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Smart Irrigation System using IoT

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ABSTRACT: A Smart Irrigation System uses technology to help farmers save water and reduce manual work. It relies on an ESP32 microcontroller and sensors for soil moisture, rain, temperature, and humidity. When the soil is too dry and there's no rain, the system starts the water pump through a relay. Farmers can see real-time sensor readings on a small OLED display and track data remotely on Thing-Speak using Wi-Fi. Powered by solar panels and a rechargeable battery, this system runs off-grid a green and cost-effective choice for rural areas. IoT-based irrigation systems like this typically save 30% to 50% of water compared to traditional methods while also boosting crop health and yields. Remote monitoring means farmers can adjust watering from a phone or computer Data-driven decisions reduce human errors and help plan irrigation better. Testing shows the system effectively cuts water use and minimizes manual labor, making it ideal for small to medium farms. In the future, adding multi-zone support, mobile alerts, and smarter controls—like weather-based automation—could make it even more efficient and powerful.

Keywords: Smart Irrigation System, IoT, ESP32, Soil Moisture Sensor, Rain Sensor, DHT11, OLED Display, Thing Speak.

1. Introduction

This project focuses on developing an intelligent irrigation system that uses IoT to manage water use more efficiently in agriculture [1], [2]. It's built around the ESP32 microcontroller, which collects real-time data from sensors measuring soil moisture, rainfall, temperature, and humidity [3], [4]. Based on these inputs, the system controls a water pump that irrigates only when needed, reducing waste and improving accuracy [4], [5]. To support sustainability, the system runs on solar power with a rechargeable battery, making it suitable for remote or off-grid locations [10]. A small OLED screen shows live environmental readings, while data is also sent to the Thing Speak platform for remote tracking and analysis [7]. The system was programmed and tested using Arduino IDE and fine- tuned through field trials to ensure dependable operation [6]. Overall, this low-cost, energy-efficient design offers a practical solution for small to mid-sized farms. It minimizes manual work, saves water, and opens the door for future upgrades like AI integration, mobile control, and weather-based automation [7], [9]. Methodology Hardware Components Description

1.1 ESP32 Board

The ESP32 microcontroller supports platforms such as Arduino IDE, Platform IO, and Micro Python, making it user-friendly and easy to integrate into embedded systems. With its strong processing power, energy efficiency, and built-in Wi-Fi and Bluetooth, it is well-suited for smart irrigation applications. It reads data from sensors, including soil moisture and DHT11 (for temperature and humidity), and controls the water pump based on pre-set logic. Its flexibility also allows for communication with GSM, Bluetooth, or Wi-Fi modules for remote monitoring and alerts, while its compact design and low power requirements make it ideal for field use

1.2 Soil Moisture Sensor

The soil moisture sensor plays a key role in detecting how much water is in the soil. It uses two metal probes to measure electrical resistance. Higher resistance indicates dry soil, while lower resistance signals moisture. This data is sent as an analog signal to the Arduino, which interprets it as a moisture percentage. If the value falls below a set threshold, the system triggers the relay to turn on the water pump. These sensors are cost-effective, easy to use, and well-suited for farming needs.

1.3 Rain Sensor

The rain sensor detects rainfall using a conductive grid that closes a circuit when wet. This sends a signal to a digital pin on the Arduino, indicating whether rain is present. Based on this input, the system can pause irrigation to prevent unnecessary water usage. Often paired with soil moisture sensors, rain sensors are easy to install, cost-effective, and ideal for smart farming setups focused on water efficiency.

1.4 Relay Module

The relay module acts as a bridge between the low- power Arduino and the high-power water pump, enabling safe control of the pump. Triggered by a digital signal from the Arduino, the relay switches on the pump using an external power supply. Typically, a 5V single-channel relay rated up to 10A is used, with built-in protection like fly back diodes to handle voltage spikes. For reliable outdoor use, proper insulation and secure mounting are important.

1.5 Water Pump

The water pump is used to deliver water to the plants whenever irrigation is needed. It operates based on signals from the Arduino, which activates the pump through a relay when soil moisture falls below a set threshold. In this project, a compact 12V DC pump is used, suitable for small-scale systems. It's lightweight, energy-efficient, and works well with solar or battery power, making it ideal for remote agricultural setups.

