

# IoT-Based Innovative Irrigation System for Chili Using Telegram Bot and Web Dashboard

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Received on 30-04-2026 | Revised on 02-06-2026 | Accepted on 26-06-2026

**Abstract**—Chili cultivation requires timely irrigation to maintain soil moisture, yet manual watering is inefficient and difficult to supervise remotely. This paper proposes an IoT-based irrigation system integrating a Telegram bot and a web dashboard for real-time monitoring and control. A soil-moisture sensor provides input to an ESP32 microcontroller, which drives a relay-operated pump using a threshold rule (ON when moisture <30%) and supports manual override via Telegram commands. Sensor readings are logged to Firebase and visualized on a Flask-based dashboard, which features moisture trend graphs. Telegram delivers notifications and supports command-based interaction. Experiments demonstrate an average accuracy of 98,57% and precision of 99,93% compared to a reference meter. End-to-end tests confirm a 0% delivery error, a Telegram notification latency of 1,0–1,8 seconds, and a pump response time of 5,3–5,9 seconds, demonstrating effective automation with practical remote supervision.

**Keywords:** Internet of Things (IoT), Smart Irrigation, Soil Moisture Sensor, Telegram Bot, Web Dashboard.

## I. INTRODUCTION

The chili pepper (*Capsicum spp.*) is a high-value horticultural commodity in Indonesia, with strong market relevance along the national value chain [1]. Additionally, peppers are widely demanded for both fresh consumption and industrial uses [2]. However, chili productivity is highly dependent on irrigation management because soil moisture that is too low or too high can induce plant stress (e.g., drought stress or waterlogging), disrupt physiological performance, and reduce yield and fruit quality [3], [4], [5], [6], [7]. Controlled-irrigation studies on chili peppers consistently show that an inappropriate water supply (deficit or excess) can decrease growth and marketable yield. In contrast, well-managed irrigation improves productivity and water-use outcomes. In parallel, recent agronomic evidence highlights the importance of maintaining soil moisture within an appropriate range. It indicates that automated soil-moisture-informed irrigation can help prevent drought stress while reducing the risk of overwatering [8]. Yet, conventional manual watering remains inconsistent and time-consuming, particularly when farmers are not continuously present on-site. As a result, the Internet of Things-based

innovative irrigation has become an increasingly adopted approach in precision agriculture, integrating sensors, connectivity, and automation to improve water-use efficiency and crop care [9].

In general, innovative IoT irrigation systems monitor key environmental parameters (e.g., soil moisture, temperature, humidity, and water level) and then implement decision rules or control logic to activate pumps/valves only when watering is required [10]. Recent architectures combining embedded controllers, telemetry, and cloud services demonstrate how continuous sensing with threshold-based or feedback-driven control can support real-time supervision and reduce unnecessary irrigation [11], [12]. Practical implementations using low-cost microcontrollers with soil-moisture sensors have also demonstrated stable closed-loop irrigation and improved water efficiency compared with manual practices, supporting sensor-based control as a feasible pathway for water savings and more consistent crop management [13].

Accurate measurement is crucial for making reliable irrigation decisions; therefore, soil moisture sensing must be calibrated and validated before deployment in the field. Recent studies have demonstrated that capacitance-based soil moisture sensors can exhibit measurement bias across various soil types and conditions. That calibration substantially improves their usefulness for irrigation management and modeling applications [14], [15], [16]. These findings motivate the careful calibration and performance evaluation of sensors as part of designing a robust smart irrigation solution.

Beyond automation, usability has a strong influence on field adoption. Chat bot and messaging-based interfaces are increasingly used to provide lightweight, remote human-machine interaction for monitoring and control in agriculture [17], [18]. However, message-only interaction can be limited for continuous visualization and historical inspection. For this reason, many IoT agriculture systems combine instant notifications and remote commands with cloud logging and web dashboards that support trend visualization and data review [8], [11],[17].

Motivated by these developments, this study proposes an innovative IoT-based irrigation system for chili cultivation,

utilizing a Telegram bot and a web dashboard. The system measures soil moisture in real time, processes the readings on a microcontroller, and controls irrigation through a relay-driven pump. Remote monitoring and manual override are provided through Telegram, while a Flask-based web dashboard offers cloud-backed visualization of soil-moisture trends to support richer monitoring and analysis. The primary objectives are to automate watering based on soil-moisture readings within a defined optimal range, integrate Telegram for real-time monitoring and remote control, and evaluate sensor accuracy, notification responsiveness, and irrigation effectiveness in maintaining favorable chili growth conditions.

## II. METHOD

### A. System Block Diagram

Creating a system block diagram is fundamental in system design to ensure that the design and implementation of devices run as expected and systematically. The system block diagram for this study is illustrated in Figure 1, and the diagram of the innovative irrigation system is shown in Figure 2, which describes how soil conditions are sensed, processed, and translated into irrigation actions through remote monitoring and control.

