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DEVELOPMENT AND IMPLEMENTATION OF A IOT (SOIL-BASED) MONITORING SYSTEM ENHANCED WITH IOT AND SOLAR ENERGY

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Abstract: Introduction: Reliable information on soil conditions is essential for precision agriculture, particularly in regions where energy supply and access to advanced technologies are limited. Methodology: This study presents the design and implementation of a smart soil-based monitoring system that integrates temperature, moisture, and pH sensors with a PIC18F260 microcontroller and an ESP8266 Wi-Fi module. The system is powered by a solar-battery hybrid unit and transmits real-time data to cloud platforms for visualization and analysis. Results: Laboratory calibration and field evaluations demonstrated mean absolute errors of 0.43 °C, 2.15%, and 0.27 for temperature, moisture, and pH measurements, respectively, with wireless latency below 2 s and packet loss under 1%. Conclusion: The results confirm that a low-cost, solar-powered IoT architecture can deliver accurate and reliable soil data, supporting sustainable and data-driven agricultural decision-making in off-grid environments.

Keywords: PIC18F260 microcontroller; Internet of Things; soil monitoring; solar energy; precision agriculture

INTRODUCTION

Agriculture remains central to food security and economic development, yet conventional farming practices are increasingly constrained by climate variability, soil degradation, and inefficient resource utilization. These challenges are particularly pronounced in developing regions, where access to real-time agronomic information and reliable power supply is limited. Precision agriculture has emerged as an effective response, leveraging embedded systems, wireless sensor networks, and Internet of Things (IoT) technologies to monitor environmental parameters and support informed decision-making [1], [2]. Soil temperature, moisture, and pH are among the most critical indicators of soil health and crop productivity, directly influencing irrigation scheduling, nutrient availability, and root development [3]. Although commercial soil monitoring solutions exist, their high cost, energy demand, and technical complexity restrict widespread adoption by small- and medium-scale farmers. The objective of this study is therefore to develop a low-cost, scalable, and energy-autonomous soil monitoring system that combines multi-parameter sensing, IoT connectivity, and solar power, with a view to improving accessibility and sustainability in precision agriculture applications.

METHODOLOGY

System Architecture

The proposed system is structured into four functional layers: sensing, processing, communication, and cloud/user interface. The sensing layer comprises soil temperature, moisture,

and pH sensors deployed in the root zone. The processing layer is built around a PIC18F260 microcontroller, which performs signal conditioning, analog-to-digital conversion, and local data handling. Wireless data transmission is achieved through an ESP8266 Wi-Fi module, forming the communication layer, while the cloud layer utilizes ThingSpeak and Blynk platforms for data storage, visualization, and analytics. Figure 1 shows the Block diagram of the system while figure 2 is a 3D View of the Designed PCB Layout and figure 3, the Etched PCB Track Layout.

