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Optimized water management for precision agriculture using IoT-based smart irrigation system

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Abstract

This project introduces a Smart Irrigation System aimed at enhancing water efficiency in agriculture through the integration of an Arduino Uno micro-controller and a variety of sensors. The system incorporates a soil moisture sensor, a DHT11 sensor for monitoring temperature and humidity, an LCD, a buzzer for alerts, and a relay module to control a pump motor. The main goal is to create an automated irrigation system that adjusts to environmental conditions, thereby optimizing water usage for plant growth. The soil moisture sensor continuously evaluates soil moisture levels, while the DHT11 sensor keeps tabs on temperature and humidity. The Arduino Uno processes this data and displays it on an LCD screen. When the soil moisture falls below a predefined threshold, the system activates a buzzer and triggers the relay to turn on the pump motor. The LCD provides real-time feedback on environmental conditions and the irrigation status. This Smart Irrigation System offers several advantages, including water conservation, energy efficiency, and improved plant health. By automating irrigation based on real sensor data, the system minimizes water wastage and ensures that plants receive optimal moisture levels. Additionally, temperature and humidity monitoring contribute to effective microenvironment management. The project serves as a demonstration of IoT-based solutions for agricultural challenges, featuring a modular design that allows for scalability. Future developments may include incorporating additional sensors, enabling wireless connectivity for remote monitoring, and integration with weather data. In summary, the system provides a practical and cost-effective solution for sustainable agriculture, promoting water conservation and efficient farming practices.

Keywords: Smart Irrigation System; Arduino Uno; Soil Moisture Sensor; DHT11 Sensor; LCD; Relay Module; Agriculture; Environmental Conditions; Automated Irrigation; IoT-based Solutions

1. Introduction

This project addresses the critical issue of efficient water resource utilization in agriculture by tackling the limitations of traditional irrigation methods that often lead to water wastage and potential harm to plant health. The proposed solution is a Smart Irrigation System centered around an Arduino Uno micro-controller and an array of sensors, providing precision and adaptability to optimize water consumption. Key components of the Smart Irrigation System include a soil moisture sensor, a DHT11 sensor for monitoring temperature and humidity, an LCD for real-time data visualization, a buzzer for alerts, and a relay module to control a pump motor. The primary objective is to establish an automated irrigation system capable of dynamically responding to changing environmental conditions that impact plant growth. The soil moisture sensor continually assesses soil moisture content, and the DHT11 sensor provides crucial information on temperature and humidity levels. The Arduino Uno processes this data and, when predefined thresholds are reached, triggers actions such as activating a buzzer for alerts and initiating the pump motor through a relay module to irrigate the plants. Real-time insights into environmental conditions and irrigation status are displayed on the LCD.

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By automating irrigation based on real-time sensor data, this Smart Irrigation System aims to minimize water wastage, improve energy efficiency, and enhance overall plant health. The inclusion of temperature and humidity monitoring contributes to a comprehensive understanding of the plant's microenvironment, enabling precise adjustments in irrigation strategies. The project serves as a notable example of applying Internet of Things (IoT)-based solutions to address agricultural challenges, promoting sustainable and resource-efficient practices. The modular design ensures scalability and adaptability, making it suitable for various plant types and environmental conditions. Potential future developments may include the integration of additional sensors, wireless connectivity for remote monitoring, and the incorporation of weather forecasting data to further optimize irrigation schedules. In conclusion, this Smart Irrigation System not only provides a practical solution to enhance agricultural practices but also actively contributes to water conservation efforts and encourages sustainable farming methodologies through the judicious use of technology.

1.1. Problem statement

Conventional agricultural irrigation methods are plagued by inherent inefficiencies, resulting in excessive water usage, energy waste, and sub-optimal plant growth. The imprecision in determining when and how much to irrigate contributes to problems such as over-watering or under-watering, negatively impacting crop yields and raising environmental concerns. The increasing scarcity of water resources highlights the urgent need for more sustainable and efficient irrigation practices. This project recognizes and tackles key issues associated with conventional irrigation systems:

- Water Wastage: Traditional methods often struggle to accurately gauge soil moisture levels, leading to the overuse of water resources.
- Energy Inefficiency: Continuous and manual operation of irrigation systems can result in unnecessary energy consumption, especially when irrigating during periods of sufficient soil moisture.
- Sub-optimal Plant Health: Inconsistent and imprecise irrigation can negatively impact plant health, causing stunted growth, reduced yields, and increased susceptibility to diseases.
- Lack of Environmental Adaptability: Traditional systems cannot often dynamically respond to changing environmental conditions, such as variations in temperature and humidity.

