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Smart Irrigation Using Arduino UNO R4 WiFi in Surman, Libya

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Abstract

This study presents the design, site-specific calibration, and functional verification of a prototype smart irrigation system using soil collected from an agricultural site in Surman, Libya. The Arduino UNO R4 WiFi controller integrates an FC-28 resistive soil-moisture sensor, DHT22, rain sensor, relay, 16×2 I²C LCD, and DC water pump. A two-point calibration used 850 ADC as the dry reference and 300 ADC as the wet/saturated reference, mapped to a 0–100% relative moisture index. Hysteresis control starts irrigation below 30% and stops it at 40%, while rain detection overrides the dry-soil request. Verification included four repeated no-rain cycles, one simulated-rain override test, and ten stability readings at 2-s intervals. The no-rain cycles produced mean start and stop indices of $28.25 \pm 0.57\%$ and $40.65 \pm 0.57\%$, with a mean pump runtime of 45.0 ± 2.58 s and one ON/OFF cycle per trial. Sensor stability averaged 627.7 ± 0.95 ADC ($40.42 \pm 0.15\%$). The results verify short-term repeatability of the locally calibrated hysteresis logic and support future IoT-connected extensions.

Keywords: Smart irrigation; Arduino UNO R4 WiFi; Relative soil-moisture index; Rain sensor; Hysteresis control; Precision agriculture.

نظام ري ذكي باستخدام Arduino UNO R4 WiFi

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الملخص

تقدم هذه الدراسة تصميمًا ومعايرةً موضوعيةً وتحققًا وظيفيًا لنموذج أولي لنظام ري ذكي، باستخدام تربة جُمعت من موقع زراعي بمدينة صرمان، ليبيا. يعتمد النظام على لوحة Arduino UNO R4 WiFi كوحدة تحكم رئيسية، ويتكامل معها مستشعر رطوبة التربة المقاومي FC-28، ومستشعر DHT22 لقياس درجة الحرارة والرطوبة الجوية، ومستشعر المطر، ووحدة مرحل كهربائي، وشاشة LCD 16×2 بواجهة I²C، إضافة إلى مضخة مياه تعمل بالتيار المستمر.

أُجريت معايرة ثنائية النقاط لمستشعر رطوبة التربة، حيث اعتمدت قراءة ADC 850 مرجعًا للحالة الجافة، وقراءة ADC 300 مرجعًا للحالة الرطبة/المشبعة، ثم حُولت القراءات إلى مؤشر نسبي لرطوبة التربة يتراوح بين 0 و100%. ويعتمد النظام على استراتيجية تحكم بنطاق التباطؤ (Hysteresis Control)، بحيث يبدأ الري عند انخفاض مؤشر الرطوبة عن 30%، ويتوقف عند وصوله إلى 40%، مع إعطاء أولوية لمستشعر المطر لإيقاف عملية الري عند اكتشاف وجود الماء على سطح الحساس.

شمل التحقق التجريبي أربع دورات ري متكررة في ظروف عدم وجود المطر، واختبارًا مستقلًا لمحاكاة المطر للتحقق من أولوية الإيقاف، بالإضافة إلى عشر قراءات متتالية لتقييم استقرار الحساس بفاصل زمني قدره ثانيتان. أظهرت دورات الاختبار دون مطر أن متوسط مؤشر بدء الري بلغ $28.25 \pm 0.57\%$ ، بينما بلغ متوسط مؤشر التوقف $40.65 \pm 0.57\%$. كما بلغ متوسط زمن تشغيل المضخة 2.58 ± 45.0 ثانية، مع تسجيل دورة تشغيل/إيقاف واحدة في كل اختبار. أما اختبار استقرار الحساس، فقد أظهر متوسط

قراءة قدره 627.7 ± 0.95 ADC، بما يعادل مؤشر رطوبة نسبياً قدره $40.42 \pm 0.15\%$.

وتؤكد النتائج قابلية تكرار منطق التحكم المعتمد على المعايير الموضوعية ونطاق التباطؤ على المدى القصير، كما تدعم إمكانية تطوير النظام مستقبلاً وربطه بتطبيقات إنترنت الأشياء (IoT) ومنصات المراقبة المتصلة.

