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Soil2Cloud: Smart Iot Irrigation Monitoring System

Tushar Mote[1], Pankaj Nagane[2], Omkar Pethkar[3], Manav Chawan[4], Vijay Shinde[5]
[1,2,3,4,5]*Department of Computer Science and Engineering, MIT Art, Design and Technology University Pune, India*

***Abstract*—This paper presents Soil2Cloud, a smart IoT-based irrigation monitoring system designed for real-time environmental monitoring and automated irrigation control. Agriculture currently accounts for a vast majority of global freshwater usage, making efficient resource management a critical challenge. The proposed system utilizes a network of sensors—including soil moisture, ambient temperature, humidity, and light intensity—interfaced with an ESP8266 microcontroller to monitor field conditions continuously. Data is transmitted securely to a cloud-based dashboard for real-time visualization and remote control. Furthermore, the system implements an automated irrigation mechanism utilizing a hysteresis-based control algorithm to optimize water usage and prevent mechanical wear on actuators. The proposed solution is highly cost-effective, energy-efficient, and easily deployable, making it highly suitable for small-scale farming, greenhouse management, and academic research applications.**

***Index Terms*—IoT, Smart Agriculture, Irrigation System, ESP8266, Soil Moisture, Automation, Cloud Computing**

I. INTRODUCTION

Agriculture is a critical sector that sustains the global population, yet it relies heavily on efficient resource management, particularly water. Traditional irrigation methods often rely on fixed schedules or manual observation, which frequently leads to either severe water wastage through over-irrigation or diminished crop yields due to under-watering. According to global agricultural reports, precision farming is essential to mitigating the impending global water crisis.

With rapid advancements in the Internet of Things (IoT) and embedded systems, it is now possible to develop smart, autonomous systems that monitor micro-climate conditions and automate irrigation processes. The Soil2Cloud system provides a robust, real-time monitoring solution using low- cost sensor nodes and cloud-based dashboards. By bridging the gap between physical agricultural environments and digital cloud analytics, Soil2Cloud reduces human intervention, lowers operational costs, and ensures optimal water usage through intelligent automation.

II. RELATED WORK

Various IoT-based agriculture systems have been developed over the past decade to monitor soil and environmental conditions. Early systems relied heavily on GSM modules and SMS-based alerts, which provided remote notifications but lacked real-time graphical data visualization. More recent iterations utilize Zigbee or LoRaWAN networks for large-scale agricultural monitoring, but these often involve high setup costs and complex infrastructure, making them inaccessible to small-scale farmers.

Furthermore, many existing Wi-Fi-based solutions implement basic threshold logic (e.g., turning a pump on strictly below a certain value and off immediately above it), which causes rapid relay switching and hardware degradation. This work presents a simplified, cost-effective system that utilizes modern web technologies and implements a hysteresis control loop, making it highly suitable and durable for small-scale applications.

III. SYSTEM ARCHITECTURE

The Soil2Cloud architecture is designed to be highly modular and scalable, divided into three primary layers:

A. Physical Perception Layer (Hardware)

This layer consists of the sensory equipment and the central processing unit located in the field:

- Microcontroller:

The ESP8266 NodeMCU is utilized as the core computing unit due to its 32-bit Ten silica processor and native IEEE 802.11 b/g/n Wi-Fi capabilities.

- Soil Moisture Sensor:

An analog capacitive or resistive sensor that measures the volumetric water content of the soil.

- DHT11 Sensor:

Captures ambient air temperature and relative humidity to help predict evaporation rates.

- LDR Light Sensor:

Monitors sunlight intensity to pre- vent watering during peak evaporation hours (midday).

- Actuator:

A 5V Single-Channel Relay Module connected to a submersible DC water pump for irrigation.

B. Network and Communication Layer

Data collected by the ESP8266 is formatted into JSON payloads. The microcontroller establishes a secure connection to the local Wi-Fi network and transmits this telemetry data to a real-time cloud database (such as Firebase or ThingSpeak) using standard HTTP/REST or MQTT protocols.

