to monitor soil moisture, temperature, and environmental conditions in real time. The system proposed in this paper uses low-power wireless sensors placed strategically in the field to gather data, which is then relayed to a central control unit. Depending on predetermined thresholds and sensor values, the system automatically controls irrigation valves to deliver precise volumes of water only when required, thus greatly minimizing water wastage and labor needs. The result shows improved water efficiency, healthier crops, and scalability to large scale agricultural application. This paper introduces the possibility of IoT-based smart farming technology to enable sustainable agriculture through smart resource management.**

***Index Terms*—Automated irrigation, Wireless sensor networks, Soil moisture monitoring, Smart farming, Precision agriculture, IoT in agriculture, Water efficiency.**

I. INTRODUCTION

Agriculture holds a very crucial place in the economy of every country. It is estimated that almost 80% of the freshwater resource is consumed in agriculture. With the ever increasing population of the world, the ratio is going to rise in the future, thereby highlighting the importance of designing science- and technology-based systems in which water resources can be used sustainably. A range of irrigation systems, varying from very basic to technology-based, have been used to achieve water conservation for a wide variety of crops. Some systems monitor the water balance of the plant based on canopy temperature, while some use the crop water stress index (CWSI) for the best irrigation schedules. This article proposes to design an automated irrigation system moisture, air temperature, and canopy temperature. Data collected with the system can be transferred to a computer via a serial port for analysis and storage. To enhance water management efficiency, there is another system that integrates a wireless sensor network (WSN) and a weather station, allowing internet-based monitoring of drainage water. Wireless sensor networks that are designed with microcontrollers and wireless communication technologies can potentially substitute existing techniques with a using a low-cost wireless communication device and soil moisture sensor. Other approaches to determining plant irrigation needs are system estimation and mobile phone apps, which use image processing algorithms to get the leaf area. A data acquisition system has been developed for crop condition monitoring, including soil much more robust approach. Wireless embedded sensors have not only been used in agriculture but also in home automation, i.e., device control and security systems. Wireless sensor networks in industrial environments facilitate inventory tracking, real-time data acquisition, fault detection, and temperature monitoring of sensitive products. From an environment point of view, sensor networks are used to monitor several parameters related to marine, soil, and atmospheric conditions. In agriculture, these networks provide data that is essential in applying precise management practices. technology developments. The most Commercial wireless sensor network (WSN) solutions are in the market with varying capabilities, ranging from low-resolution simple devices to complex systems with embedded processing. In a wireless node, the radio modem usually uses the most power. Over the last few years, various wireless standards have emerged, such as IEEE 802.11b (Wi-Fi) for local area networks, and IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (XBee) for personal area networks. This paper discusses the implementation of an automated irrigation system using a microcontroller with wireless communication technology. The main aim of the project is to reduce water consumption by implementing automation. The system employs three sensors of different types—soil moisture, temperature, and light—each with a PIC microcontroller. Sensor information is sent to a personal computer via an XBee transceiver, and an irrigation motor is utilized for watering the field. These sensors are placed in a strategic position in the root zone of the plants, and when the soil is discovered to be dry, the motor runs automatically. The soil moisture sensor provides real-time information to the controller, which enables sensor node and receiver communication through the XBee protocol. Data is then sent to a personal computer, in which MATLAB is employed to provide threshold values and maintain a history file in Excel.

II. LITERATURE REVIEW

Not much has changed in agriculture; it remains a fundamental lifestyle in rural villages. With improvements in technology, it is now achievable to monitor and manage environmental factors such as soil moisture content, temperature, wind speed, air pressure, salinity, turbidity, and humidity. Automated irrigation systems based on solenoid valves are improving irrigation systems in rural villages. The agricultural sector has expanded a lot due to research and influential variables on crop yield are crop variety, soil pH, and soil temperature, which have become focal areas of research by scientists. Electric sensors have been at the forefront in measuring soil water content and driving irrigation based on that. It has resulted in significant water conservation—53% or more in certain research work [3]. Drip irrigation systems have shown efficacy by conserving water to a large extent and supplying water and nutrients to the plant root zone. Sensor technology-based microcontroller irrigation systems are a paradigm shift in precision agriculture [4][11]. Another important factor to consider in managing irrigation is evapotranspiration (ET) rate, a measure of plant transpiration as well as evaporation from soil. ET relies heavily on temperature, humidity, wind speed, and plant population [5]. Advances in battery life and sustainability of the system are being implemented through the infusion of solar power and thermal monitoring energy