الكلمات المفتاحية: الري الذكي؛ Arduino UNO R4 WiFi؛ مؤشر رطوبة التربة النسبي؛ مستشعر المطر؛ التحكم بنطاق التباطؤ (Hysteresis Control)؛ الزراعة الدقيقة.

1. Introduction

At the agricultural site in Surman considered in this study, irrigation was not guided by continuous soil-moisture feedback. This provided the practical motivation for testing a controller that could make irrigation decisions from a local sensor reading rather than from time alone. Soil-moisture sensing, weather inputs, and automatic actuators are widely used in smart-irrigation systems, while recent reviews emphasize that reliable sensing and local calibration are as important as connectivity for practical deployment (García et al., 2020; Vallejo-Gómez et al., 2023; Dutta et al., 2026).

Soil moisture sensing is particularly useful because it provides direct information about changes in the root-zone environment and can support threshold-based automatic irrigation. In olive production, automated irrigation scheduling supported by soil-moisture measurements has been shown to be technically feasible and useful for reducing dependence on continuous human intervention (Millán et al., 2020). Earlier IoT-oriented systems likewise demonstrated the feasibility of combining sensors, communication, and pump or valve control for automated irrigation management (Khelifa et al., 2015; Saraf and Gawali, 2017).

However, transferring a sensor-based irrigation design from one site to another requires attention to local sensor response and calibration. Low-cost resistive sensors produce raw analog values whose interpretation depends on installation conditions, soil contact, and the selected calibration range. For this reason, the present study focuses on a simple local closed-loop system whose

control thresholds are derived from a site-specific two-point empirical calibration using soil obtained from the Surman agricultural site rather than from generic unverified thresholds.

The objective of this work is to design and verify an Arduino UNO R4 WiFi-based smart irrigation prototype that: (1) monitors a calibrated relative soil-moisture index, ambient temperature, and relative humidity; (2) detects wetting of the rain-sensor plate as a rainfall proxy; (3) automatically starts irrigation when the calibrated soil-moisture index is below 30% in the absence of rain; (4) maintains irrigation until the index reaches 40%; and (5) prevents irrigation when rain is detected. The current study evaluates local autonomous control and sensor calibration. Cloud analytics, predictive weather integration, and quantified water-saving percentages are not claimed as experimental outcomes in this paper.

2. Related Work

García et al. (2020) reviewed IoT-based smart irrigation systems and highlighted the widespread use of soil, water, and weather sensors together with wireless communication and low-cost nodes. Their review showed that soil moisture sensing is a central component of irrigation automation and that low-cost hardware can improve accessibility for smaller agricultural users.

Saraf and Gawali (2017) presented an IoT-based smart irrigation monitoring and controlling system using real-time field inputs and remote communication. Khelifa et al. (2015) also investigated smart irrigation for water-limited agricultural environments in Algeria, illustrating the relevance of automated irrigation to North African conditions. These studies support the broader concept of integrating sensing and automatic actuation, but they do not remove the need for local calibration of the sensing element used at a specific site.

For olive orchards, Millán et al. (2020) demonstrated automatic irrigation scheduling using soil-moisture information within a more advanced decision-support framework. Recent reviews also identify interoperability, field verification, cost, scalability, and context-specific design as continuing challenges in smart-irrigation deployment (Vallejo-Gómez et al., 2023; Dutta et al., 2026). The present work does not attempt to reproduce those more complex

architectures. Instead, it addresses a narrower implementation question: whether a simple controller, calibrated with soil from the intended agricultural site, can follow the required irrigation start, stop, and rain-inhibition rules before cloud or predictive functions are added. Table 1 summarizes the main differences between representative prior studies and the present prototype.

Table 1. Comparison of representative smart-irrigation studies and the present work.

Study	Approach / focus	Control / connectivity	Relevance to present work
Khelifa et al. (2015)	Smart irrigation in a water-limited North African context	Sensor-based irrigation with IoT-oriented control	Regional relevance; supports automated irrigation under water constraints.
Saraf and Gawali (2017)	Real-time smart-irrigation monitoring and control	Field sensing with remote communication	Demonstrates remote monitoring; present work emphasizes local calibrated control first.
García et al. (2020)	Review of IoT-based smart irrigation	Soil/water/weather sensing and wireless nodes	Establishes soil-moisture sensing as a core component of irrigation automation.
Millán et al. (2020)	Automatic irrigation scheduling in an olive orchard	Soil-moisture sensing within an advanced scheduling framework	Shows crop-specific scheduling; present work uses simpler threshold control.
Anoop and Bala (2024)	IoT and machine-learning automatic irrigation	IoT sensing combined with ML-based decision support	Represents a more data-driven architecture than the present local controller.
Present study	Site-specific FC-28 calibration with rain-priority hysteresis control	Local autonomous control; Wi-Fi reserved for future extension	Focuses on low-complexity calibration and verified start/stop/rain-inhibition logic.