In Figure 1, the soil moisture sensor measures the moisture condition of the chili-growing media in real-time and sends the readings to the ESP32, which functions as the central controller of the system. Based on the predefined moisture threshold, the ESP32 determines whether irrigation is required. When the soil is detected as dry (below the threshold), the ESP32 generates a control output to the relay module, enabling it to switch the pump ON and deliver water automatically. Conversely, once the moisture level reaches the desired range, the ESP32 deactivates the relay, causing the pump to turn off and preventing overwatering.

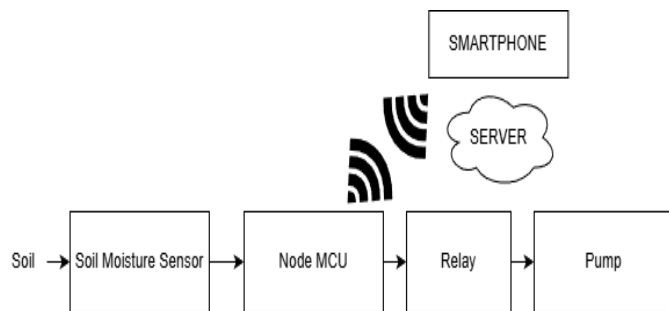


Figure 1. System Block Diagram

For IoT connectivity, the ESP32 communicates with a server via Wi-Fi to transmit system information, including soil moisture values, pump status, and operating mode. This server serves as the central data and communication layer, enabling remote access to system data via a smartphone. Through the smartphone interface, users can monitor the current condition of the irrigation system and interact with it remotely. Overall, the proposed architecture follows a straightforward process from sensing to control and actuation (sensor–controller–relay–pump) and extends this basic loop with server-based connectivity, allowing the system to be conveniently monitored

and controlled from a smartphone. This results in a practical IoT irrigation solution for chili cultivation.

A web dashboard displays these variables to users and provides moisture visualization, such as trend graphs, to support continuous monitoring and evaluation of irrigation behavior over time. Remote interaction is enabled through a Telegram Bot that serves as a lightweight human–machine interface (HMI), allowing users to request real-time system status and change operating modes (auto/manual). When manual mode is selected, users can directly switch the pump on or off through Telegram commands. By combining automated sensing and actuation with cloud data logging, dashboard-based visualization, and Telegram-assisted monitoring and control, the proposed architecture delivers a practical and innovative IoT irrigation system for chili cultivation.

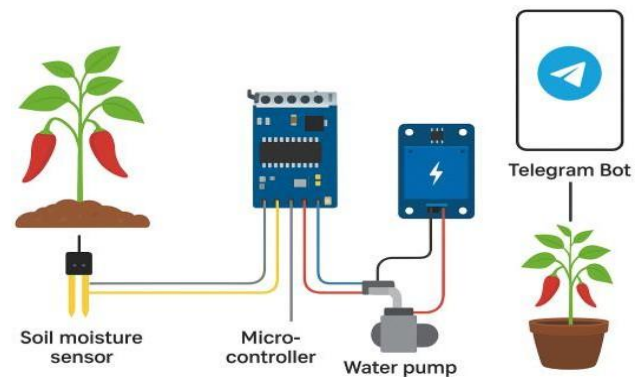


Figure 2. Diagram of the Innovative Irrigation System

### B. System Flow Design

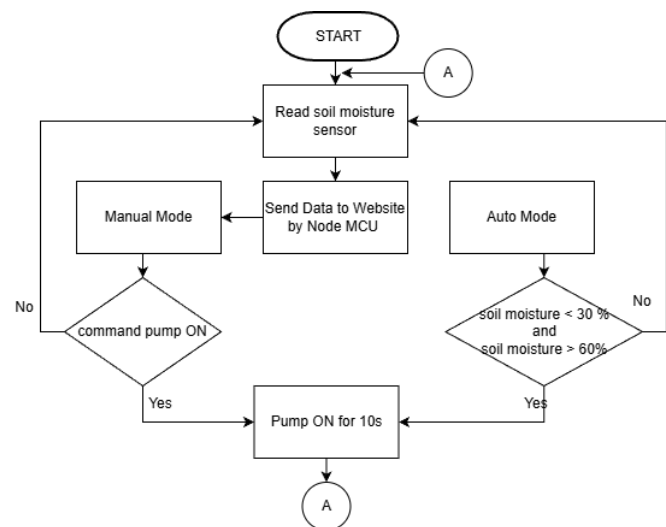


Figure 3. System Flow Diagram

The operational sequence of the proposed system is summarized in the flowchart shown in Figure 3. The workflow begins with system start-up, during which the ESP32 initializes the sensing and control modules and establishes the communication routine required for data transmission. The system then acquires the soil moisture reading as the primary input, representing the current water status of the chili-growing media. Immediately after acquisition, the measured value is transmitted by the ESP32 to the web interface, ensuring that the

