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POWER EFFICIENT SMART IRRIGATION SYSTEM FOR AGRICULTURE

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ABSTRACT
In modern agriculture, the integration of agricultural networking technologies plays a crucial role in shaping future agricultural development trajectories. This study explores the implementation of a Smart Irrigation System leveraging Internet of Things (IoT) technology, aimed at enhancing farming operations. The development of a power-efficient smart irrigation system for agriculture is essential in addressing the challenges posed by water scarcity and energy consumption in farming practices. This study focuses on the implementation of an IoT-based irrigation system designed to optimize water usage while minimizing energy consumption. By leveraging sensors and actuators interconnected through IoT technology, the system enables real-time monitoring and precise control of irrigation processes based on environmental data such as soil moisture, temperature, and humidity. The integration of machine learning algorithms further enhances the system's ability to predict irrigation needs accurately, thereby improving crop yields and promoting sustainable water management practices. This research emphasizes the importance of technological innovation in agriculture to achieve efficient resource utilization and environmental sustainability.

Keywords: Power efficient, Solar IoT, Smart Irrigation, Sensors, ESP8266

INTRODUCTION
In contemporary agriculture, the adoption of advanced technologies has become increasingly pivotal in addressing the dual challenges of water scarcity and energy efficiency. The evolution of smart irrigation systems represents a significant stride towards sustainable agricultural practices, leveraging innovations in Internet of Things (IoT) and machine learning (ML) to optimize water management [1-2]. These systems aim not only to enhance crop yields but also to ensure efficient resource utilization, thereby supporting agricultural sustainability in the face of growing global demand.

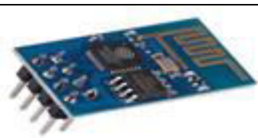
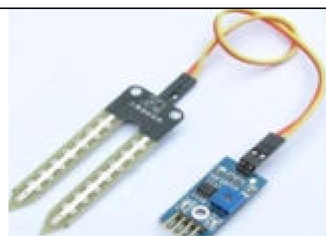
Currently, agriculture faces formidable challenges posed by climate change, population growth, and limited water resources. As traditional irrigation methods prove inadequate in meeting modern agricultural demands, smart irrigation systems have emerged as a transformative solution. These systems utilize IoT-enabled sensors to gather real-time data on soil moisture levels, weather conditions, and crop water requirements. By integrating this data with ML algorithms, such as decision trees and neural networks, smart irrigation systems can autonomously adjust irrigation schedules and optimize water usage [3]. This capability not only improves the resilience of crops to climate variability but also reduces water wastage and minimizes energy consumption associated with irrigation pumps and systems.

Historically, the evolution of irrigation systems has been marked by significant advancements aimed at improving efficiency and sustainability. Early irrigation practices relied heavily on manual labor and simple gravity-fed systems, limiting their scalability and effectiveness. The introduction of mechanized irrigation techniques in the 20th century, such as sprinkler and drip irrigation, represented a leap forward in water conservation and agricultural productivity. These methods enabled more precise water application directly to plant roots, reducing evaporation losses and improving nutrient uptake efficiency [4]. However, the reliance on predetermined schedules and limited real-time data integration remained a constraint, necessitating further innovation.

Looking ahead, the future of smart irrigation systems promises continued evolution and adaptation to meet the evolving needs of agriculture. Advances in sensor technology, IoT connectivity, and ML algorithms are expected to further enhance the capabilities of smart irrigation systems. Future systems may incorporate predictive analytics and AI-driven decision support tools to anticipate crop water requirements with unprecedented accuracy.

Moreover, the integration of renewable energy sources, such as solar-powered irrigation pumps, holds promise for reducing the carbon footprint of agricultural operations while enhancing energy efficiency [5-7]. The ongoing development of autonomous irrigation systems capable of self-adjusting based on real-time environmental data represents a significant leap towards achieving sustainable water management in agriculture. By embracing these advancements, agriculture can not only bolster food security and economic prosperity but also mitigate environmental impact, ensuring a resilient future for global food production amidst changing climatic conditions. (Table 1).