Limited Automation: Many existing systems require constant human monitoring and intervention, leading to inefficiencies and increased labor demands.The Smart Irrigation System proposed in this project addresses these challenges by introducing an automated, sensor-driven approach. Real-time monitoring of soil moisture, temperature, and humidity allows the system to intelligently adjust irrigation practices. This approach promotes water conservation, enhances energy efficiency, and improves overall plant health. The project offers a practical solution to the drawbacks of traditional irrigation systems, paving the way for sustainable and technologically advanced agricultural practices.

2. Literature survey

Velasquez-Munoz, A. J., & Barco, R. (2016). IoT-Based Smart Irrigation System.

This paper introduces a Smart Irrigation System leveraging the Internet of Things (IoT) to address challenges in traditional irrigation practices. Through sensor networks and IoT technologies, the system allows real-time monitoring and control of irrigation processes. It collects data on soil moisture, weather conditions, and other environmental factors, processed centrally for adaptive and precise irrigation management. The paper discusses the system's architecture, components, and functionalities, emphasizing its potential to enhance water efficiency, reduce resource wastage, and optimize crop yields.[1]

N. Sales, O. Remedios, and A. Arsenio, “Wireless sensor and actuator system for smart irrigation on the cloud,” (2015 IEEE 2nd World Forum on IoT)

This paper presents a Wireless Sensor and Actuator System designed for smart irrigation with cloud integration. Utilizing wireless sensor networks, the system collects real-time data on soil moisture and environmental conditions. Cloud computing capabilities are leveraged for remote monitoring and control of irrigation processes. The paper discusses the system's architecture and implementation, highlighting its potential for water conservation, efficiency, and scalability. The findings contribute to IoT applications in agriculture, showcasing the benefits of cloud-based solutions for smart irrigation.[2]

S. Rawal, “IoT-based smart irrigation system,” (International Journal of Computer Applications, 2017)

This paper introduces an IoT-based smart irrigation system designed to enhance traditional agricultural practices. Incorporating sensor nodes, the system monitors soil moisture levels and climatic conditions in real time. The collected data is analyzed through a centralized system for informed decisions on irrigation scheduling and water resource management. The paper discusses the system architecture, implementation, and practical implications, emphasizing its potential for optimizing water usage and improving crop yield.[3]

Dinesh, K., & Prabhu, R. (2019). IoT-based Smart Agriculture: A Review.

This paper provides a comprehensive review of IoT-based smart agriculture, exploring the integration of IoT technologies to enhance various aspects of agricultural practices. It covers sensor networks, data analytic, and communication protocols in precision farming, emphasizing the role of IoT in monitoring soil conditions, crop health, and environmental factors. The paper offers insights into the current state of IoT in agriculture, highlighting challenges, opportunities, and potential areas for future research and development.[4]

Han, L., Gong, L., & Kang, T. (2019). IoT for Smart Precision Agriculture and Farming in Rural Areas.

This paper explores the application of IoT in smart precision agriculture, focusing on rural areas. It investigates how IoT technologies optimize farming practices, resource utilization, and overall agricultural productivity. The authors discuss the deployment of IoT-enabled devices for real-time monitoring of environmental conditions, crop health, and irrigation systems, emphasizing the potential benefits of smart farming in rural contexts.[5]

This paper offers a comprehensive review of IoT-based smart agriculture, emphasizing the integration of IoT technologies to enhance agricultural efficiency. It covers sensor deployment, data analytic, and communication protocols, providing an overview of advancements in the field. The authors explore IoT applications in precision farming, highlighting its role in monitoring soil conditions, crop health, and irrigation systems. The paper identifies challenges, emerging trends, and future research directions in the realm of IoT-based smart agriculture [6].