1.6 DHT 11

The DHT11 is a compact digital sensor designed to measure both temperature and humidity levels. It operates using a thermistor to detect temperature and a capacitive sensor to monitor humidity. Ideal for basic environmental monitoring, the DHT11 is widely compatible with microcontrollers like Arduino and Raspberry Pi due to its simple communication interface. This sensor functions within a temperature range of 0°C to 50°C and provides humidity readings between 20% and 80%. While not highly precise, offering about ±2°C for temperature and ±5% for humidity, it is well-suited for low-cost applications. It updates once every second and requires a voltage supply of 3 to 5 volts, drawing minimal current.

1.7 Solar Panels

A small 70mm x 70mm solar panel rated at 5Vand 100mA was used as the primary power source in this project. Despite its compact size, it provides efficient energy output, making it ideal for portable or space-limited applications. This panel converts sunlight into electricity, supporting an off-grid, eco- friendly power solution essential for the system’s sustainable operation.

1.8 TP4056 Module

The TP4056 is a widely used module for charging single-cell 3.7V lithium-ion batteries. It integrates a charger with built-in safety features such as protection against overcharging, over-discharge, and short circuits. In this project, it was employed to regulate the charging of a lithium-ion battery using a 5V solar panel. This module ensures safe and efficient charging by controlling voltage and current, making it a great choice for small-scale renewable energy applications.

2. Architecture of the System Block Diagram

The block diagram represents the overall architecture of the system. It includes the interaction between sensors, the microcontroller, and output components:

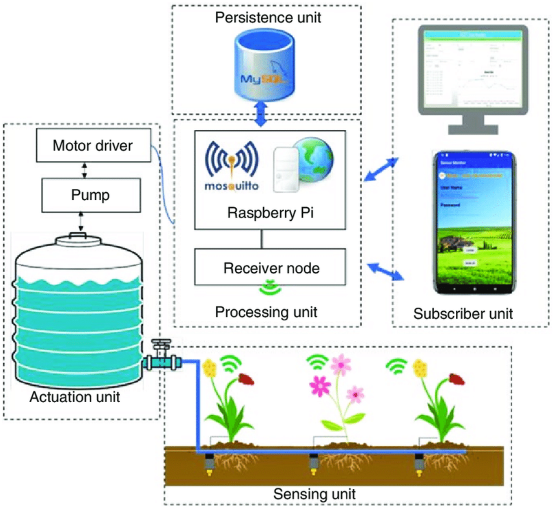

Figure 1: *Block diagram architecture of the system*

Flowchart o smart irrigation system

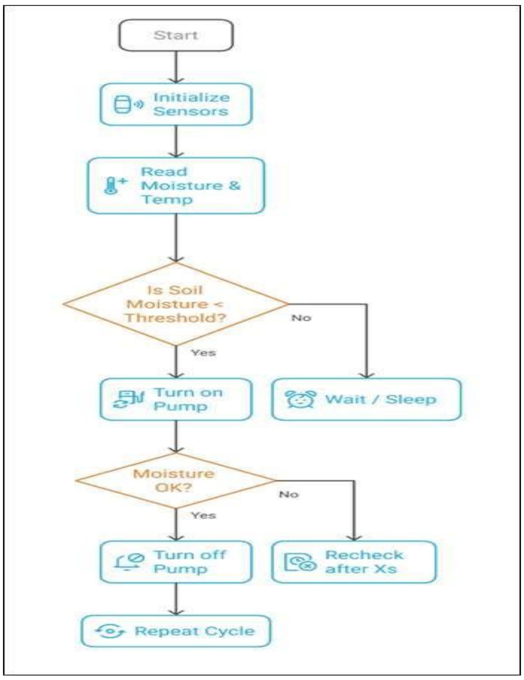

Figure 2: *Flow chart operation*

2.1 Workflow and Flowchart

The system workflow involves monitoring soil moisture and making decisions to irrigate based on preset conditions. The logic is simple but effective for automation.