Table 1: Components of proposed system

Name of Module	Image	Description
Node MCU ESP8266		The ESP8266 is a versatile and cost-effective Wi-Fi module widely utilized in the field of embedded electronics and Internet of Things (IoT) applications. The ESP8266 module integrates a microcontroller unit (MCU) with built-in Wi-Fi connectivity
Relay		Relay module is an electronic device that consists of one or more relays, which are electromagnetic switches capable of controlling electrical circuits. These modules are commonly used in various electronic and automation projects to enable microcontrollers or other low-power devices to control higher-power circuits or devices.
DHT11		DHT11 is a basic and cost-effective sensor designed for measuring temperature and humidity levels in various environments • Supply Voltage: +5 V • Temperature range :0-50 °C error of ± 2 °C • Humidity :20-90% RH ± 5% RH error
Soil Moisture Sensor		Soil Moisture Sensors play a crucial role in modern agriculture and environmental monitoring by providing real-time data on soil moisture conditions, helping optimize water usage and promote healthier plant growth.
HC-05 Bluetooth Module		HC-05 Bluetooth Module with popular Wi-Fi module ESP8266 and control an LED wirelessly by sending commands via Bluetooth. This LED can be replaced by a Relay and an AC appliance to build a Automation Application.

Water Pump		A smart water pump is a device that can be used in domestic, commercial, and agricultural applications. It has sensors that are switched on and off according to the requirement and monitor the water level in a tank or well. This can help to save water and energy.

BACKGROUND

The paper introduces a novel wireless humidity sensor tailored for precision agriculture applications, forming part of a wireless sensor network dedicated to monitoring soil water content and groundwater depth. This network infrastructure is detailed, facilitating the implementation of an intelligent irrigation control system that integrates real-time rainfall data and expert assessments [8-11]. An enhanced automatic irrigation system is described, utilizing localized humidity feedback. This system incorporates a hose with an embedded valve connected to a pressurized water supply, featuring a sprinkler head and a moisture sensing probe adjacent to the sprinkler head, generating an electrical signal proportional to local soil moisture content [12-13].

In addition to technological advancements, the review emphasizes critical technical and regulatory considerations, setting the stage for leveraging Internet of Things (IoT) technologies in water management. The focus is on developing a cost-effective smart irrigation system tailored for middle-class farmers, particularly in regions like India [14], [15]. Addressing the limitations of conventional high-cost automation systems for farm use, the paper introduces an affordable intelligent irrigation technology [16], [17]. This innovation incorporates a GSM-SMS-powered greenhouse control system within a remote measurement and control framework, integrating a microcontroller, GSM monitor, sensors, and actuators linked to a PC-based database system at a central station [18]. As the landscape of IoT-connected devices expands, the establishment of Wireless Sensor Networks (WSNs) becomes increasingly essential. These networks, comprised of sensor-equipped smart objects, facilitate real-time data acquisition, compilation, and analysis for applications such as optimizing irrigation cycles to reduce water consumption and enhance economic and environmental sustainability [19].

PROPOSED SYSTEM MODEL

The automated irrigation system described integrates a microcontroller, Wi-Fi technology, and an Android operating system to facilitate efficient soil condition monitoring and irrigation management. Low-cost soil humidity and temperature/moisture detectors are strategically positioned in the field and connected to an Arduino board, acting as the central control unit [20]. This setup enables continuous data processing by the microcontroller, which receives sensor data wirelessly via Wi-Fi [21]. Wi-Fi technology supports reliable and extended-range data transmission between the sensors and the microcontroller, allowing real-time monitoring of soil conditions without the need for physical sensor access. The system operates autonomously based on predefined threshold values for humidity, moisture, and temperature, activating the irrigation motor when soil humidity falls below the threshold and deactivating it when conditions are adequate. Mobile operation via an Android device enables the user to monitor soil conditions, analyze sensor data, and make irrigation decisions remotely, leveraging Wi-Fi connectivity for seamless interaction with the irrigation system. The transition from Bluetooth to Wi-Fi connectivity aims to enhance cost-effectiveness while maintaining system functionality.