B. Sarwar, I. Bajwa, S. Ramzan, B. Ramzan, and M. Kausar, “Design and application of fuzzy logic-based firemonitoring and warning systems for smart buildings.

This study describes an intelligent Fire Monitoring and Warning System (FMWS) that uses fuzzy logic to determine whether a threatening fire is actually present and to notify the Fire Management System (FMS) of its presence. This work examines the development and implementation of a Fuzzy Logic Fire Monitoring and Warning System that utilizes Global System for Mobile Communication (GSM) technology to transmit an alarm message. The technology relies on minuscule, inexpensive, and compact sensors to guarantee reproducibility of the outcome. MATLAB ver. 7.1 (The MathWorks, Natick, MA, USA) is used for simulation work, and satisfactory experiment results are obtained [7].

B. Sarwar, I. S. Bajwa, N. Jamil, S. Ramzan, and N. Sarwar, “An intelligent fire warning application using IoT and an adaptive neuro-fuzzy inference system.

This research presents a novel idea: utilizing temperature, humidity, and smoke change rate in the presence of fire, ANFIS can be used to identify an actual fire incidence. The model uses sensors to gather important data from sensor nodes. Fuzzy logic then transforms the raw data into a linguistic variable that is trained in ANFIS to determine the likelihood that a fire would occur. Additionally, the suggested concept creates notifications that send a message straight to the user's smartphone. Our method makes sure that this solution is repeatable and makes use of inexpensive, small-sized sensors. The trials are conducted using MATLAB-based simulation, and the output produced is satisfactory [8].

M. S. Munir, I. S. Bajwa, M. A. Naeem, and B. Ramzan, “Design and implementation of an IoT system for smart energy consumption and smart irrigation in tunnel farming.

The studies covered in this paper was tested on a limited area (a tunnel farm, for example), but the findings indicate that the strategy employed may be applied to broad fields for effective irrigation. Additionally, the experimental results beat both the manual method and comparable methods for sensor-based irrigation systems [9].

H. Sattar, I. S. Bajwa, R. U. Amin, et al., “An IoT-based intelligent wound monitoring system.

In the current study, we suggested a sensor-based intelligent wound assessment system. Our suggested solution is divided into two modules. The first module is an Arduino-based circuit that we utilized to measure the wound factors (wound temperature, oxygenation levels, air temperature, and air humidity) using sensors LM35, MAX30100, and DHT22. For effective wound assessment status decision-making based on measurement of wound variables, we employed entropy-based decision trees in the second module. Based on their values, our suggested decision tree module categorized the input into three potential assessment classes: good, satisfactory, and worrying. To select the optimal feature for splitting, decision trees employed information gain statistics and entropy. We used MATLAB to implement the suggested assessment system [10].

M. S. Munir, I. S. Bajwa, and S. M. Cheema, "An intelligent and secure smart watering system using fuzzy logic and blockchain.

There is a great need to develop agriculture in this day and age, when everything is based on technology, particularly in our agricultural nation of Pakistan. In order to boost agricultural output and efficiency, we must employ computer technology. Our idea is an Internet of Things (IOT)-based expert system that uses a smartphone to monitor and operate a garden from any location. Utilizing real-time sensor data collection, the system directs farmers and gardeners [11].

K. Xiao, D. Xiao, and X. Luo, "Smart water-saving irrigation system in precision agriculture based on wireless sensor network," Transactions of the Chinese Society of Agricultural Engineering, vol.26, pp.170-175,2010.

We presented the architecture of the wireless sensor network, talked about the calibration of the sensor and irrigation decision results for agricultural application, and established the wireless sensor network based on the self-designed wireless sensor to monitor the moisture content and water height of field soil. In order to facilitate the growth of precision agriculture, we created a wireless sensor network-based smart irrigation control system that uses expert and real-time moisture and irrigation decision-making data. It was established that the method could be used for precision agriculture while saving water [12].

M. Saqib, T. A. Almohamad, and R. M. Mehmood, "A low-cost information monitoring system for smart farming applications," Sensors, vol.20, no.8, p.2367,2020.