3. Materials and Methods

3.1 Study Area and Experimental Context

The experimental work used soil collected from a private agricultural site in Surman, western Libya. No laboratory particle-size analysis was performed; therefore, this study does not assign a laboratory-verified textural class to the soil. The prototype was developed as a small-scale smart irrigation controller intended to represent the sensing and actuation logic required for automated irrigation in a local farm environment. The experimental objective was functional verification of the control algorithm rather than long-term agronomic yield assessment.

3.2 Hardware Architecture

The main controller was an Arduino UNO R4 WiFi. According to the official Arduino documentation, the board uses a 32-bit Renesas RA4M1 microcontroller and includes an ESP32-S3 module for wireless connectivity together with an integrated 12×8 LED matrix (Arduino, 2026). In the present experiment, the Wi-Fi capability was not used to claim cloud-based control; the verified control loop operated locally on the Arduino board.

The sensing, display, and actuation components were an FC-28 resistive soil-moisture sensor, a DHT22 sensor for ambient temperature and relative humidity, a digital rain sensor, a 16×2 LCD equipped with an I²C backpack for local real-time visualization, a 5 V two-channel relay module (one channel used), and a DC water pump. The soil sensor was connected to A0, DHT22 data to D2, rain-sensor digital output to D3, and relay control input to D4. The LCD used the board's SDA and SCL lines. The pump was supplied separately and switched through the relay contacts so that motor current did not pass through an Arduino I/O pin. The analog input was operated at the Arduino default 10-bit ADC resolution, yielding digital values from 0 to 1023. Table 2 lists the hardware components and Arduino pin mapping; Figures 1 and 2 show the wiring diagram and bench-top experimental prototype, respectively.

Table 2. Hardware components and Arduino pin mapping.

Component	Function	Arduino Pin	Signal Type
FC-28 Soil Moisture Sensor	Relative soil-moisture sensing	A0	Analog input
DHT22	Air temperature and relative humidity	D2	Digital data
Rain Sensor	Rain/wetting detection	D3	Digital input
5 V Relay Module	Pump switching	D4	Digital output
DC Water Pump	Irrigation actuator	Via relay	Switched load
16×2 I ² C LCD	Local display of measured variables and system status	SDA, SCL	I ² C interface

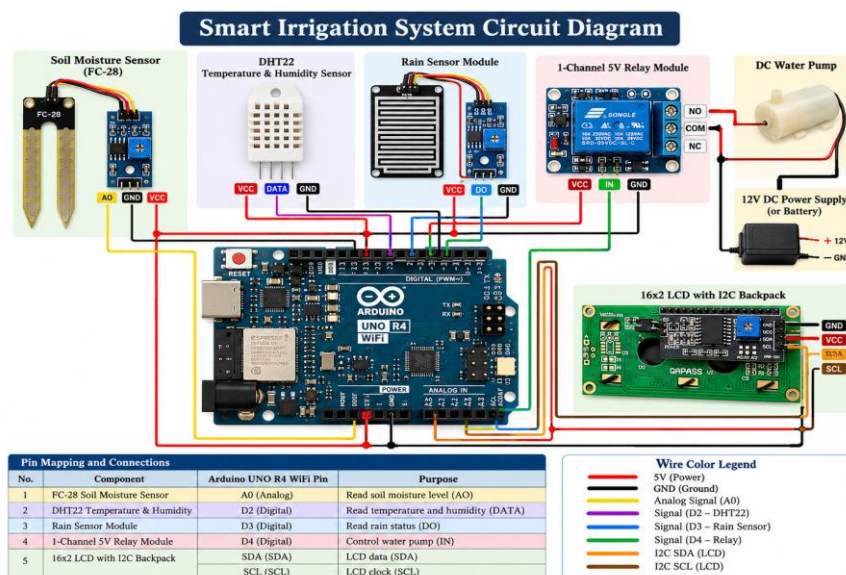


Figure 1. Wiring diagram of the proposed smart irrigation prototype. One relay channel is shown because only one channel of the two-channel module was used for pump control.

