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Eco-smart irrigation: An IoT based smart irrigation solution for sustainable water management in Agriculture

Vansh G. Joshi, Hitesh G. Phule, Rohit R. Salunke, Diya Chuphal and Akash S. Sogarwal
School of Engineering and Technology, MGM University, Chhatrapati Sambhajnagar

*Corresponding Author's E-mail: vanshgj26@gmail.com, asingh@mgm.ac.in

Mob.: +91-9075404897

ABSTRACT

The eco-smart irrigation system presents an IoT-based smart irrigation solution designed to enhance water use efficiency in agriculture. Utilizing an ESP32 microcontroller, Thing Speak for cloud-based data monitoring, and soil moisture sensors, the system automates irrigation based on real-time soil moisture levels. This approach minimizes water waste by delivering precise irrigation, aligning with sustainable agricultural practices. As agriculture remains a dominant consumer of freshwater resources, innovative methods for reducing water use are crucial for sustainability. The eco-smart irrigation system is practical, affordable, and scalable, demonstrating potential for widespread adoption in both small- and large-scale farming environments. This paper discusses the methodology, technical components, and data-driven approach that forms the backbone of eco-smart irrigation, evaluating its real-time performance and adaptability in diverse soil conditions. Findings suggest the system not only reduces water usage but also significantly cuts labour costs, improves crop yields, and contributes to environmental sustainability.

Keywords : *Smart Irrigation, IoT, ESP32, Soil Moisture Sensor, Water Conservation.*

1. Introduction :

Agriculture accounts for approximately 70% of global freshwater usage, with much of this water being lost to inefficient irrigation practices. Conventional methods, such as flood or manual irrigation, lead to substantial water wastage, soil degradation, and increased labor requirements. In the context of increasing water scarcity, innovative solutions that maximize water-use efficiency are essential to ensure sustainable agricultural productivity. The eco-smart irrigation system addresses this need by integrating IoT technology for smart, data-driven irrigation. Leveraging the ESP32 microcontroller, cloud-based Thing Speak monitoring, and real-time soil moisture sensors, this system offers a responsive and automated approach to irrigation, delivering water precisely when and where it is needed [1]. This paper outlines the design and testing of eco-smart Irrigation, demonstrating its capability to reduce water use, lower operational costs, and boost crop health. Key challenges addressed include data accuracy, energy efficiency, and adaptability to varying soil conditions.

1.1 Internet of Things (IoT):

The Internet of Things (IoT) is the link of uniquely identifiable bedded computing bias within the breathing Internet structure. The Internet of goods connects bias and vehicles using electronic sensors and the Internet [2]. IoT bias have cliché in consumer requests with wearable IoT (Internet of Wearable goods), analogous as smart watches, and home operation products, like Google home. It's estimated over 30 billion could to be connected to the Internet of goods by 2020. The operations of Internet of goods in husbandry target conventional husbandry operations to meet the adding demands and drop product loses. IoT in husbandry uses robots, drones, remote sensors, and computer imaging combined with Continuously progressing machine knowledge and logical tools for covering crops, surveying, and mapping the fields, and give data to farmers for rational estate operation plans to save both time and capitalist.

1.2 Applicability of IoT in Agriculture:

IoT smart irrigation is a hi-tech and effective system of doing husbandry and growing food in a sustainable way. It's an operation of enforcing bias and innovative technologies together into husbandry. Smart husbandry majorly depends on lot, thus, barring the need for physical work of growers and farmers and adding productivity in every possible manner. You may also check the Low- cost Agriculture Business Ideas for newcomers. With the recent husbandry trends dependent on husbandry, lot has brought huge benefits similar as effective use of water, optimization of inputs and numerous further. IoT grounded smart husbandry Improves the entire husbandry by covering the field in real- time. With the help of detectors and interconnectivity, the lot in agriculture has not only saved the time of the growers but has also reduced the extravagant use of coffers similar as water and electricity. It keeps colorful factors similar as moisture, temperature, soil, etc. under check and also gives a demitasse clear real time observation [3,4].

1.3 Benefits of adopting IoT in Agriculture:

The whole IoT ecosystem is made up of detectors that can descry real- time rainfall. Conditions similar as moisture, downfall, temperature and further veritably directly. The IoT system has enabled rainfall stations to automatically acclimate the climate conditions according to a particular set of instructions [5]. The relinquishment of the IoT system in glass houses has excluded mortal intervention, therefore making the entire procedure cost-effective and adding delicacy at the same time.