The current information monitoring systems are ineffective at meeting the demands of large-scale agricultural fields due to their greater deployment costs and shorter communication ranges. To address the issues of long-distance information monitoring, a low-power, long-range, low-cost serial communication module is suggested. By adding intermediate nodes, a tree-based communication mechanism in the suggested system is able to increase the communication range. A microcontroller, a moisture sensor, a solar panel, a rechargeable cell, and a communication device make up each sensor node. Every node has the ability to handle network traffic as both a router and a sensor node. Every day, the central node sends reduced data logs to the cloud for later analysis [13].

2.1. Existing system

In the realm of traditional agricultural practices, irrigation systems have traditionally relied on manual intervention and fixed schedules, often lacking precision and adaptability to dynamic environmental conditions. These conventional methods typically involve periodic watering based on predetermined time intervals or visual assessments by farmers. Critically, the assessment of soil moisture levels, a key parameter for effective irrigation, is often subjective, resulting in sub-optimal water usage and potential negative impacts on crop health. Furthermore, these systems commonly lack the integration of advanced technologies and sensors capable of providing real-time data on crucial environmental factors such as temperature and humidity. The absence of automated control mechanisms often leads to energy inefficiencies and increased labor demands, as continuous monitoring and adjustments are necessary to maintain an optimal irrigation schedule. In essence, existing irrigation systems fall short of addressing the growing need for precision, efficiency, and adaptability required by modern agriculture. Recognizing these limitations, the proposed Smart Irrigation System aims to revolutionize traditional practices by integrating Arduino Uno micro-controller technology and a suite of sensors. This innovative approach seeks to provide a more responsive, automated, and data-driven irrigation system, addressing the shortcomings of existing systems and ushering in a new era of sustainable and efficient agricultural practices.

3. Methodology

The Smart Irrigation System employs a systematic approach to enhance irrigation practices by seamlessly integrating advanced technology with traditional agricultural processes. The methodology revolves around designing and implementing a modular system centered on an Arduino Uno micro-controller and an array of sensors. Key components include a soil moisture sensor for continuous, real-time measurement of soil moisture content, a DHT11 sensor monitoring temperature and humidity levels, an LCD for visualizing data, a buzzer for immediate alerts, and a relay module controlling the pump motor. The Arduino Uno processes data from these sensors and executes predefined algorithms to determine optimal irrigation actions. The operational flow is as follows: The soil moisture sensor continually assesses soil moisture content, with the DHT11 sensor monitoring temperature and humidity. When soil moisture drops below a predefined threshold, the Arduino Uno activates the buzzer for immediate alerts and triggers the relay module to start the pump motor for irrigation. The LCD provides real-time feedback on environmental conditions and the irrigation status.

The modular design enables scalability and adaptability to diverse agricultural settings and plant types. Calibration procedures are implemented to ensure sensor accuracy and predefined thresholds are set for soil moisture levels to optimize irrigation. The incorporation of an alert system enhances user notification in critical conditions. This methodology guarantees a comprehensive and responsive irrigation system, utilizing real-time sensor data for intelligent decision-making. The implementation prioritizes user-friendliness, allowing for easy setup and customization, while also fostering resource efficiency and sustainability in agriculture. Continuous testing and refinement are integral aspects of the methodology, validating the system's performance under various environmental conditions and ensuring reliability in practical agricultural scenarios.

