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Prototype of an IoT-Based Automatic Plant Watering System Using a Soil Moisture Sensor at Smart Farm Academy in Tapos Village, Tigaraksa

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Abstract. At Smart Farm Academy in Tapos Village, operators decided when to water plants by inspecting the soil. This study developed a prototype that uses a resistive soil moisture sensor and an ESP32-WROOM to control a pump and report its status remotely. We evaluated the decision rule against 77 moisture records dated 20–30 September 2026, examined simulated pump and monitoring scenarios, and analyzed a questionnaire completed by one site operator. On the percentage scale used in the evaluation, readings below 30% called for watering. All 17 readings below this threshold were labeled ON, and all 60 readings at or above it were labeled OFF. In the 12-case pump simulation, both ON commands and all ten OFF commands matched the expected states. Ten tabulated state transitions had a mean response interval of 2.8 s. The operator rated the prototype 45 out of 50. The results show that the simulated controller applied the specified threshold consistently. Field measurements of soil water content, pump discharge, and water use are still needed to establish irrigation performance.

Keywords: *Automatic Irrigation, Soil Moisture Sensor, ESP32-WROOM, Internet of Things, Pump Control.*

A. INTRODUCTION

At Smart Farm Academy in Tapos Village, Tigaraksa, the decision to water depended on an operator's visual assessment. A dry-looking surface could prompt irrigation even when the soil around the probe remained moist. Conversely, a scheduled visit could occur too late to identify a dry interval. The practical requirement was a repeatable decision at the point of measurement and a way for the operator to see whether the controller had requested water.

A resistive soil moisture probe offers a way to make that decision explicit. The probe responds to the electrical properties of the soil, so interpreting its output as water content requires calibration for the soil in which it is used (Adla et al., 2020). For the prototype at Tapos, the immediate question was how to act on a reading. A threshold on the sensor scale allowed the operator to inspect the point at which the controller would request water, even though the corresponding moisture requirement of a particular crop had yet to be established.

The operator also needed to interpret the pump status between visits. An idle pump, viewed on its own, gives little indication of whether the controller has responded as intended. When the display pairs the pump status with the soil reading, the operator can check whether the controller calls for water under dry conditions and withholds it when the soil is already moist. This pairing also makes it possible to trace an unexpected command back to the reading that prompted it.

Agricultural automation can move routine decisions from a fixed schedule to a response to local conditions (Food and Agriculture Organization of the United Nations [FAO], 2022). In irrigation, the distinction between a pump command and water actually delivered matters. Gutiérrez et al. (2014), for example, evaluated a networked irrigation system over a field season and compared water consumption. A short controller test can answer a narrower question: does a given sensor input produce the intended command?

We addressed that question with an ESP32-based prototype at the academy. The evaluation examined three outcomes: agreement between moisture categories and pump

commands, the interval between a recorded change in soil condition and a change in pump state, and the operator's assessment of the system. The study covered a single site and did not distinguish among crop species.

B. METHOD

1. Prototype Development

We used an engineering research and development approach. Observation and interviews established how the operator assessed soil conditions and initiated watering. The prototype followed five stages: requirements analysis, system design, prototype construction, testing, and refinement. The design separated sensing, local control, and remote monitoring so that each function could be evaluated independently.

Table 1. Application of the Prototyping Method to the Watering System

Stage	Work Undertaken or Specified
Requirements analysis	Identify when the operator needs to see soil moisture and pump status.
Design	Define the sensor input, decision thresholds, relay output, and monitoring data.
Prototype construction	Integrate the probe, controller, pump relay, and monitoring interface.
Testing	Exercise the ON and OFF branches and examine detection-to-command intervals.
Refinement	Review unstable readings, sensor placement, and network interruptions.

2. Sensing, Actuation, and Monitoring

The proposed device uses a two-prong resistive probe and an interface board to supply an analog signal to the ESP32-WROOM (Figure 1). The controller classifies the signal and sends a digital command to a relay that switches the water pump. The remote interface is designed to display moisture and pump status over Wi-Fi. The operator can therefore inspect both the input to the decision and its output.