The Automated Irrigation System incorporating a GPRS Module is tailored to optimize water management in agriculture, focusing on enhancing crop cultivation efficiency. This system integrates a distributed wireless sensor network with soil humidity and temperature detectors deployed within a comprehensive Wireless Sensor Network (WSN). Central to its architecture are gateway units responsible for transmitting sensor data to the base station, controlling irrigation selectors, and managing collected data [22]. An embedded algorithm within a microcontroller governs the operational logic of the system, meticulously adjusting water dispensation based on real-time field conditions and crop water requirements. The microcontroller issues commands to the selector for precise control of water flow through the stopcock unit. Powered sustainably by photovoltaic panels, the system emphasizes energy efficiency throughout its operations. Utilizing the cellular network for bidirectional communication enables continuous monitoring and scheduling of irrigation activities. This connectivity also supports web-based interfaces for programming and overseeing the irrigation process, ensuring seamless management and accessibility [23].

Continuous real-time data collection and monitoring capabilities enable the system to dynamically optimize irrigation parameters, effectively conserving water resources while maximizing crop yields. This integrated approach underscores the system's commitment to sustainable agriculture practices through efficient water management and technological innovation. This integrated system represents an advanced and technology-driven approach to irrigation management in agriculture, promoting resource efficiency and precision in crop cultivation practices (Figure 1).

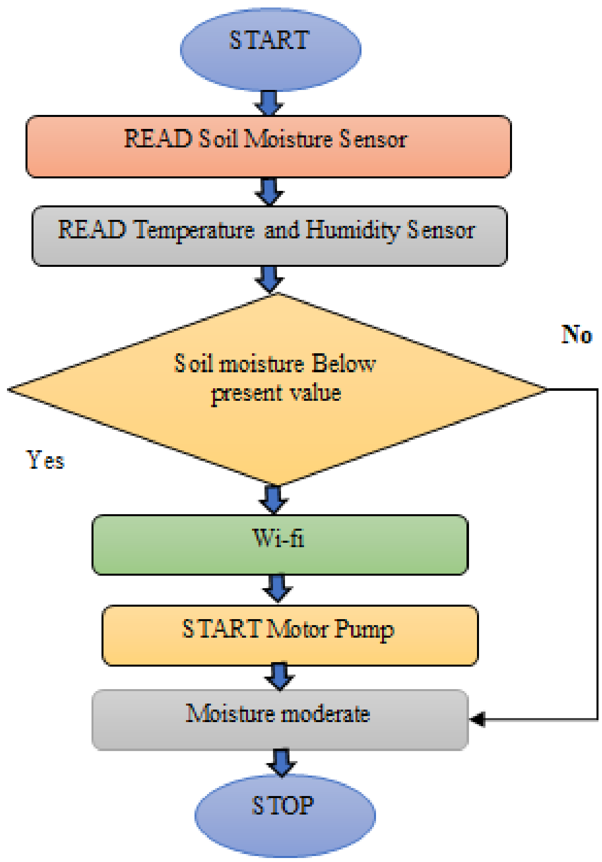


Figure 1: Proposed System Architecture

The following segment introduces Bluetooth technology in the context of a Crop Monitoring System. The wireless sensor network employed in crop monitoring proves to be a valuable tool for meticulous and effective farming practices [24]. This system operates by monitoring the entire agricultural field from a remote location, utilizing the Internet of Things (IoT) [25]. The operation is based on a detector network incorporating two distinct types of nodes. To optimize energy usage, an energy-saving algorithm is implemented within the nodes [26]. The communication protocol employed for data transmission from the nodes to the base station is a tree-grounded protocol. This system consists of two types of nodes: one node responsible for collecting various environmental and soil parameter values, and the other node equipped with a camera to capture images and provide visual coverage of the crops.