3.1. Components

3.1.1. Arduino Uno

Figure 1 Arduino Uno

3.1.2. Soil Moisture Sensor with Soil Moisture Sensor Probe

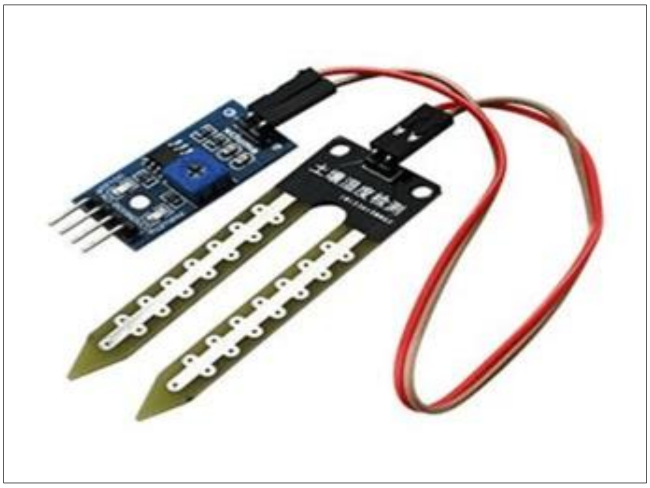

Figure 2 Soil Moisture Sensor with Soil Moisture Sensor Probe

3.1.3. DHT11 Sensor

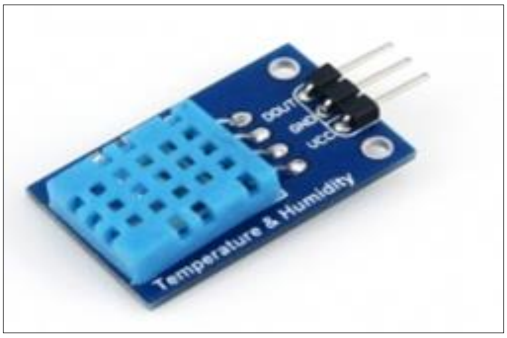

Figure 3 DHT11 Sensor

3.1.4. LCD Display

Figure 4 LCD Display 16*2

4. Proposed system

The envisioned Smart Irrigation System represents a revolutionary solution designed to overcome the limitations of traditional irrigation methods. Harnessing the capabilities of an Arduino Uno microcontroller and an array of sensors, this system introduces a transformative approach to agricultural irrigation, emphasizing precision, efficiency, and sustainability. At the core of the proposed system are key components such as a soil moisture sensor for continuous monitoring of soil moisture levels, a DHT11 sensor providing real-time data on temperature and humidity, an LCD for visualizing relevant information, a buzzer for immediate alerts, and a relay module to control the pump motor. These components intricately connect to the Arduino Uno, forming the foundation of a responsive and automated irrigation system. Intelligent algorithms implemented on the Arduino Uno drive the system's operation. The soil moisture sensor continuously relays feedback on soil moisture content, complemented by the DHT11 sensor's data on temperature and humidity levels. When the soil moisture falls below a predefined threshold, the system activates the buzzer for immediate alerts and triggers the relay module, initiating the pump motor for precise and timely irrigation. The LCD provides users with clear insights into environmental conditions and the ongoing irrigation process.

A distinctive attribute of the proposed system is its modular design, facilitating scalability and adaptability to various agricultural settings and plant types. Calibration procedures ensure the accuracy of sensor readings, and the system's user-friendly interface simplifies setup and customization. The proposed Smart Irrigation System represents a significant leap forward in agricultural practices, delivering an intelligent, data-driven solution that minimizes water wastage, enhances energy efficiency, and promotes optimal plant health. Its responsiveness to dynamic environmental conditions tailor’s irrigation actions to the specific needs of plants, contributing to sustainable farming practices. Continuous refinement and testing will further validate the system's efficacy, positioning it as a promising tool for modern, resource-efficient agriculture.