(a) Resistive probe and interface (b) ESP32 development board



Figure 1. Soil Moisture Sensor and ESP32 Board Illustrated in the System Design

The design and the evaluation describe soil moisture on two scales. In the firmware design, a higher analog-to-digital converter (ADC) count indicates drier soil. The specified bands were 570–1399 for wet soil, 1400–2524 for moist soil, and 2525–4095 for dry soil. Figure 2 shows the corresponding pump decision. The design did not assign a soil class to counts below 570. The percentage-based evaluation used the thresholds in Table 2.

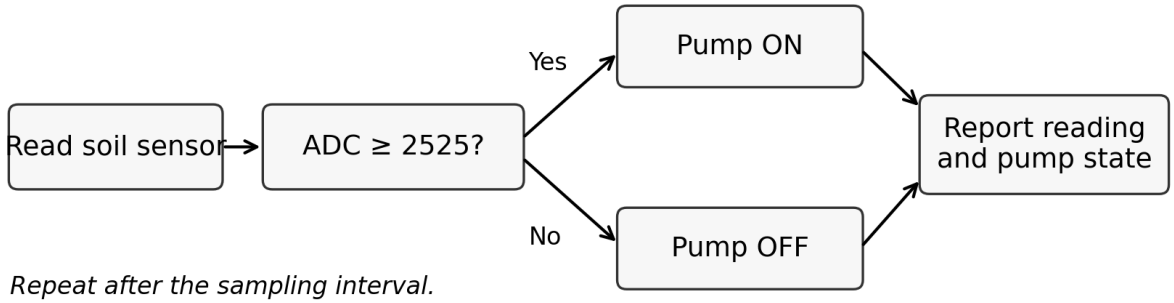


Figure 2. Pump Decision in the ADC-Based Design, Adapted from the Prototype Flowchart

Table 2. Soil Classification and Pump Command on the Two Reporting Scales

Soil Class	Design Input (ADC Counts)	Evaluation Input (%)	Pump Command
Dry	2525–4095	Below 30	ON
Moist	1400–2524	30 through 60	OFF
Wet	570–1399	Above 60	OFF

The ADC and percentage columns describe the intended behavior on each scale. The evaluation records do not pair a raw ADC count with each percentage. We therefore used the reported percentages directly and did not convert them into volumetric water content. Independent calibration is important for resistive probes because their response can vary with the soil and its electrical properties (Adla et al., 2020).

3. Evaluation procedure

The moisture series contains seven entries per day at two-hour intervals from 06:00 to 18:00 Western Indonesian Time on 20–30 September 2026. For each entry, we compared the recorded pump label with the output of the percentage rule. We also examined 12 pump-control simulation cases, ten time-stamped transitions, the monitoring scenarios, and the black-box and white-box evaluations. The 12 pump cases reproduce the first 12 moisture entries and were analyzed as a subset.

For each timed transition, we subtracted the time of detection from the recorded time of the pump-state change. For user acceptance, one academy operator rated ten statements on a five-point scale. We divided the sum of the ratings by the maximum possible score of 50. The simulation, timing table, and questionnaire answer different questions and were evaluated separately.

C. RESULT AND DISCUSSION

1. Moisture categories and pump decisions

The 77 moisture entries ranged from 22.3% to 71.5%. Seventeen fell below the watering threshold, 40 fell in the moist band, and 20 fell in the wet band (Table 3). All 17 dry entries carried an ON label. All 60 moist or wet entries carried an OFF label. The closest recorded values on either side of the switching point were 29.5% and 30.4%, so the series did not exercise the exact 30.0% boundary.

Table 3. Moisture Values and Recorded Pump Decisions, 20–30 September 2026

Class	Entries	Range (%)	Mean (%)	ON / OFF
Dry	17	22.3–29.5	26.24	17 / 0
Moist	40	30.4–59.7	47.70	0 / 40
Wet	20	60.4–71.5	64.74	0 / 20

On 20 September, the sequence illustrates how the rule operates. At 08:00 the entry was 46.4% and the pump label was OFF. At 10:00 the value fell to 29.1% and the label changed to ON. By 12:00 the recorded value was 66.2% and the label was OFF again. These two-hourly entries identify the state at each sampling time. Pump runtime and the volume delivered between entries cannot be reconstructed from them.

