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Design and Implementation of an IoT-Based Soil Moisture Sensing System for Real-Time Agricultural Monitoring

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Abstract: *Efficient use of water has become one of the most critical challenges in modern agriculture. Conventional soil moisture measurement techniques provide only instantaneous readings and lack the ability to store or transmit data remotely. To address these limitations, this work presents the development of an IoT-based soil moisture sensing system using a capacitive soil moisture sensor and an ESP32 microcontroller.*

The system continuously monitors soil moisture levels and displays the values locally on a 16×2 LCD while simultaneously transmitting data to the Blynk cloud platform for remote access. A calibration-based approach is used to convert raw sensor readings into meaningful moisture percentage values. The entire system is powered using a rechargeable battery integrated with a Battery Management System (BMS), ensuring safe and reliable field operation.

Experimental observations indicate that the system provides stable performance, reasonable accuracy, and reliable wireless communication, making it suitable for practical agricultural applications.

Keywords*:* IoT, Soil Moisture Monitoring, ESP32, Smart Agriculture, Wireless Monitoring

I. INTRODUCTION

Agriculture heavily depends on proper irrigation practices, and inefficient water usage can directly affect crop productivity. In many traditional setups, farmers rely on manual observation or basic instruments that do not provide continuous monitoring or historical data. This often leads to either over-irrigation or under-irrigation.

With the advancement of the Internet of Things (IoT), it has become possible to design systems that can monitor environmental conditions in real time and make the data accessible from remote locations. Soil moisture is one of the most important parameters for irrigation control, and continuous monitoring of this parameter can significantly improve water management.

In this work, an IoT-based soil moisture sensing system is developed that provides real-time monitoring along with local and remote visualization. The system is designed to be low-cost, portable, and suitable for deployment in actual agricultural fields.

II. SYSTEM ARCHITECTURE

The overall system is composed of several interconnected modules that work together to perform sensing, processing, and communication tasks.

The major components used in the system are:

Capacitive Soil Moisture Sensor

ESP32 Microcontroller

16×2 LCD Display with I2C Interface
Blynk IoT Cloud Platform
Rechargeable Battery with BMS
The sensor measures soil moisture and sends an analog signal to the ESP32. The microcontroller processes this data, displays it locally on the LCD, and uploads it to the cloud platform via Wi-Fi.

Fig. 1. Block diagram of the IoT-based soil moisture sensing system showing sensor input, processing unit, display, and cloud communication.

III. HARDWARE DESIGN

A. Soil Moisture Sensor

A capacitive soil moisture sensor is used in this system due to its better durability and resistance to corrosion compared to resistive sensors. It works by detecting changes in the dielectric constant of the soil, which varies with moisture content. The sensor produces an analog voltage output corresponding to the moisture level.

B. ESP32 Microcontroller

The ESP32 acts as the core processing unit of the system. It is well suited for IoT applications because of its built-in Wi-Fi capability and efficient power consumption.
The main functions performed by the ESP32 include:

- Reading analog data from the sensor
- Converting raw values into calibrated moisture percentage
- Sending data to the cloud platform
- Interfacing with the LCD display

C. LCD Display

A 16×2 LCD display with an I2C interface is used to show real-time soil moisture values. The use of an I2C module reduces the number of required connections and simplifies interfacing with the microcontroller.

D. Power Supply

The system is powered using a rechargeable lithium battery along with a 1S Battery Management System (BMS). The BMS provides protection against overcharging, deep discharge, and short circuits, making the system safe for continuous outdoor operation.

Fig. 2. Hardware setup showing ESP32, soil moisture sensor, LCD display, and power module connections.

IV. SOFTWARE DESIGN

The software for the system is developed using the Arduino IDE. The program follows a cyclic process to continuously monitor and update soil moisture data.

The main steps involved are:

- Acquire analog data from the soil moisture sensor
- Apply calibration to convert raw values into percentage
- Display the result on the LCD
- Transmit the data to the Blynk cloud platform
- Repeat the process after a short delay

A. Calibration Method

To obtain meaningful readings, the sensor output is calibrated between dry and wet soil conditions. The conversion is performed using a linear mapping approach.