- 1) IoT results are concentrated on optimizing the use of coffers like water, energy, land.
- 2) Precision irrigation using the IoT system relies on the data collected from different detectors in
- 3) The field which helps growers directly allocate just enough coffers to within one factory. IoT in the husbandry assiduity has helped the growers to keep the quality of crops and
- 4) Fertility of the land, therefore enhancing the product volume and quality. IoT system results in husbandry introduce robotization, for illustration, demand-grounded.

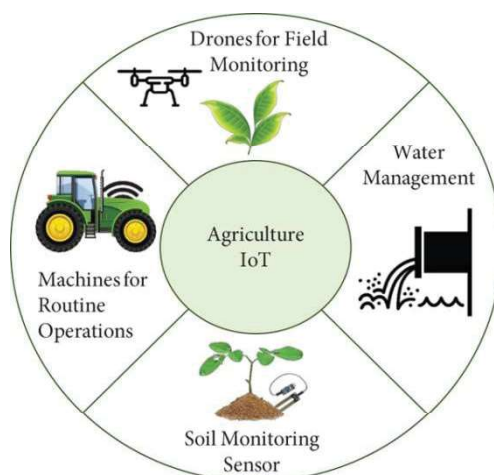


Fig.1. Benefits of IOT in Agriculture

2. Literature review:

Traditional irrigation techniques often lead to over-irrigation, risking soil health and wasting water [15]. There is significant development in technologies that can be employed for agriculture for crop health monitoring and water conservation which is depicted from Fig.1.

2.1 Background Study

Recent years have seen significant interest in the development of smart irrigation systems to address global water conservation goals. Studies reveal that monitoring soil moisture can enhance water conservation and improve crop yields, which is essential for regions prone to drought. Advances in IoT and sensor technology have enabled new systems that optimize water use by deploying it based on real-time environmental data. The introduction of cloud based platforms, such as ThingSpeak, allows remote monitoring and adjustments, offering insights into water use patterns, soil conditions, and crop health [6,7,8].

2.2 Integrated Technologies:

Numerous studies emphasize the effectiveness of microcontrollers, particularly Arduino and ESP32, in automating irrigation. ESP32, with built-in WIFI capabilities, has become a popular choice for IoT-based agriculture projects due to its versatility, low power consumption, and affordability. Systems using ThingSpeak have demonstrated effectiveness in storing and visualizing real-time data, which helps in identifying trends and making informed decisions. These technologies have shown promise in transforming traditional irrigation into a precision-oriented practice, promoting sustainability in agriculture [9,10,11].

In the existing method, farming is performed manually by farmers who are unable to predict weather conditions. The introduction of soil moisture, humidity, and temperature sensors helped quantify the land's condition, and systems like sprinkler and water pumps are used to automate irrigation. [12,13,14].

However, these methods face challenges such as the need for constant manual monitoring, data being stored locally by connection through Arduino, and highwater consumption. Additionally, issues like fluctuating power supply and poor connectivity in rural areas can undermine the effectiveness of such systems. There are few demerits associated with existing farming system of integration as follows:

- Increased manual labour
- Heavy reliance on internet connectivity
- Inaccurate data storage and retrieval
- High water consumption

2.3 Proposed system of Integration:

The proposed system for smart irrigation integrates a combination of hardware and software components, including soil moisture sensors, an ESP32 microcontroller, and Thing Speak for remote monitoring.

The system uses IoT to automatically manage irrigation based on real-time soil moisture data, ensuring efficient water use and the merits associated are as follows:

- Reduced power consumption
- Direct irrigation to the soil, minimizing water waste
- Efficient use of water, aligning with sustainable practices
- Simplified for farmers, requiring minimal technical expertise

3. Methodology:

The eco-green irrigation system integrates various components to automate and optimize irrigation. The integrated circuit of proposed system is as shown in Fig. 2.



Fig.2. Integrated Circuit Connections of Proposed System

The integrated system has various components like soil moisture sensor, ESP32 Microcontroller, relay module and DC pumps, transformer, rectifying circuit, LCD display, ThingSpeak cloud platform etc. which are briefly explained in following subsections.

3.1 Soil Moisture Sensors : Two strategically placed sensors monitor soil moisture, providing real-time feedback. The data is processed by the ESP32 microcontroller to control irrigation actions. The soil moisture sensor is as shown in Fig.3.