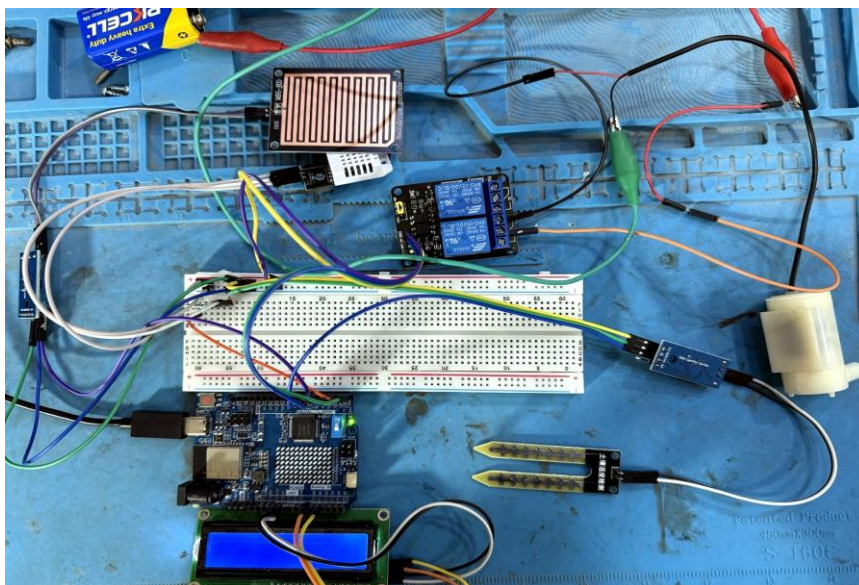


Figure 2. Bench-top experimental prototype integrating the Arduino UNO R4 WiFi, DHT22, FC-28 soil-moisture sensor, rain sensor, 16×2 I²C LCD, relay module (one channel used), and DC water pump.

3.3 Soil-Moisture Sensor Calibration

The FC-28 soil-moisture sensor was calibrated using two empirical reference states established with soil collected from the Surman agricultural site: a dry reference of 850 ADC counts and a wet/saturated reference of 300 ADC counts. Because the FC-28 was not calibrated against gravimetric or volumetric water-content measurements, the resulting 0–100% scale is reported as a calibrated relative soil-moisture index rather than as volumetric water content. The index *M* was calculated using a linear mapping between the two reference values:

$$M (\%) = [(ADC_{dry} - ADC_{current}) / (ADC_{dry} - ADC_{wet})] \times 100$$

Using $ADC_{dry} = 850$ and $ADC_{wet} = 300$, the 30% start threshold corresponds to approximately 685 ADC counts, while the 40% stop threshold corresponds to approximately 630 ADC counts. Values outside the calibrated range were constrained to 0–100%.

These thresholds were subsequently used in the autonomous irrigation logic. Table 3 summarizes the site-specific calibration and control parameters.

Table 3. Site-specific two-point FC-28 calibration and control parameters.

Relative Moisture Index	Empirical ADC Value	System Action
0% (dry reference)	850	Pump may start if no rain and index <30%
30% (start threshold)	685	Start irrigation if pump is OFF and no rain
40% (stop threshold)	630	Stop irrigation if pump is ON
100% (wet/saturated reference)	300	Pump OFF

3.4 Control Algorithm

The proposed controller employs a hysteresis-based irrigation strategy. Rain detection has the highest control priority: whenever wetting is detected on the rain-sensor plate, the pump is forced OFF regardless of the relative soil-moisture index. In the absence of rain, irrigation starts when the calibrated index falls below 30%. Once started, the pump remains ON while the index rises through the 30–40% hysteresis band and stops only when the index reaches 40%. If the pump is already OFF while the index lies between 30% and 40%, it remains OFF. Using separate start and stop thresholds reduces rapid relay switching around a single threshold and provides more stable pump operation.

The DHT22 measurements are used for environmental monitoring rather than direct irrigation control. Current temperature, relative humidity, relative soil-moisture index, rain-sensor state, and pump status are presented locally on the 16×2 I²C LCD, while the built-in LED matrix provides an additional visual indication of system state. Figure 3 illustrates the implemented hysteresis-based irrigation control algorithm.