Moisture (%) = (ADCmax − ADCvalue) / (ADCmax − ADCmin) × 100

Where:

- ADCmax represents the dry soil value
- ADCmin represents the wet soil value

V. SYSTEM FLOWCHART

The operation of the system follows a continuous loop where data is sensed, processed, displayed, and transmitted.

- Flowchart

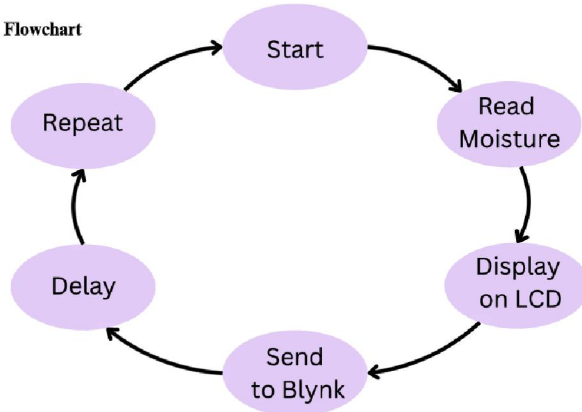

Fig. 3. Flowchart representing the sequence of operations in the soil moisture monitoring system.

VI. EXPERIMENTAL SETUP

A. Blynk Interface

The Blynk platform is used to visualize the soil moisture data remotely. It provides a user-friendly interface with widgets such as gauges and graphs to monitor real-time values and trends.

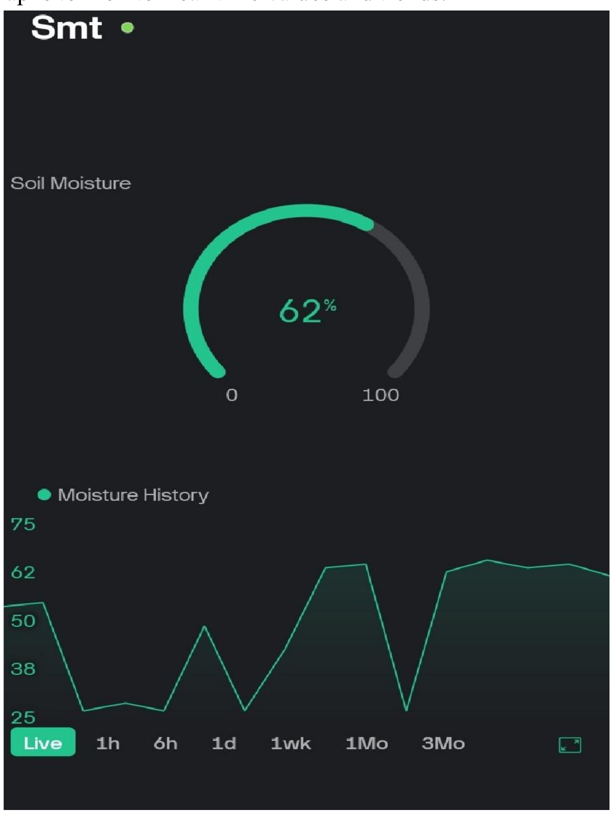

Fig. 4. Mobile application interface displaying real-time soil moisture percentage and historical data trends.

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B. Testing Procedure

The sensor was tested under different soil moisture conditions. The readings were observed both on the LCD and through the Blynk application to verify consistency and reliability.

VII. RESULTS AND PERFORMANCE EVALUATION

The developed system was tested under various conditions, and the following observations were made:
The system achieved an accuracy of approximately ±4–6%
The response time was around 2 seconds
Wireless communication remained stable during operation
The LCD displayed consistent and readable outputs
The system covered a full range of 0–100% moisture levels

A. Comparison with Existing Systems

Parameter	Conventional System	Proposed System
Data Logging	Not Available	Available
Remote Monitoring	Not Available	Available
Power Supply	Wired	Battery-Based
Cost	Relatively High	Low
Scalability	Limited	High

IX. FUTURE SCOPE

The system can be further improved by incorporating:

- Automatic irrigation control mechanisms
- Additional sensors such as temperature and pH
- Solar-powered energy systems
- Data analytics and predictive irrigation techniques

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