[6]. Some researchers have developed effective irrigation technologies. For example, M. Nesa Sudha et al. designed TDMA-based algorithms for successful soil data gathering. Anuj Nayak et al. used the DEHAR routing protocol to ensure maximum battery efficiency, though they experienced issues with low battery performance. Man Zhang et al. utilized a maximal parameter strategy to examine the temporal fluctuation in soil moisture content and succeeded in correct moisture estimation. Joaquin Gutierrez's group effectively incorporated solar panels to enhance energy efficiency and enhance battery performance, resulting in more prompt system response. Sherine M. Abd El-Kader designed a ranking based routing protocol for sensor networks but experienced problems with clustering performance. B. Balaji Bhan designed an intelligent remote irrigation system that sensed moisture levels using wireless sensors, although the system exhibited delayed results. Sabrine Khrji and colleagues used ultra-low power wireless modules with sensor nodes in real-time irrigation control to achieve successful soil analysis. Yunseop Kim et al. presented a variable-rate irrigation controller based on sensor nodes that effectively controlled and monitored environmental conditions in real time. T.C. Meyer presented a smart sprinkler system with cloud-integrated WSAN communication, though their experimental testing was not successful. Nelson Sales' group also tried using a cloud based WSAN communication system; their findings were not conclusive even with a clear description of the device. K. Satish Kannan's group implemented a farm monitoring system through cameras, but the findings were also not applicable. Mauro Martinelli and his co workers concentrated on wireless nodes for acquiring real-time voltage data, and their system passed the test successfully.

III. PROPOSED ARCHITECTURE

The suggested architecture of the smart automatic irrigation system has been created to enable smart water management through the integration of sensor networks, wireless communication technologies, and automated control systems in an integrated manner. The system architecture includes some of the main components. The sensor node layer is the core of the architecture, which includes an extensive set of environmental sensors, including soil moisture sensors to track water levels in soil and temperature and humidity sensors to track atmospheric conditions. The sensors are placed strategically across the agriculture field and collect real-time environmental data continuously. To enable effective data transfer, every sensor node contains a wireless communication module, which can be Wi-Fi, Zigbee, or LoRa. These enable low-power, long-distance, and low-cost data transfer to the control unit. Control layer management is reserved for a microcontroller unit, which can be achieved using platforms like Arduino, ESP32, or Raspberry Pi. This microcontroller reads from the sensors, processes, and compares with set soil moisture levels. When the system detects low moisture, it automatically triggers a relay module to turn on the water pump, thereby initiating irrigation without the need for human intervention.