C. Application and Cloud Layer

The uppermost layer is a responsive web-based dashboard built using HTML, CSS, and JavaScript. It actively listens to the cloud database for state changes, allowing users to view real-time dynamic gauges of their farm’s health, review historical data, and trigger manual irrigation overrides from any mobile or desktop device.

IV. METHODOLOGY

The operational workflow of the Soil2Cloud system is defined by a continuous monitoring and feedback loop:

1) Data Acquisition:
The ESP8266 polls the DHT11, LDR, and Soil Moisture sensors at predefined intervals (e.g., every 5 seconds).

2) Signal Processing:
Analog signals from the soil and light sensors are mapped to percentage values (0% to 100%).

3) Cloud Synchronization:
Processed data is pushed to the cloud database.

4) Logic Evaluation:
The microcontroller evaluates the current soil moisture against predefined optimal crop thresholds.

5) Actuation:
If the logic conditions are met, the ESP8266 sends a digital HIGH/LOW signal to the relay to control the water pump. Simultaneously, the pump’s operational status is updated on the web dashboard.

V. MATHEMATICAL MODEL AND CONTROL LOGIC

To prevent the “chattering” effect—where the water pump rapidly turns on and off when the moisture level hovers exactly at the threshold point—a hysteresis control model is implemented.

Let $M(t)$ be the soil moisture percentage at time t, and let $P(t)$ be the binary state of the water pump, where 1 denotes ON and 0 denotes OFF.

$$P(t) = \begin{cases} 1 & \text{if } M(t) \le 30\% \\ 0 & \text{if } M(t) \ge 60\% \end{cases}$$

$$P(t - \Delta t) \quad ,$$

Otherwise, this equation ensures that once the soil dries to below 30%, the pump turns on and *remains* on until the moisture reaches a fully saturated state of 60%. If the moisture is between 30% and 60%, the pump maintains its previous state ($P(t - \Delta t)$). Additionally, total water consumption W over a specific period can be estimated if the pump’s flow rate R (in liters per minute) is known:

$$W = R \times \sum_{i=1}^{n} (P(t_i) \cdot \Delta t)$$

VI. IMPLEMENTATION AND RESULTS

The physical prototype of the system was successfully assembled using a breadboard, jumper wires, and a 5V power supply. The software backend was integrated with a real-time NoSQL database to ensure low-latency data transfer.

During the testing phase over a 48-hour period, the system exhibited the following key performance indicators:

- Latency:

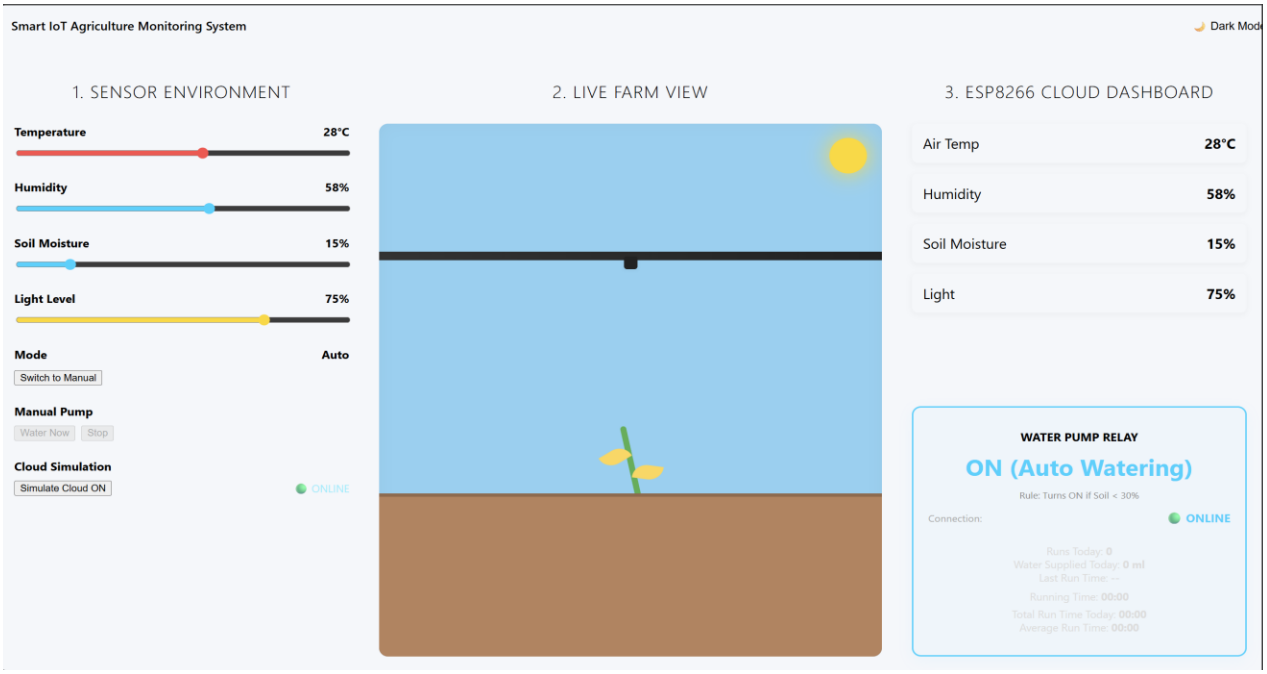
Data updates from the physical sensor to the mobile dashboard occurred in under 1.5 seconds.