4.1. Block diagram

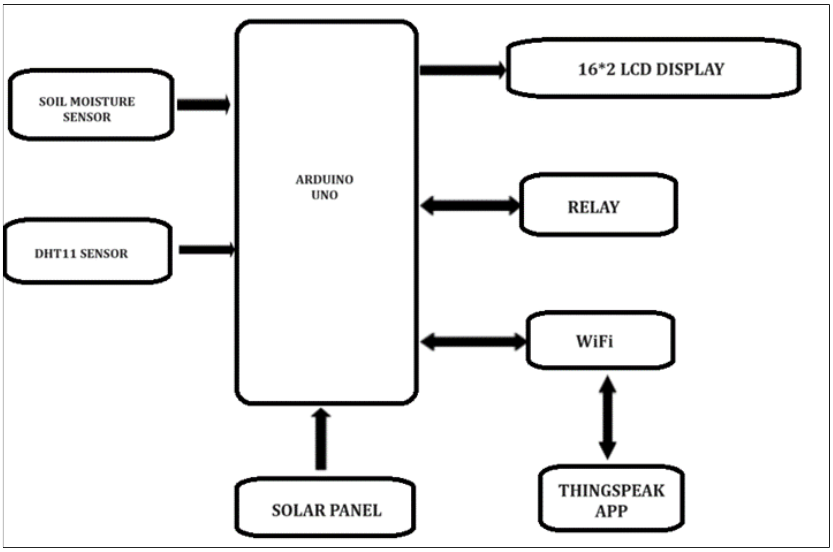

Figure 5 Block diagram

5. Result and discussion

Figure 6 Temperature

Following the implementation of the Smart Irrigation System, the results showcase a significant improvement in irrigation efficiency and resource utilization when compared to traditional methods. The real-time monitoring capabilities of the soil moisture sensor and the DHT11 sensor, coupled with the automated control facilitated by the Arduino Uno microcontroller, have proven highly effective in optimizing irrigation practices. During testing, the system demonstrated its ability to dynamically respond to changing soil moisture levels. Upon detecting moisture levels below the predefined threshold, the system promptly activated the relay module, initiating the pump motor for targeted irrigation. The immediate alerts generated by the buzzer effectively informed users of critical conditions, enabling timely intervention. The LCD played a crucial role in visualizing real-time environmental conditions and irrigation status, providing users with valuable insights for decision-making. This user-friendly interface enhances the system's practicality and accessibility for farmers. The modular design showcased adaptability to different plant types and environmental conditions, offering scalability for various agricultural settings. Calibration procedures were instrumental in ensuring the accuracy of sensor readings, contributing to the precision of the irrigation process.