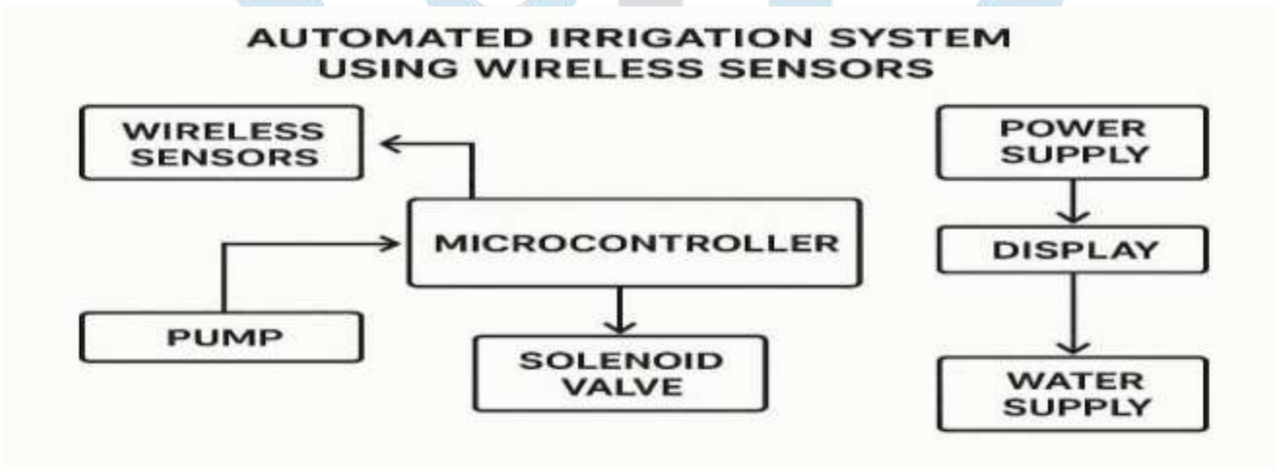

Fig 1: Block diagram of proposed architecture

The actuation layer controls the physical components of the irrigation system, including water pumps and solenoid valves. It ensures the delivery of water at the precise time needed, thereby reducing wastage and ensuring effective utilization of water. As an added feature, the system can be integrated with a cloud-based or Internet of Things (IoT) platform such as ThingSpeak, Blynk, or Firebase. This allows for the transfer of data from the microcontroller through the internet, thereby enabling remote monitoring and control via smartphones or web interfaces. Furthermore, these platforms can hold historical data, which can be used for in-depth analysis and optimization of the system. For seamless and uninterrupted operation, the entire setup is powered by either conventional energy sources or solar panels, which increase energy efficiency and provide off-grid capability, thereby making the system appropriate for deployment in remote agricultural regions.

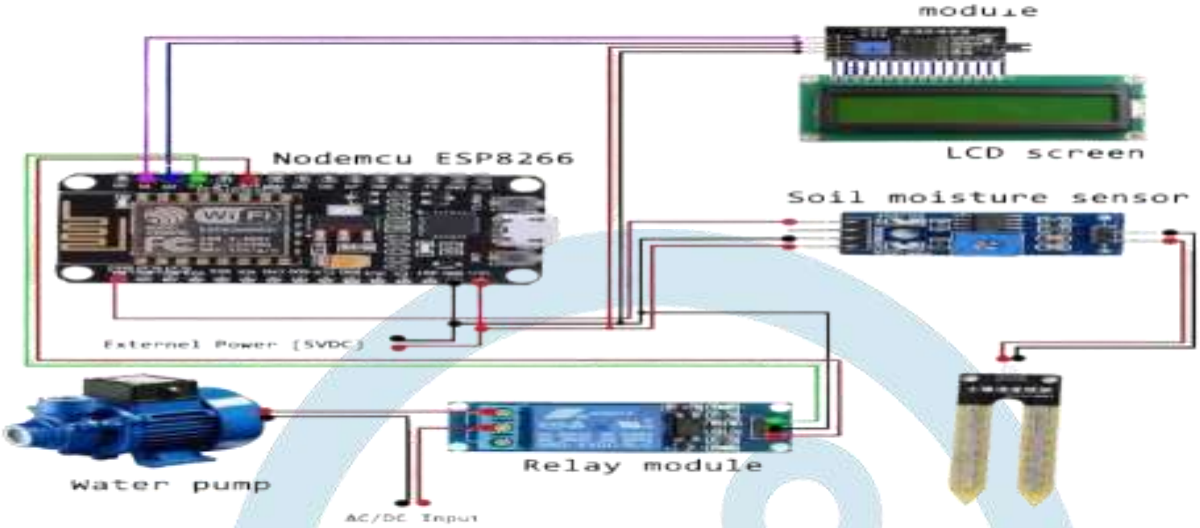

FIG 2 : ARCHITECTURE DIAGRAM OF PROPOSED SYSTEM .

IV. METHODOLOGY

The Automated Irrigation System Using

Wireless Sensors framework is organized in several stages in order to support efficient use of water in agriculture processes. The primary steps comprise sensor deployment, data acquisition and transmission, processing of data, decision-making, actuation, and optional integration in the cloud to offer extended monitoring. The organized framework provides a guarantee of the system operating autonomously and responding in real-time to any variations in the environment.

The first step involves the installation of sensors. This involves the application of appropriate sensors, for example, soil moisture sensors that measure the volumetric water content of the soil. These sensors can be resistive or capacitive and can provide analog or digital outputs. Additionally, temperature and humidity sensors like the DHT11 or DHT22 are used to measure atmospheric conditions influencing plant growth and soil moisture evaporation. The sensors are installed in strategic positions at different depths in the soil to provide accurate and representative moisture levels across the field, thus minimizing localized data bias. They are also made to be able to withstand harsh environmental conditions like rain, dust, and sunlight, hence being long lasting and reliable in outdoor agricultural environments.

After sensor deployment, the next step is data transmission. Sensor values are transmitted wirelessly to a processing unit, usually a microcontroller like an Arduino, ESP32, or Raspberry Pi. Wireless communication protocols like Wi-Fi, Zigbee, or LoRa are used by the system, depending on the particular needs of range, power consumption, and data rate. For instance, LoRa is optimally used in vast fields of agriculture because of its high range, while Wi-Fi or Zigbee is suitable for small or medium-sized fields. To maintain data accuracy and reliability during transmission, the system applies error-checking techniques like parity bits or checksum algorithms. Data exchange between sensors and the microcontroller is carried out using lightweight protocols like MQTT or HTTP, thereby ensuring effective data exchange, particularly when connecting to cloud platforms for analysis and storage.