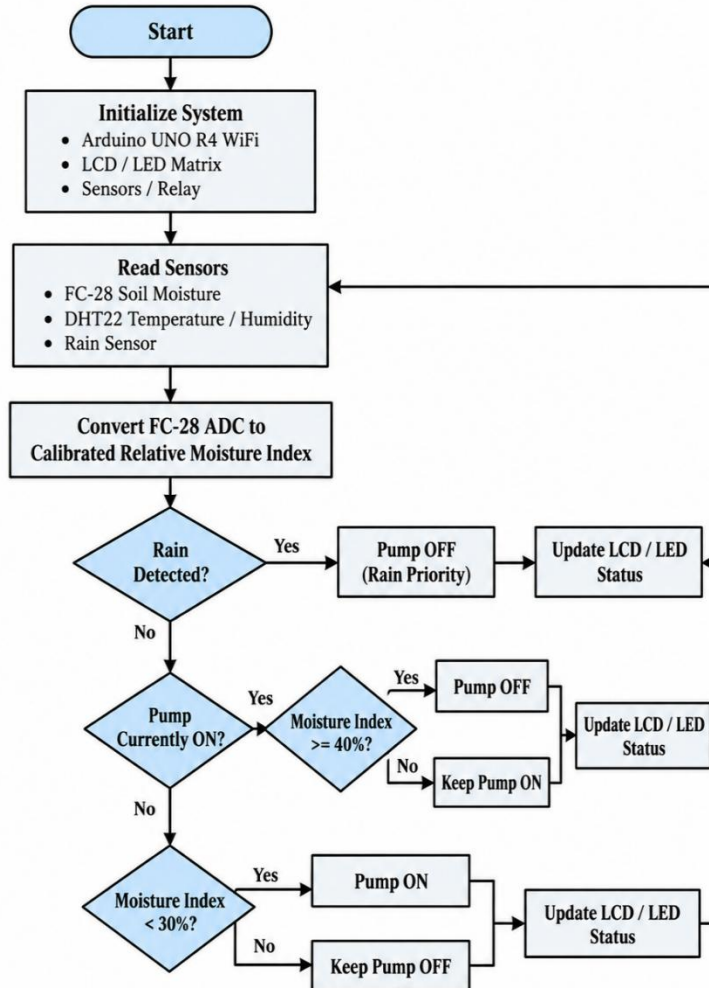


Figure 3. Flowchart of the hysteresis-based irrigation control algorithm implemented in the proposed system.

3.5 Software Implementation

The firmware was developed in the Arduino environment using the DHT, Wire, LiquidCrystal_I2C, and Arduino_LED_Matrix libraries. The program reads the DHT22, FC-28, and rain sensor at two-second intervals, converts the calibrated FC-28 ADC reading to a relative moisture index, applies the rain-priority hysteresis decision logic, controls the relay, and updates the local LCD and

LED matrix. The reference pin mapping is A0 (soil), D2 (DHT22), D3 (rain), and D4 (relay), with SDA/SCL used for the I²C LCD.

3.6 Functional Verification Procedure

Experimental verification was conducted on 30 September 2026 at an ambient temperature of 28.5 °C and relative humidity of 42%, using a 2-s sampling interval. The protocol comprised four repeated threshold-controlled irrigation cycles under no-rain conditions, one separate simulated-rain priority test, and a sensor-stability test. In each no-rain cycle, the start ADC value, start relative moisture index, stop ADC value, stop relative moisture index, pump runtime, and number of ON/OFF cycles were recorded. For the rain-priority test, the rain-sensor plate was deliberately wetted while the relative moisture index was below the 30% start threshold to verify that rain detection inhibited pumping. Sensor stability was evaluated from ten consecutive ADC readings recorded at 2-s intervals under a stable post-irrigation condition.

3.7 Statistical Analysis

Descriptive statistics were used because the experiment was intended as functional verification rather than a large-sample agronomic trial. Arithmetic means, sample standard deviations (SD; $n-1$ denominator), minima, and maxima were calculated for the repeated no-rain cycles and for the sensor-stability readings. The simulated-rain trial was evaluated separately as a categorical control-priority test because the rain intervention changes the pump-termination condition and is therefore not statistically comparable with the no-rain threshold cycles.