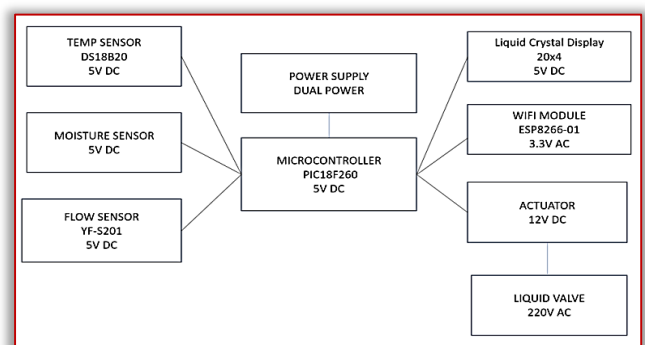


Figure 1. Block diagram

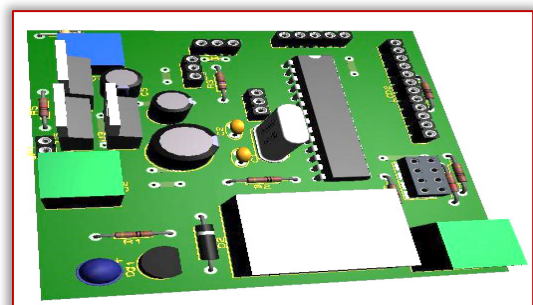


Figure 2: 3D View of the Designed PCB Layout

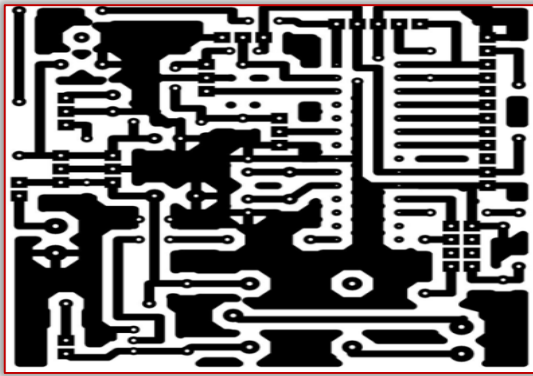


Figure 3. Etched PCB Track Layout

Hardware Implementation

A DS18B20 digital sensor was selected for soil temperature measurement due to its accuracy and noise immunity. Soil moisture was measured using a capacitive sensor, chosen over resistive alternatives to reduce corrosion and long-term drift. An analog pH probe with appropriate signal conditioning circuitry was employed to capture soil acidity levels. All components were integrated on a custom-designed printed circuit board to minimize noise, improve reliability, and enhance field robustness. Figure 4 shows the overall system circuit diagram showing the integration of sensors, microcontroller, IoT module, and solar energy system

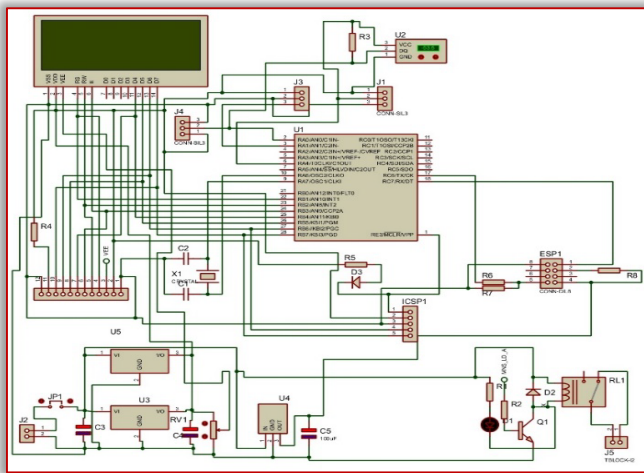


Figure 4. Overall system circuit diagram

Software Design and IoT Communication

Firmware for the PIC18F260 was developed in C/C++, implementing periodic sensor sampling, data conversion, and packet formatting. Sensor readings are transmitted at 10-second intervals to the cloud using HTTP-based RESTful APIs for ThingSpeak and MQTT for Blynk. Connection retries and basic fault-handling routines were implemented to ensure reliable data delivery under fluctuating network conditions.

Power Supply and Energy Management

To ensure autonomous operation, the system employs a hybrid power unit consisting of a 10 W photovoltaic panel, a lithium-ion battery, and a charge controller. Solar energy is harvested during

daylight hours and stored in the battery, which supplies regulated 5 V power to the electronics during low-light or night-time conditions.

RESULTS AND DISCUSSION

The system gave the same results every time during different tests. After switching from a breadboard setup to a printed circuit board, the signal became more stable, improving by more than 20%. This was because there was less electrical noise and better grounding. The LCD screen showed the soil data right away in Figure 4, making it easier to use locally without needing an internet connection. Each sensor was checked against high-quality lab equipment to make sure it was accurate.

The calibration process compared the readings from the PIC18F260 sensors with the readings from standard tools for soil temperature, moisture, and pH, all under controlled conditions

Calibration results indicated strong linear agreement between sensor outputs and laboratory reference instruments. The computed mean absolute and root mean square errors fall within acceptable limits for agricultural monitoring applications. Wireless communication tests showed stable connectivity, with latency below 2 s and packet loss under 1%. Extended power tests confirmed uninterrupted operation for over 72 hours under varying weather conditions, validating the effectiveness of the solar-battery subsystem. Field deployment across loamy, sandy, and clayey soils revealed consistent sensor performance and meaningful variation in soil parameters, demonstrating the system's practical applicability. Figure 5 shows the Photograph of the assembled smart-based soil while figures 6, 7 and 8 show the calibration curves.