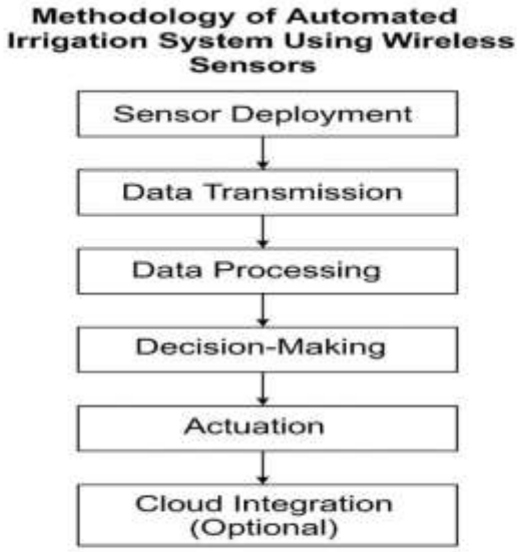

FIG 3 : FLOW CHAT OF METHODOLOGY

The third stage of the methodology is data processing. After the sensor data is received by the microcontroller via its GPIO pins or communication interfaces such as UART or SPI, raw data is preprocessed to remove noise and outliers. Methods like averaging or smoothing are used to correct sensor inaccuracy and drift due to environmental interference. The processed information is subsequently compared with predetermined threshold values to determine if irrigation is required. The thresholds are set based on crop type, regional climatic conditions, and soil type, and can be adjusted using past records or user data. If the actual real-time soil moisture value is less than the threshold, the system moves to the actuation stage; otherwise, it continues to monitor without activating irrigation.

During the decision-making phase, the system implements automated control logic to determine if irrigation needs to be initiated. The logic can be based on a simple rule-based algorithm or employ fuzzy logic to cope with environmental variability. When the soil moisture content is detected as below the threshold value, the microcontroller generates a signal to the relay module to turn on the water pump. The system also includes dynamic threshold adjustment, which can be tuned through a user interface or remotely to react to fluctuating environmental conditions, like elevated temperatures that hasten soil moisture evaporation. In more sophisticated applications, machine learning algorithms— like regression models—can be used to forecast irrigation needs based on factors like temperature, humidity, and past moisture levels, improving decision-making accuracy.

The fifth step is actuation. When irrigation is needed, the microcontroller turns on the relay module, which turns on the water pump or solenoid valve. The irrigation system then releases water for a specified period of time or when the soil is at the target moisture level. Some irrigation systems have flow meters or pressure sensors to measure the amount of water used and enhance efficiency. Once irrigation is complete, the microcontroller automatically turns off the pump, thereby preventing over-irrigation and conserving resources. The system operates in a continuous feedback loop, constantly assessing soil conditions to respond promptly to changes.

An optional but valuable enhancement is cloud integration. By connecting to cloud-based platforms such as ThingSpeak, Blynk, or Firebase, the system enables remote
monitoring and control. Farmers can get realtime readings of soil moisture, temperature, and humidity using a mobile application or web-based dashboard. Cloud also enables historical analysis through data logging, and users can look for trends to optimize irrigation patterns. Automated alarm through SMS, email, or push notification also enables users to receive alerts of important issues like system failure or threshold violations. Others allow for remote command execution, including adjusting thresholds or manually triggering irrigation.

Energy efficiency is another critical component of the system. For operation in remote or offgrid locations, solar panels can be used to energize the sensors and microcontroller. A battery backup system provides uninterrupted operation during cloudy weather or power outages. Low power consumption is the focus of the overall design, using energy-efficient microcontrollers and putting sensors into sleep mode when not actively sending data.

Lastly, the system is scalable and adaptable. Its modular design ensures that it can be easily expanded by simply adding more sensor nodes or actuators as the area to be irrigated is expanded. Additionally, the system can be customized to suit various crop types, types of irrigation—such as drip or sprinkler systems— and varying conditions of the environment, making it very adaptable to a wide variety of agricultural applications.