RESULT AND ANALYSIS

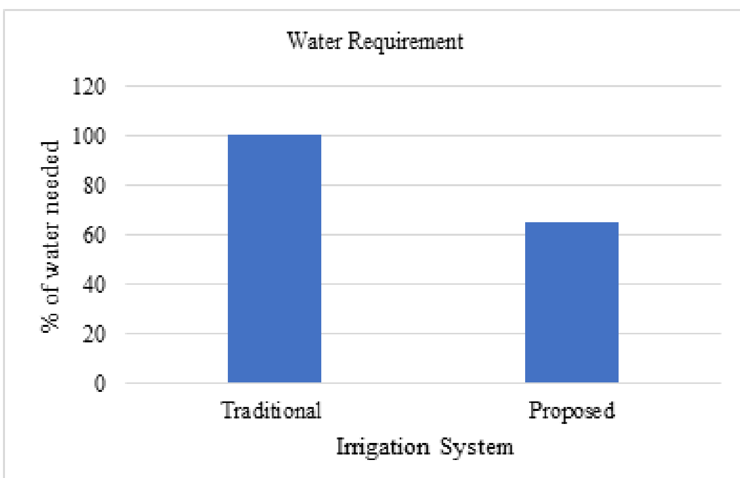
The smart irrigation system underwent testing in a garden factory, specifically catering to shops with a daily water demand ranging from 600 to 800 mm. Within the programming of the Arduino board, the humidity range was defined as 300 to 700. This range corresponds to specific resistance values translated into digital format by the Arduino. These settings likely dictate the system's response to soil humidity levels, triggering irrigation when the measured humidity falls below 300 and ceasing it when it exceeds 700. water efficiency comparison table between smart irrigation and traditional irrigation systems, using a scale from 1 to 5, where 5 indicates high water efficiency (Table 2):

Table 2: Smart Vs Traditional irrigation system

Water Efficiency Aspects	Smart	Traditional
Real-time Monitoring	5	2
Soil Moisture Sensing	5	2
Customized Watering Plans	5	2
Weather-Based Adjustments	5	2
Automated Scheduling	5	2
Water Conservation Practices	5	2
Precision Watering	5	2
Uniform Watering	3	4
Potential for Overwatering	2	4

The decision to set the humidity range within these parameters suggests a careful calibration to ensure optimal soil moisture conditions for the garden factory. By translating humidity levels into a digital format, the system can precisely interpret and act upon the data collected by the sensors. This digital interpretation is likely a key factor in the accuracy and efficiency of the irrigation system, aligning with the Arduino's programming logic

Figure 2: Traditional vs Proposed system water requirement



In traditional irrigation methods, the percentage of water needed is considered at 100%. This signifies that the conventional approach to watering crops often involves uniform and fixed schedules, regardless of the actual moisture requirements of the soil. Traditional irrigation systems may rely on time-based or manual control, leading to potential overwatering, water wastage, and inefficiencies in resource utilization (Figure 2). The proposed smart irrigation system introduces a significant advancement by reducing the percentage of water needed to 65%. This reduction is attributed to the system's ability to leverage technology, including soil moisture sensors and data analytics, to assess the real-time moisture content in the soil. With this information, the smart irrigation system optimizes the watering schedule, delivering water precisely when and where it is needed. By responding dynamically to environmental conditions, weather forecasts, and the actual moisture needs of the crops, the proposed system minimizes water wastage, promotes water conservation, and enhances the overall efficiency of irrigation practices. This reduction in the percentage of water needed reflects the potential for the smart irrigation system to contribute to sustainable and resource-efficient agriculture.

Furthermore, the statement asserts that the smart irrigation system is proven to be cost-effective and comprehensive in its ability to conserve water and mitigate water wastage. The cost-effectiveness may stem from the system's ability to irrigate based on real-time soil conditions, avoiding unnecessary watering and optimizing resource utilization. Additionally, the system's completeness may refer to its ability to address the specific water demands of the garden factory while simultaneously reducing water wastage, thereby contributing to sustainability and resource conservation. Overall, the successful testing and positive outcomes on water conservation and efficiency underscore the effectiveness and practicality of the implemented smart irrigation system in the context of the garden factory.

DISCUSSION

The results presented underscore the substantial advantages of Smart irrigation systems over Traditional methods in enhancing water efficiency across various critical aspects of agricultural irrigation. The higher ratings achieved by the Smart system in real-time monitoring, customized watering plans, weather-based adjustments, and automated scheduling highlight its capability to optimize irrigation practices dynamically. By continuously monitoring soil moisture and weather conditions in real time, the Smart system can adjust irrigation schedules promptly, reducing water wastage and ensuring precise water application tailored to crop requirements.