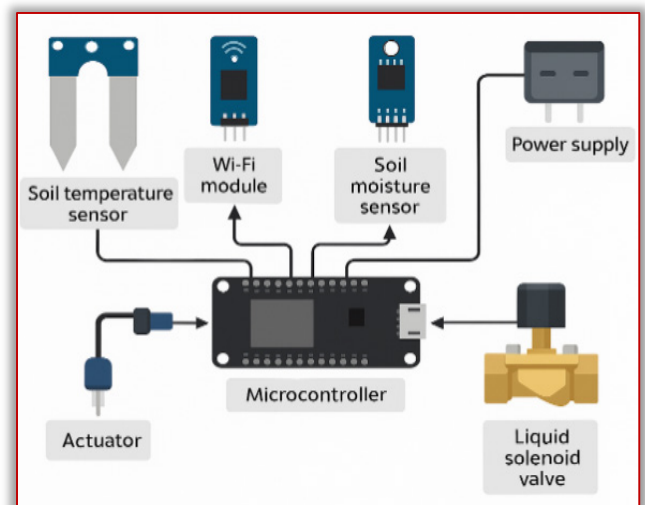


Figure 5. Photograph of the assembled smart-based soil

The system's design is flexible, making it easy to add more sensors or devices like solenoid valves for automatic watering with little changes to the software. This makes the system able to handle different farming needs easily.

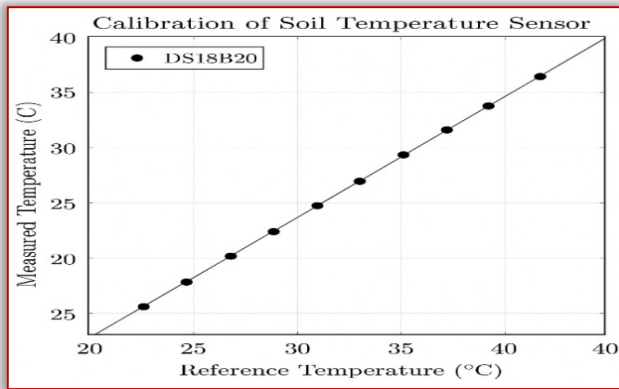


Figure 6: Calibration Curve Measured Temperature with respect to Referenced Temperature.

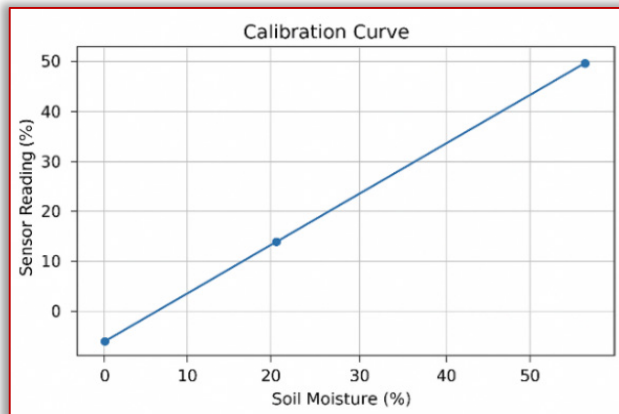


Figure 7: Calibration Curve for Sensor Reading with respect to Soil Moisture.