4. Results and Discussion

The site-specific FC-28 calibration produced a dry reference of 850 ADC counts and a wet/saturated reference of 300 ADC counts. Linear normalization of this interval produced control points of approximately 685 ADC at a 30% relative moisture index and 630 ADC at a 40% relative moisture index. These values were implemented as the start and stop thresholds, respectively, establishing a 10-percentage-point hysteresis interval between pump activation and deactivation.

Four repeated no-rain irrigation cycles showed consistent threshold behavior. The mean start ADC value was 694.5 ± 3.11 , corresponding to a mean calibrated relative moisture index of $28.25 \pm 0.57\%$. The mean stop ADC value was 626.5 ± 3.11 , corresponding to $40.65 \pm 0.57\%$. Mean pump runtime was 45.0 ± 2.58 s, and exactly one ON/OFF cycle was observed in each trial, indicating that the 30–40% hysteresis band prevented relay chattering during the repeated tests. Table 4 summarizes the repeated no-rain pump-cycle results and descriptive statistics.

Table 4. Repeated no-rain pump-cycle results and descriptive statistics.

Trial	Start ADC	Start M (%)	Stop ADC	Stop M (%)	Run (s)	Cycles
1	696	28.0	625	40.9	46	1
2	691	28.9	628	40.4	44	1
3	698	27.6	623	41.3	48	1
4	693	28.5	630	40.0	42	1
Mean ± SD	694.5 ± 3.11	28.25 ± 0.57	626.5 ± 3.11	40.65 ± 0.57	45.0 ± 2.58	1.0 ± 0.0

The sensor-stability test also showed limited variation. Across ten consecutive readings, the FC-28 output averaged 627.7 ± 0.95 ADC counts, equivalent to a calibrated relative moisture index of $40.42 \pm 0.15\%$. The ADC range was 626–629, and no abrupt spikes were recorded during the 20-s observation window. Table 5 summarizes the sensor-stability statistics from the ten consecutive readings.

Table 5. Sensor-stability summary from ten consecutive readings at 2-s intervals.

Metric	n	Mean	SD	Min	Max
ADC reading	10	627.7	0.95	626	629
Relative moisture index (%)	10	40.42	0.15	40.2	40.7

In the separate rain-priority test, the relative moisture index was below the 30% irrigation-start threshold when the rain-sensor plate was wetted. The controller forced the pump OFF upon rain

detection, confirming that the rain input overrides the dry-soil irrigation request. This test was analyzed separately from the no-rain repetition statistics. Table 6 summarizes the functional verification results for the tested control conditions.

Table 6. Functional verification of the irrigation control logic.

Condition	Moisture index	Rain state	Pump response	Result
Dry condition, no rain	<30%	Dry / no rain	Pump started and continued until 40%, then stopped	Passed
Dry condition, simulated rain	<30%	Wetted / rain detected	Pump forced OFF upon simulated rain detection	Passed
Stop-threshold condition	$\geq 40\%$	Not applicable	Pump remained OFF / stopped	Passed

The repeated measurements strengthen the functional evidence beyond a simple pass/fail description. Across four no-rain cycles, the pump consistently started below 30% and stopped at approximately 40%, with a mean runtime of 45.0 ± 2.58 s and one ON/OFF cycle in every trial. The ten-reading stability test showed only small variation (627.7 ± 0.95 ADC; $40.42 \pm 0.15\%$), supporting short-term repeatability of the sensing signal under the tested condition. In the separate rain-priority test, wetting the rain-sensor plate overrode the dry-soil request and forced the pump OFF. Compared with repetitive flood irrigation, this demand-based logic is intended to avoid unnecessary irrigation events; however, water savings were not measured volumetrically in this experiment.

The prototype should therefore be interpreted as a functionally verified local autonomous irrigation controller rather than a fully quantified water-saving platform. A calibrated flow meter was not included, so no numerical water-saving percentage is claimed. Future controlled comparisons with conventional flood irrigation should measure delivered water volume, pump runtime, and energy consumption over repeated irrigation cycles.

The main result of the experiment is therefore functional rather than agronomic. The controller responded correctly to the tested soil-moisture and rain-sensor states without requiring cloud services or external decision-support software. This is consistent with studies that identify soil-moisture sensing and automatic actuation as core elements of smart irrigation (García et al., 2020; Anoop and Bala, 2024). More advanced systems can add remote sensing, mapping, or decision-support functions (Millán et al., 2020), but those functions were outside the scope of the present prototype.