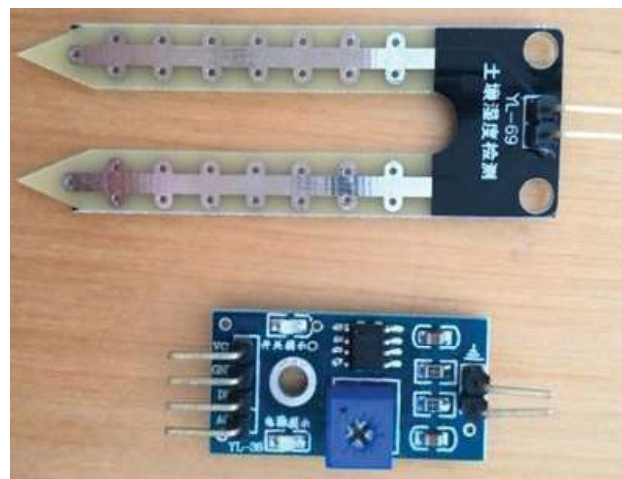


Fig.3. Soil Moisture Sensor

3.2 ESP32 Microcontroller : As the central control unit, the ESP32 microcontroller (Fig. 4) receives data from sensors and transmits it to ThingSpeak for remote monitoring.

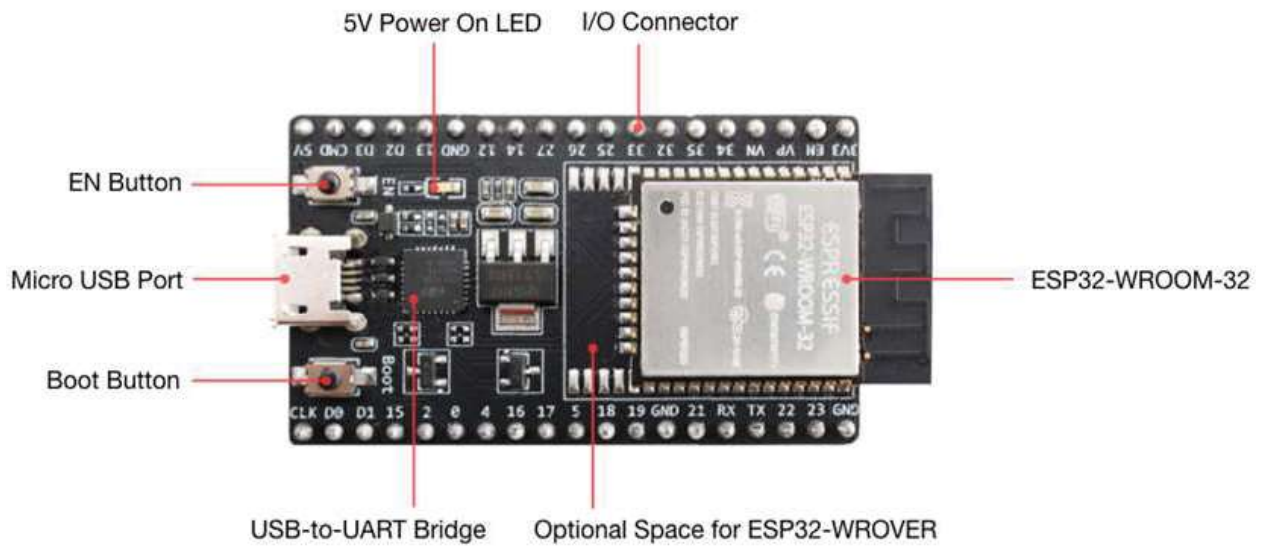


Fig.4. ESP-32 Module

3.3 Relay Module and DC Pumps : The relay module (Fig. 5) activates irrigation DC water pumps (Fig. 6) when soil moisture falls below a set threshold, delivering water efficiently.



Fig.5. Relay Module



Fig. 6 DC Water Pump

3.4 Transformer and Rectifying Circuit : These integrated Transformer (Fig.7) and rectifying circuit components ensure the pumps receive a stable DC power supply.



Fig.7. Transformer

3.5 LCD Display : Provides real-time feedback on moisture levels and pump status.

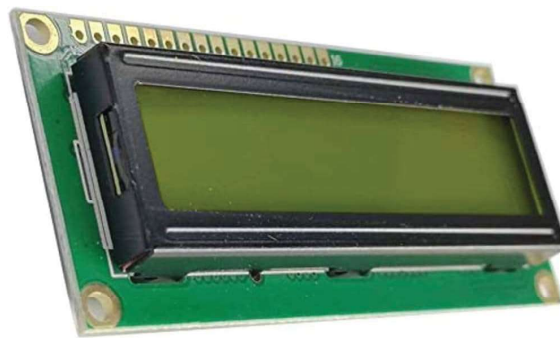


Fig.8. LCD Display

3.6 Thing Speak Cloud Platform : This platform enables remote monitoring and data analysis, allowing users to track irrigation trends and optimize schedules.