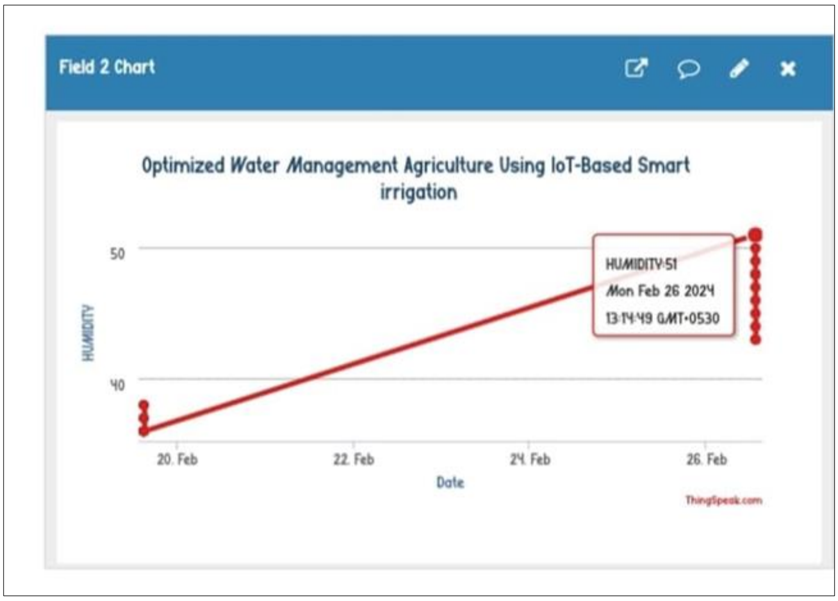

Figure 7 Humidity

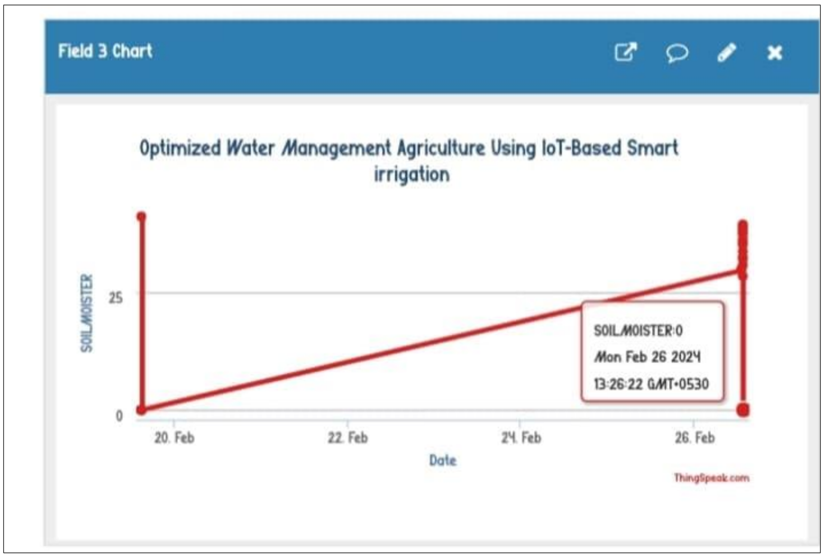

Figure 8 Soil Moisture

In discussing the results, it is noteworthy that the Smart Irrigation System effectively addresses the identified limitations of traditional irrigation methods. By minimizing water wastage, the system contributes to water conservation efforts. The automation of irrigation based on sensor data enhances energy efficiency, reducing the need for constant manual monitoring. Furthermore, the system's adaptability and scalability make it a versatile solution for diverse agricultural scenarios. However, ongoing refinement and testing are imperative to address potential challenges, such as sensor calibration drift over time and the system's performance under varying environmental conditions. Additionally, user feedback and further real-world testing will be crucial to ensuring the system's reliability and effectiveness in practical agricultural applications. In conclusion, the Smart Irrigation System demonstrates promising results in enhancing irrigation practices, promoting sustainability, and effectively addressing the shortcomings of traditional methods. The integration of advanced technologies and real-time data-driven decision-making lays the foundation for a more efficient and resource-conscious approach to agriculture.

6. Conclusion and Future Scope

In summary, the Smart Irrigation System, utilizing the capabilities of an Arduino Uno microcontroller and an array of sensors, has made substantial progress in addressing the inefficiencies of traditional agricultural irrigation practices. Real-time monitoring of soil moisture, temperature, and humidity has empowered the system to provide precise and automated control over the irrigation process, resulting in significant improvements in water conservation, energy efficiency, and plant health compared to conventional methods. The system's modular design and adaptability position it as a versatile solution applicable to diverse agricultural settings and plant varieties. The inclusion of a user-friendly interface, featuring an LCD and a buzzer for alerts, enhances accessibility for farmers. However, continuous refinement and testing are imperative to tackle potential challenges and further establish the system's reliability across various environmental conditions.

Looking towards the future, the Smart Irrigation System holds promising potential for enhancements. The integration of additional sensors for comprehensive environmental monitoring, such as nutrient levels and sunlight exposure, could augment its capabilities. Wireless connectivity offers the opportunity for remote monitoring and control, providing farmers with increased flexibility and accessibility. Incorporating machine learning algorithms could enable the system to adapt to specific plant and soil characteristics over time, optimizing irrigation strategies. Furthermore, integrating weather forecasting data into the system could enable it to anticipate and respond proactively to upcoming weather conditions, further enhancing its ability to adapt to dynamic environmental changes. In conclusion, the Smart Irrigation System not only signifies a notable advancement in sustainable agriculture but also lays the groundwork for future innovations. Through continual refinement and the integration of cutting-edge technologies, the aim is to create a holistic, intelligent, and adaptive irrigation solution that contributes to efficient resource usage, environmental sustainability, and enhanced agricultural productivity.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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	**Dr. R. Vadivel** is an Associate Professor, in the Department of Information Technology, Bharathiar University, Tamil Nadu, India. He received his Ph.D degree in Computer Science from Manonmaniam Sundaranar University in the year 2013. He obtained his Diploma in Electronics and Communication Engineering from State Board of Technical Education in the year 1999, B.E., Degree in Computer Science and Engineering from Periyar University in the year 2002, M.E., degree in Computer Science and Engineering from Annamalai University in the year 2007. He had published over 96 journals papers and over 40 conferences papers both at National and International level. His areas of interest include Information Security, Data mining, Digital Signal Processing.