Workflow Steps:

- The system powers on and initializes sensors.
- Reads values from soil moisture and temperature sensors.
- Compares soil moisture against threshold.
- If moisture is below the threshold, activate the relay to start the pump.
- Continues monitoring.
- Stops pump once adequate moisture is reached.

3. System Implementation

3.1 Simulation Model Using Proteus Software

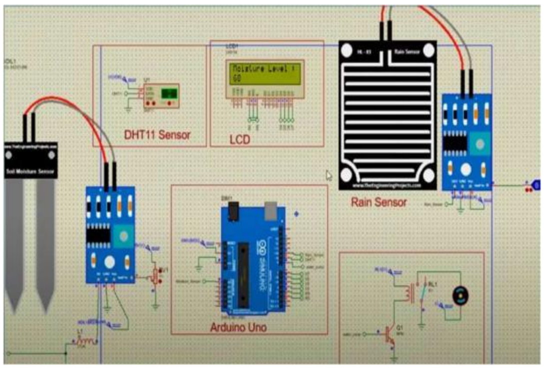

Figure 3: *Proteus based simulation diagram*

Proteus is a versatile simulation and circuit design software widely used for developing and testing electronic systems. It enables users to create circuit diagrams, simulate components, and verify microcontroller-based projects like Arduino, PIC, and ARM before hardware implementation.

In the given image, a Smart Irrigation System is designed using Proteus. It includes key components like:

Soil Moisture Sensor: Detects soil water levels.

DHT11 Sensor: Measures temperature and humidity.

Rain Sensor: detects rainfall to prevent unnecessary watering.

LCD Display: shows environmental data.

Arduino Uno: Processes sensor inputs and controls outputs.

Water Pump Motor: Turned on/off via relay based on sensor readings. The Arduino reads values from the sensors and activates the water pump through a relay only when the soil is dry and there's no rainfall, ensuring efficient water usage. This simulation demonstrates the full working of the irrigation system virtually, allowing for error checking before physical implementation.

3.2 Experimental Setup

The experimental setup was designed to replicate real farming conditions for evaluating the smart irrigation system. A test plot with different soil types and crop varieties was prepared to assess the system's adaptability. The ESP32 microcontroller acted as the control hub, managing sensors like the DHT11 for temperature and humidity, soil moisture sensors, a relay, and a water pump. Sensors were placed at various soil depths for accurate readings, while the pump ensured even water distribution. Power was supplied through a DC source and a solar-powered battery, promoting sustainability. Wi- Fi-enabled remote monitoring and initial calibration and dry runs were performed to ensure reliable operation. Data was continuously logged for analysis and performance evaluation.

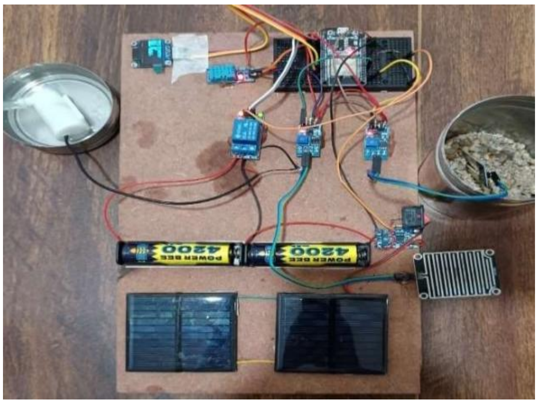

Figure 4: *Hardware setup of the entire system*

4. Results and Analysis

4.1 Performance Evaluation

Performance evaluation of the smart irrigation system involved assessing parameters such as response time, reliability, water efficiency, sensor accuracy, and adaptability to varying environmental conditions.

The system was tested over multiple days, cycles, and operational scenarios. The ESP32's consistent ability to make real-time decisions based on accurate sensor readings significantly contributed to its success.

On average, the smart irrigation system demonstrated a water usage reduction of nearly 40- 50% compared to traditional manual watering methods. This was primarily achieved through its ability to apply water only when needed, minimizing waste. Furthermore, data collected from Thing Speak dashboards helped detect patterns in soil behaviour and optimize future irrigation cycles.