This capability not only conserves water but also enhances crop yields by maintaining optimal soil moisture levels throughout different growth stages. Moreover, the Smart system's ability to mitigate the potential for overwatering is particularly noteworthy, as excessive water use can lead to environmental degradation and economic inefficiencies. The integration of precision watering techniques and uniform water distribution further enhances its effectiveness in resource management. However, it's important to acknowledge that Traditional methods may still hold advantages in certain aspects, such as uniform watering practices, where mechanical systems provide consistent water distribution across fields. The results highlight the comparative advantages of a Smart irrigation system over Traditional methods across various water efficiency aspects:

- **Real-time Monitoring:** The Smart system scores significantly higher with a rating of 5 compared to the Traditional method's 2. This reflects the Smart system's capability to continuously monitor soil conditions and water usage in real time, providing timely data for optimized irrigation decisions.
- **Soil Moisture Sensing:** Both systems score equally high in this aspect, indicating that both are capable of effectively sensing soil moisture levels. However, the Smart system's integration of real-time data and automated responses likely enhances its effectiveness.
- **Customized Watering Plans:** The Smart system excels with a rating of 5, suggesting its ability to tailor irrigation schedules based on specific crop needs and environmental conditions. In contrast, the Traditional method, with a rating of 2, likely relies on generalized or manual watering schedules.
- **Weather-Based Adjustments:** Similar to customized plans, the Smart system's rating of 5 indicates its superior capability to adjust irrigation schedules based on real-time weather data. Traditional methods, scoring 2, may lack this dynamic adjustment capability.
- **Automated Scheduling:** Again, the Smart system scores higher (5) compared to the Traditional method (2), emphasizing its automated approach to scheduling irrigation, reducing the need for manual intervention and improving efficiency.

- **Water Conservation Practices:** Both systems score high (5 for Smart, 2 for Traditional), but the Smart system likely achieves this through precise water management strategies and automated adjustments based on sensor data.
- **Precision Watering:** The Smart system scores equally high (5) as it ensures precise application of water where needed, avoiding unnecessary watering. Traditional methods, though effective, may not match this precision.
- **Uniform Watering:** The Traditional method scores slightly better (4) than the Smart system (3), indicating that it may provide more uniform water distribution across fields. This could be due to the simplicity of mechanical irrigation systems used in Traditional methods.
- **Potential for Overwatering:** The Smart system scores lower (2) than the Traditional method (4), suggesting it has mechanisms in place to minimize overwatering through data-driven decisions. Traditional methods may rely more on fixed schedules or manual observation, potentially leading to overwatering.

The Smart irrigation system demonstrates superior performance across most water efficiency aspects due to its integration of advanced technology, real-time data monitoring, and automated decision-making capabilities. This positions it as a more efficient and sustainable option compared to Traditional irrigation methods, which often rely on manual processes and fixed schedules.

CONCLUSION

In conclusion, this study underscores the transformative potential of Smart irrigation systems in revolutionizing agricultural water management practices. The findings highlight the clear advantages of Smart systems over Traditional methods, particularly in terms of real-time monitoring, customized watering plans, weather-based adjustments, automated scheduling, and water conservation practices. By integrating advanced technologies like sensor networks, data analytics, and automated controls, Smart irrigation systems enable precise and efficient water application tailored to specific crop needs and environmental conditions. This not only enhances agricultural productivity by maintaining optimal soil moisture levels but also contributes significantly to sustainable resource management and environmental stewardship. The study emphasizes the pivotal role of Smart irrigation in addressing global challenges such as water scarcity and climate variability, thereby supporting efforts towards food security and agricultural sustainability. Moving forward, continued research and development efforts are crucial to further refine Smart irrigation technologies, making them more accessible, affordable, and adaptable for farmers worldwide. Embracing these innovations is essential for fostering resilient agricultural systems capable of meeting the growing demands of a changing climate while minimizing environmental impact and ensuring long-term agricultural viability.

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