- Automated Irrigation:

The hysteresis logic successfully engaged the pump only, when necessary, drastically reducing the total operational time of the pump compared to timer-based systems.

- User Interface:

The mobile-responsive dashboard accurately displayed live pump status, current moisture percentages, temperature, and allowed seamless switching between “Auto” and “Manual” modes



Temperature 28°C

Humidity 58%

Soil Moisture 15%

Light Level 75%

Mode Auto

Manual Pump

Cloud Simulation ONLINE

Air Temp 28°C

Humidity 58%

Soil Moisture 15%

Light 75%

WATER PUMP RELAY

ON (Auto Watering)

Rule: Turns ON if Soil < 30%

Connection: ONLINE

Runs Today: 0
Water Supplied Today: 0 ml
Last Run Time: --

Running Time: 00:00

Total Run Time Today: 00:00
Average Run Time: 00:00

Figure 1: Dashboard of System

As shown in figure 1 user can toggle automatic implementation as well as manual monitoring, the system monitors real-time water supply quantity, running time, and total runs a day

VII. ADVANTAGES

- Water Conservation: Irrigates purely based on plant need, entirely eliminating water waste.
- Hardware Longevity: The dual-threshold mathematical logic prevents relay burnout.
- Cost-Effective: Utilizes open-source software and inexpensive, readily available hardware.
- Accessibility: Cloud integration allows farmers to monitor their crops from anywhere globally.

VIII. APPLICATIONS

- Precision Agriculture: For small to medium-sized commercial crop fields.
- Greenhouse Management: Regulating delicate micro- climates for exotic plants.
- Urban Farming: Automated care for rooftop gardens and community plots.
- Academic Environments: Serving as a foundational platform for IoT and agricultural research.

IX. FUTURE SCOPE

While the current system performs reliably, future iterations can be enhanced through several advanced integrations:

- Machine Learning Integration: Implementing predictive algorithms that analyze historical temperature and humidity data to forecast soil drying rates before they happen.
- Weather API Integration: Preventing automated watering if local internet weather forecasts predict heavy rainfall within the next 24 hours.
- Expanded Sensor Nodes: Transitioning from a single ESP8266 to a multi-node Mesh Network to cover larger geographic farming areas.
- Renewable Energy: Powering the hardware nodes using small solar panels and Li-ion battery management systems for true off-grid autonomy.

X. CONCLUSION

The Soil2Cloud project demonstrates a highly effective, accessible, and reliable IoT-based irrigation solution. By shifting away from traditional guesswork and manual labor, it pro- vides real-time monitoring and intelligent, data-driven control. The implementation of hysteresis logic specifically improves the mechanical lifespan of the system while reducing water wastage. Ultimately, this system serves as a highly adaptable framework suitable for both academic research and practical, real-world deployment in the pursuit of sustainable agriculture.

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