2. Functional tests and response intervals

All 12 cases in the pump-control simulation matched their expected outcomes. Only two cases required an ON command. The remaining ten tested the OFF branch under moist or wet conditions. Table 4 separates these cases from the monitoring and software checks, several of which exercise the same input conditions.

Table 4. Scope and Outcome of the Simulated Functional Checks

Evaluation	Coverage	Reported Outcome
Pump control	12 moisture inputs	2 ON and 10 OFF commands matched the expected state.
IoT monitoring	5 scenarios	Wi-Fi connection, reading updates, ON and OFF display, and handling of disconnection were reported as expected.
Black-box tests	12 scenarios	Covered startup, moisture transitions, repeated readings, dashboard access, and network interruption. Reconnection depended on the configured feature.
White-box checks	6 program paths or operations	Covered sensor acquisition, dry and moist/wet branches, relay output, monitoring updates, and repetition. The monitoring-update result was conditional on IoT implementation.

The timing table lists five moist-to-dry transitions and five dry-to-wet transitions. Four intervals were 2 s, four were 3 s, and two were 4 s. Their sum was 28 s, giving a mean of 2.8 s (Table 5). The start and end events represent detection and a pump-state change. They do not measure the time for water to reach the root zone.

Table 5. Tabulated Intervals Between Detection and Pump-State Change

Transition	Events	Intervals (s), in Recorded Order	Mean (s)
Moist to dry	5	2, 2, 3, 3, 4	2.8
Dry to wet	5	3, 4, 2, 2, 3	2.8
All transitions	10	Range 2–4	2.8

3. Operator assessment

The site operator awarded five ratings of 5 and five ratings of 4 (Table 6), for a total of 45/50. The highest ratings concerned ease of use, the display and interpretation of readings, and activation of watering under dry conditions. The operator rated remote monitoring and visibility of pump status at 4/5. These scores describe one operator's experience at the study site.

Table 6. User Acceptance Ratings From the Smart Farm Academy Operator

Item	Aspect Rated	Score (1–5)
UAT-01	Ease of understanding and using the system	5
UAT-02	Clarity of the displayed soil moisture information	5
UAT-03	Ease of interpreting the moisture value	5
UAT-04	Ability to distinguish dry, moist, and wet soil	4
UAT-05	Suitability of automatic watering for the moisture condition	5
UAT-06	Automatic pump activation when soil is dry	5
UAT-07	Remote access to moisture information	4
UAT-08	Visibility of pump status in the monitoring interface	4
UAT-09	Support for monitoring moisture and irrigation	4
UAT-10	Overall usefulness for watering at Smart Farm Academy	4

4. Interpretation and Limitations

Within the supplied series, the controller decision can be reproduced from the percentage alone. The 60% boundary distinguishes two soil labels but has no effect on the pump: both moist and wet soil produce an OFF command. The consequential boundary is 30%. Testing exactly 30.0% and repeatedly crossing that value would establish whether the implemented controller switches as specified when readings fluctuate near the threshold.

The available evidence concerns control logic and a single operator's assessment. Repeated agreement between simulated inputs and expected outputs cannot establish probe accuracy, physical relay response, or water savings. These outcomes require different measurements: paired probe and reference moisture readings, observation of pump operation alongside the command log, and a comparison of delivered water under manual and automatic irrigation. A crop-specific evaluation would also be needed before treating 30% as an agronomic target.

D. CONCLUSION

The ESP32-WROOM prototype links soil moisture sensing to a local pump decision and remote status reporting. All 77 tabulated entries followed the specified 30% switching rule, and all 12 simulated pump cases produced the expected command. The ten reported transition intervals averaged 2.8 s. One operator rated the system 45/50. These results support the use of the rule in the prototype and identify the next field tests needed to evaluate actual water delivery.

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