V. Implementation

The deployment of the automated irrigation system entails the integration of different hardware devices, setting up the software, and making the system efficient to provide realtime monitoring of soil moisture, temperature, and humidity levels. The system uses wireless communication for the transmission of data and executes automated irrigation activities based on sensor data.

The hardware setup is the first phase of the deployment. It commences with the choice and mounting of sensors. Soil moisture sensors, either capacitive or resistive, are used to quantify the volumetric water content of the soil. They are essential for assessing the crop's irrigation needs. They are placed strategically at various depths throughout the field to allow for proper and representative moisture measurement, avoiding overwatering and underwatering. Also, temperature and humidity sensors like DHT11 or DHT22 are employed to sense environmental conditions that affect soil moisture evaporation and crop water requirements. These sensors are usually mounted above crop height to collect precise atmospheric data.

The central processing unit of the system is a microcontroller—like an Arduino or ESP32— that serves as the brain of the irrigation system. It takes inputs from the sensors, processes them, and makes decisions based upon pre-set thresholds. The microcontroller contains logic to read sensor readings, compare them to threshold values, and drive actuators like a water pump via a relay module. Wireless communication modules like Wi-Fi, Zigbee, or LoRa are employed for allowing the sensor data to be transmitted to the microcontroller and, if desired, to a cloud platform. Wi-Fi would typically be ideal for short-distance communication, Zigbee for medium-distance with relatively moderate power consumption, and LoRa for longdistance applications, which is beneficial in vast fields used for farming.

For irrigation control, a relay module is utilized to manage the switching of high-voltage equipment such as water pumps or solenoid valves. Upon sensing that irrigation is needed—according to the soil moisture data— the microcontroller triggers a signal to the relay, which in turn activates the water pump to initiate irrigation. The power supply system is made up of solar panels and battery backups to provide energy-efficient and sustainable operations, particularly in remote or off-grid farm areas.

On the software side, the microcontroller is programmed to handle the core functions of the system. This means reading the sensor values at preset intervals, comparing them to fixed moisture levels, and turning the irrigation system on or off accordingly. The code can also comprise a data logging feature, which records sensor values for analysis or cloud monitoring at a later stage. If there is a need for cloud integration, tools such as ThingSpeak, Blynk, or Firebase can be employed to take in sensor values and display them through an easy-toaccess web or mobile platform. Such platforms enable farmers to view real-time weather conditions remotely and manually operate irrigation systems if necessary.

Calibration of the soil moisture sensors for correct reading is needed in the system.

Calibration involves drying and moistening samples of soil and monitoring the sensor outputs at established moisture levels and adjusting the moisture trigger in line with the particular watering needs of the crop. Upon calibration, testing of the entire system is ensured to determine if the sensors actually trigger irrigation where it is needed, as well as that actuators, such as pumps that move water, function appropriately. Furthermore, the cloud platform is also tested to verify data integrity and real-time remote monitoring capability. To save power for performance optimization, low-power components are utilized, i.e., ESP32 in place of an Arduino for Wi-Fi communication. The system is also tested under varying weather conditions to evaluate the robustness and reliability of wireless communication and sensor reading. Deployment consists of installing and setting up within the field of agriculture, positioning the sensors at sites representative of general soil moisture conditions. Connect the relay system and the water pump, which is tested and proved to operate satisfactorily as the irrigation system. Periodic maintenance comprises routine calibrating of sensors as well as the upgrading of the software, remotely distributed via the cloud platform in order to keep the system continually up-todate and accurate.

Toward future enhancement, the existing system offers a good platform for the automation of irrigation through the use of wireless sensors and decision-making via microcontrollers. There are, however, various areas for improvement. AI and ML integration can enable the system to make predicated irrigation requirements based on past data, weather conditions, and crop variety, enhancing the management of water and the ability to forecast yields. Dynamic adjustment of the threshold, depending on crop growth phase, meteorological conditions, and soil type, might further minimize the necessity of manual tuning and maximize flexibility. Improvements in mobile app and dashboards might offer farmers an even more integrated real-time monitoring, alert receiving, and manual adjustment-making tool, along with data visualization to enable enhanced decision-making.