5. Limitations

The present work has several limitations. First, the repeated experiment was limited to four no-rain pump cycles, one simulated-rain override test, and a short ten-reading stability sequence; these data support functional repeatability but do not replace long-term field or seasonal trials. Second, the study did not include a calibrated flow meter; therefore, volumetric water savings relative to conventional flood irrigation were not quantified and are discussed only qualitatively. Third, the FC-28 is a low-cost resistive sensor whose long-term response can be affected by corrosion, salinity, and soil contact conditions. Fourth, the 0–100% moisture scale is a normalized relative index derived from two empirical ADC reference points and should not be interpreted as volumetric water content. Finally, additional field trials over multiple irrigation cycles and crop-growth stages are required before making broader agronomic or economic claims.

6. Conclusion and Future Work

The prototype successfully implemented the control sequence tested in this study using soil obtained from an agricultural site in Surman, Libya. In four repeated no-rain cycles, irrigation started at a mean calibrated relative moisture index of $28.25 \pm 0.57\%$ and stopped at $40.65 \pm 0.57\%$, with a mean pump runtime of 45.0 ± 2.58 s and one ON/OFF cycle per test. Ten consecutive stability readings produced 627.7 ± 0.95 ADC counts ($40.42 \pm 0.15\%$), while a separate simulated-rain test confirmed that rain detection overrides the dry-soil irrigation request. These results verify short-term

functional repeatability of the programmed hysteresis logic, but they do not establish a numerical water-saving percentage. The two-point calibration values remained 850 ADC counts for the dry reference and 300 ADC counts for the wet/saturated reference.

Future work should add a calibrated flow meter to quantify water consumption and compare the system directly with conventional flood irrigation over repeated cycles. Longer field trials should evaluate sensor stability, crop response, pump runtime, and energy consumption. A capacitive soil-moisture sensor can also be evaluated against the resistive FC-28 for improved long-term durability. The Wi-Fi capability of the UNO R4 WiFi can subsequently support cloud dashboards and mobile monitoring, while predictive irrigation based on weather forecasts or machine-learning models can be evaluated after sufficient field data have been collected.

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References

- Arduino. (2026). Arduino UNO R4 WiFi User Manual. Arduino Documentation. <https://docs.arduino.cc/tutorials/uno-r4-wifi/cheat-sheet/> (accessed 29 September 2026).
- Anoop, E. G., & Bala, G. J. (2024). IoT and ML-based automatic irrigation system for smart agriculture system. *Agronomy Journal*, 116, 1187–1203. <https://doi.org/10.1002/agj2.21344>
- Dutta, S., Gorain, S., Roy, S., Banerjee, S., & Sah, R. P. (2026). Integrating IoT and communication technologies for smart and precision irrigation systems toward sustainable water management. *Discover Internet of Things*, 6, 82. <https://doi.org/10.1007/s43926-026-00314-w>
- García, L., Parra, L., Jimenez, J. M., Lloret, J., & Lorenz, P. (2020). IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation

- in Precision Agriculture. Sensors, 20(4), 1042.
<https://doi.org/10.3390/s20041042>
- Khelifa, B., Amel, D., Amel, B., Mohamed, C., & Tarek, B. (2015). Smart irrigation using Internet of Things. 2015 Fourth International Conference on Future Generation Communication Technology (FGCT), 1–6.
<https://doi.org/10.1109/FGCT.2015.7300252>
- Millán, S., Campillo, C., Casadesús, J., Pérez-Rodríguez, J. M., & Prieto, M. H. (2020). Automatic irrigation scheduling on a hedgerow olive orchard using an algorithm of water balance readjusted with soil moisture sensors. Sensors, 20(9), 2526.
<https://doi.org/10.3390/s20092526>
- Saraf, S. B., & Gawali, D. H. (2017). IoT based smart irrigation monitoring and controlling system. 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), 815–819. <https://doi.org/10.1109/RTEICT.2017.8256711>
- Vallejo-Gómez, D., Osorio, M., & Hincapié, C. A. (2023). Smart Irrigation Systems in Agriculture: A Systematic Review. Agronomy, 13(2), 342.
<https://doi.org/10.3390/agronomy13020342>