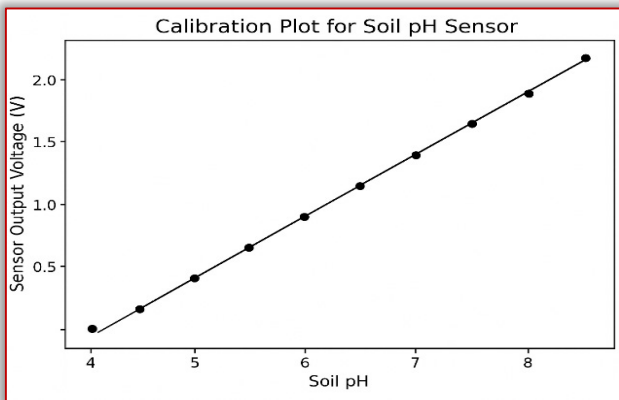


Figure 8: Calibration plot for soil pH sensor displaying correlation between voltage output and pH value

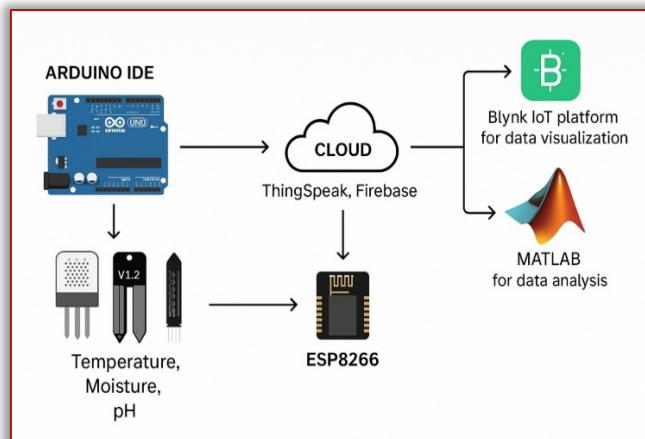


Figure 9: The Cloud Platform

To validate the performance of the developed system, laboratory and field tests were conducted across different soil types loamy, sandy, and clayey. The system's readings were compared with reference instruments to determine accuracy and reliability. Statistical measures such as Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were computed to evaluate performance.

— Temperature sensor accuracy: ± 0.5 °C (MAE = 0.43 °C)

— Moisture sensor accuracy: ± 2.5 % (RMSE = 2.42 %)

— pH sensor accuracy: ± 0.3 pH units (RMSE = 0.31)

Wireless connectivity tests indicated a packet loss rate below 1% and latency under 2s, confirming stable IoT performance. The power system was tested for 72 hours, maintaining uninterrupted operation under varying light conditions [6]. These results demonstrate the system's robustness and suitability for deployment in field environments. Part of this system is having two power sources, which helps keep things running smoothly even when working in the field. The power system includes:

— Main Power: A 5V lithium-ion battery that can power the system for up to 12 hours without needing a charge;

— Backup Power: A 10W solar panel linked to a charge controller that manages the voltage and stops the battery from getting too full.

This setup ensures the system keeps working even on cloudy days or at night and helps it stay running for long periods in remote farms that don't have access to regular electricity. The solar energy is turned into direct current (DC), stored in the battery, and then sent to the microcontroller and sensors through controlled 5V power lines. This method supports green energy efforts in smart farming. Data is sent every 10 seconds, giving nearly real-time updates.

Two main tools are used:

— ThingSpeak: This is the main place where data is stored and analyzed, helping to keep track of past readings and showing them through MATLAB scripts [8];

— Blynk IoT: This gives users a way to check live soil data through a phone app using visual tools like gauges and charts, and also sends alerts [9].

These two platforms are connected, so users can access both live and past data at the same time. The cloud dashboard lets people watch the system from anywhere, log in, and save customized data, supporting better farming practices [10].

The system starts by collecting data from sensors, then processes and sends it. Each sensor sends its readings—either as analog or digital signals—to the microcontroller, which turns them into accurate measurements.

The ESP8266 sends these measurements to ThingSpeak and Blynk servers using Wi-Fi. The

cloud services show this data on dashboards that can be accessed through web browsers or mobile apps. Users can check soil conditions in real time, get alerts, and change watering or fertilizing plans based on what they see [11].

CONCLUSION

This study has demonstrated the successful development and implementation of a smart soil-based monitoring system that integrates IoT connectivity with solar energy. The system provides accurate, real-time measurements of key soil parameters and operates reliably in off-grid environments. Its modular and low-cost design makes it suitable for both smallholder and large-scale agricultural applications. Future work will focus on integrating predictive analytics and automated irrigation control to further enhance system intelligence and autonomy.

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