Figure 5: *Output of OLED when motor OFF*

Figure 6: *Output of OLED when motor ON*

The system's robustness was also evident in its ability to withstand minor power fluctuations, intermittent Wi-Fi connectivity, and extreme temperature changes. Modular design allowed seamless integration of additional sensors, making the system scalable for larger agricultural setups. The ESP32's built-in capabilities, combined with Thing Speak's visualization tools, enhanced the overall operability and reliability of the platform.

Through iterative testing, the system consistently maintained high performance metrics, including over 98% uptime, minimal false triggers, and zero hardware failures. These results underscore its potential to revolutionize water management practices in agriculture and support eco-friendly farming initiatives.

4.2 Thing Speak Data Collection

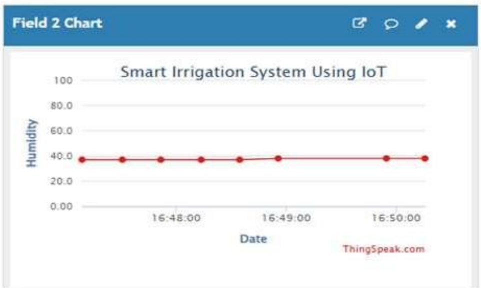

Figure 7: *Thing Speak Temperature readings*

The integration of the Thing Speak IoT platform played a crucial role in monitoring and visualizing real-time environmental data from the smart irrigation system. Using the ESP32 microcontroller, sensor data such as temperature, humidity, soil moisture, and rainfall was transmitted at regular intervals to the cloud.

4.2 Thing Speak Data Collection

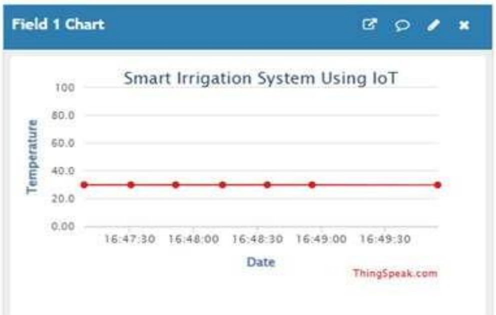

Figure 8: *Thing speak humidity readings*

Temperature Chart (Field 1) showed consistent readings around 27°C.

Soil Moisture Chart (Field 3) demonstrated fluctuations, especially a notable increase after pump activation.

Rain Sensor Chart (Field 4) showed a sudden rise in rain detection values, indicating changing weather conditions.

These visualizations allowed remote users to monitor trends, verify sensor accuracy, and evaluate system performance. The platform also supported data export for further offline analysis, helping assess variables like irrigation frequency, water usage, and sensor responsiveness under different environmental conditions. This streamlined approach made the system highly adaptable and efficient for smart farming.

Figure 9: *Thing speak soil moisture* readings

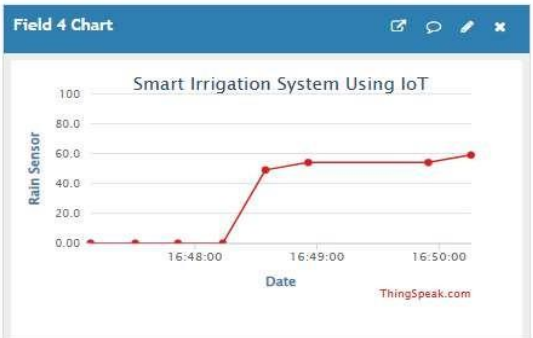

Figure 10: *Thing speak rain sensor readings*

5. Conclusion

The smart irrigation system developed in this project highlights the powerful impact of combining embedded systems with IoT to modernize traditional farming methods.

Using components like the ESP32, soil moisture sensors, relays, and the Thing Speak platform, the system enables automated and efficient water management based on real-time data.

Testing shows notable improvements in water savings, crop health, reduced manual work, and overall system performance. Cloud-based monitoring allowed remote access and decision-making, reducing the need for physical supervision. This project demonstrates the value of precision agriculture in promoting sustainable farming, conserving resources, and addressing labour and climate challenges effectively.

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