3.6 Working Process

The system continuously monitors soil moisture. When levels drop below a pre-set threshold, the ESP32 triggers the relay, activating the pump. Water is delivered until the moisture level reaches the desired threshold. Real-time data is sent to ThingSpeak for cloud monitoring, allowing users to review trends and make adjustments to irrigation practices.

4. Results and discussion:

4.1 Results:

The eco-green irrigation system was tested under varying soil and weather conditions, with the following key observations:

- **Water Usage Reduction:** The system significantly reduced water consumption by providing irrigation only when necessary.
- **Response Time:** The ESP32 activated the pumps within seconds of detecting a low moisture level, maintaining soil health efficiently.
- **Data Trends:** The system's data visualization helped identify areas that retained moisture longer, optimizing irrigation schedules. .

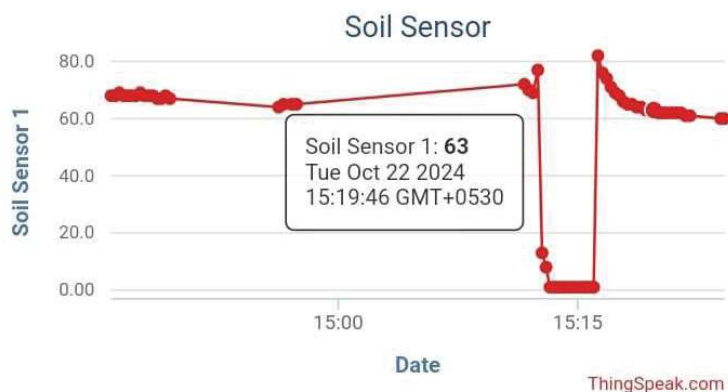


Fig.9. Data of Field 1 (X-axis time and Y-axis Moisture (%))

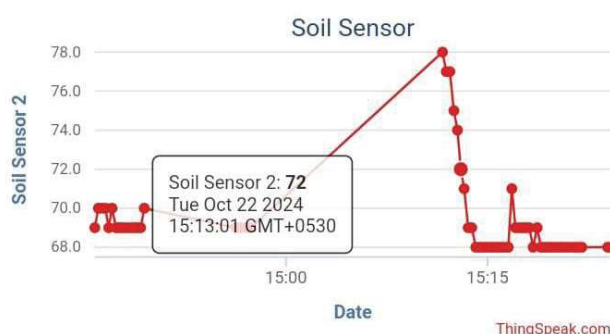


Fig.10 Data of Field 2 (X-axis time and Y-axis Moisture (%))

The results show that the eco-green irrigation system assist for enhancing the water conservation, reduces labour costs, and improves crop yields, making it an effective solution for sustainable agriculture. Sample data for Field 1 (Fig.9) shows variations of moisture content of soil (%) while sample data of Filed 2 (Fig. 10) shows maintained moisture content of soil (%) above 65 % using integrated technologies of eco-smart irrigation.

4.2 Discussion

The successful deployment of the eco-green irrigation system underscores the potential of IoT for precision agriculture. The system automation based on real-time soil moisture data reduces water wastage and enhances crop health. Cloud-based monitoring through ThingSpeak provides users with actionable insights, enabling them to make informed decisions and optimize irrigation schedules. There is capability to integrate additional sensors, such as temperature, humidity, and rain sensors, to make the system more responsive to weather changes. Furthermore, one can enhance the system's energy efficiency by integrating solar power and this make the system more sustainable and suitable for off-grid environments.

5. Conclusions :

The eco-smart irrigation system represents a significant advancement in sustainable agriculture. The combination of IoT based soil moisture monitoring with automated irrigation makes the farming system efficient alternative to traditional farm irrigation methods. The integrated eco-smart irrigation system has indicated an improvement for water conservation, reduction of labour, and improves the crop health. This demonstrates its potential to contribute to global water conservation goals. Future upgrades, including weather-responsive sensors, energy-efficient components, and predictive analytics, will further enhance the system's performance and expand its applicability across different farming scales and environments.

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