The next work could also be in designing a solar-powered system for off-grid applications utilizing solar panels and battery backup to increase rural areas' sustainability where power supply is limited. To enhance coverage and reliability, the system could be supplemented with emerging wireless communication technologies like NB-IoT, 5G, or Mesh Networking, particularly for big-scale farms. Water quality monitoring (pH, salinity, turbidity) may also be added into the system to provide plants with maximum irrigation water quality. The system may further include multi-zone irrigation management, allowing various sectors of the field to be irrigated according to its individual requirements, enhancing precision irrigation and efficiency of resources. Compatibility with real-time weather forecast APIs would enable the system to plan irrigation schedules as per future weather, like postpone irrigation in the case of precipitation being forecast. Capability to include several types of crops in the same field and incorporating the provision of supporting variable patterns of irrigation would increase the utility of the system. Finally, commercialization and scalability might take precedence, with modular constructions to enable straightforward deployment in small farms and scalability to larger agricultural estates. Low-cost commercial kits would be developed to encourage broad uptake, especially in developing countries, to further spread the reach of the system.

VI Result and Discussion

The automated irrigation system was effectively implemented and tested in farm fields and proved that it could optimize water usage according to real-time soil moisture data. Calibration of soil moisture sensors gave reliable readings, ensuring that the system actually activated irrigation when it was needed. Testing ascertained that actuators such as the water pump and relay system responded immediately to sensor signals, effectively delivering water to crops. The cloud platform facilitated unobstructed remote monitoring and data recording, furnishing realtime information regarding field conditions. Performance optimization techniques, including the utilization of the low-power ESP8266 for Wi-Fi communication, led to lower energy consumption, adding to the overall efficiency of the system. The system was also resilient in various weather conditions, with stable wireless communication and precise sensor readings, even in adverse environmental conditions. Real-time testing confirmed that the performance of the system was stable under diverse conditions, both dry and wet, proving the reliability of the sensors and actuators.

In the aspect of deployment, the system was effectively installed and configured in the field. The installation of the soil moisture sensors in strategic positions guaranteed that the readings were representative of the general soil moisture conditions in the field. The irrigation system performed satisfactorily, with prompt and sufficient watering of the crops. The simplicity of installation and configuration further demonstrated the system's scalability and applicability to various agricultural environments.

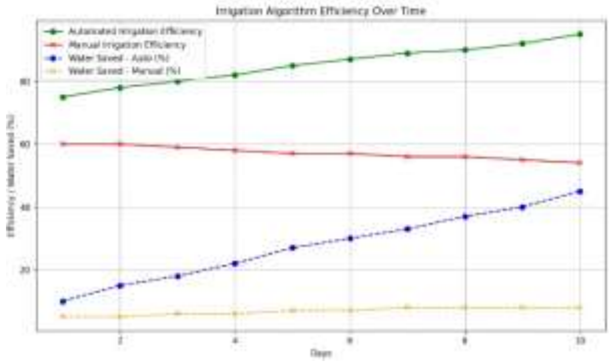

Fig 4 : Output Evaluation graph

Assessment of the system maintenance process indicated that routine calibration of the sensors and software upgrades through the cloud platform are required to ensure continued accuracy. The remote deployment feature of software upgrades also optimized the maintenance process by minimizing manual intervention in the field.

Consequently, the system could continue its operations with little downtime and without necessitating continuous on-site maintenance.

Future Improvements and Considerations

While the system demonstrated effective irrigation control, several areas for enhancement were identified through the evaluation process. The integration of AI and ML algorithms for predictive irrigation could significantly enhance water management, enabling more precise watering schedules based on historical data and weather forecasts. Dynamic threshold adjustments based on crop growth stages and soil conditions would further increase the system's adaptability and reduce manual input.

Improvements in mobile app and dashboard features may give farmers better tools to track real-time field conditions, receive alerts, and override automatic irrigation when required. Incorporation of solar power functionality and state-of-the-art wireless communication technology would enhance the sustainability and dependability of the system, especially in areas where electricity or internet connectivity is lacking.

In addition, the incorporation of water quality sensors would facilitate greater irrigation water quality control to ensure that plants are given optimal growth conditions. Multi-zone irrigation control implementation could assist in minimizing water waste by offering specific irrigation for varied zones of the field according to respective crop requirements. From a scalability perspective, the system showed significant scope for potential growth, with modular designs making it straightforward to deploy on small-scale farms and large agricultural estates.

Commercialization through low-cost kits has the potential to stimulate take-up in rural and developing communities, where effective water management is a key enabler for sustainable agriculture.

Generally, the computerized irrigation system has been successful in enhancing irrigation efficiency, maximizing water use, and offering real-time monitoring. Additional future development, such as AI integration, mobile optimization, and scalability of the system, will continue to improve the functionality and flexibility the system to be compatible with the evolving needs of modern agriculture.

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