monitoring platform is continuously updated with the latest soil condition. Following data transmission, the controller executes the decision stage by selecting the operating mode, namely automatic or manual control. In automatic mode, the ESP32 compares the measured soil moisture to a predefined threshold to determine the irrigation demand. The irrigation threshold of 30% was selected based on agronomic evidence for chili pepper cultivation. Kabir et al. [3] and Mohammed & Hussien [5] reported that bell pepper and chili pepper yield and growth are significantly impaired when soil water availability drops below approximately 30% of field capacity, as plants begin to experience drought stress at this point. Additionally, Bello et al. [4] highlighted that maintaining soil moisture above a critical lower bound is essential to avoid yield losses in pepper crops. Therefore, the 30% threshold represents a conservative lower bound that triggers irrigation before significant plant stress occurs. Specifically, when the soil moisture is below 30%, the soil is classified as dry, and irrigation is triggered. The ESP32 activates the relay driver to energize the water pump for a fixed actuation period of 10 s, providing controlled watering while limiting the risk of excessive irrigation. After the actuation interval elapses, the system returns to the monitoring loop (point A) to re-measure soil moisture and reassess irrigation requirements in the subsequent cycle.

In manual mode, irrigation is performed exclusively in response to user intervention. The system remains in a monitoring state while awaiting a command to activate the pump. When a pump-on-command is issued, the ESP32 drives the relay to switch the pump on for 10 seconds. After this, the process returns to point A to resume sensing and update the website with the latest readings. If no command is received, the pump remains off, and the system continues to repeat the sensing and reporting steps without actuation.

Overall, Figure 3 formalizes the closed-loop behavior of the proposed innovative irrigation system, which involves periodic soil moisture acquisition, continuous reporting to the web interface, and irrigation actuation determined either by a threshold-based rule in automatic operation or by user commands in manual operation. This design ensures repeatable irrigation decisions, supports remote supervision through real-time visualization, and provides a controlled watering mechanism through time-bounded pump activation, thereby improving operational consistency compared with conventional manual watering.

### III. RESULTS AND DISCUSSION

#### A. Testing the Soil Moisture Sensor

The sensor testing process in this study focuses on validating the soil moisture sensor as the primary input of the innovative irrigation system. In the proposed system, the soil moisture reading is used to determine whether irrigation should be activated. When the soil condition is detected as dry (below the defined moisture threshold), the system activates the pump. When the soil moisture is sufficient, the pump is turned off. To assess the accuracy and precision of the soil moisture sensor readings (i.e., the closeness of the sensor’s numerical output to the reference meter reading, and the repeatability of consecutive readings under the same soil condition, respectively), this research adopts the benchmark approach used in prior sensor-

testing studies, where measurement data are compared with reference values. The calculation of sensor accuracy and precision is defined as:

$$\% \text{ accuracy} = \left( 1 - \left| \frac{Y - X_n}{Y} \right| \right) \times 100\% \quad (1)$$

$$\% \text{ precision} = \left( 1 - \left| \frac{X_n - \bar{X}_n}{\bar{X}_n} \right| \right) \times 100\% \quad (2)$$

Where Y represents the reference parameter value, X<sub>n</sub> represents the n-th sensor measurement value, and X represents the average of repeated measurements at the same test condition. These equations produce percentage (%) values that indicate how close the sensor reading is to the reference (accuracy) and how consistent the sensor readings are across repetitions (precision).

In implementation testing, the soil moisture sensor was evaluated under various soil conditions, ranging from dry to very wet, to observe whether it can consistently capture moisture changes. The soil moisture sensor was tested by comparing its readings with those of a digital soil moisture meter (used as the reference instrument). Ten distinct soil moisture conditions were prepared by varying the amount of water added to a fixed soil sample. At each condition, five repeated measurements (n = 5) were taken with the capacitive sensor, and a single stable reading was recorded from the reference meter. The recorded soil moisture values varied from dry to moist and very wet conditions, indicating that the sensor output responds to changes in soil moisture values. The test results of the soil moisture sensor compared with those of the digital soil moisture meter yielded a value with a small error rate under each soil moisture condition.

Test result data in Table I, when entered as (1), produces test results with an average accuracy of 98,57%. The accuracy can be considered good because it is close to 100%. Testing the precision of soil moisture sensor readings using method (2) yielded an average precision of 99,93% for the soil moisture sensor readings. The level of precision can be considered good because it is close to 100%. These values were computed across 10 test conditions with five repeated measurements (n = 5) per condition, totaling 50 sensor readings, each compared against the corresponding reference soil moisture meter value.

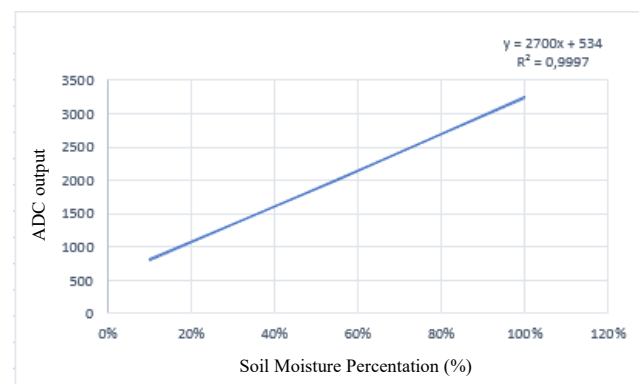


Figure 4. Linear graph of soil moisture sensor output

Figure 4 presents the calibration curve relating soil moisture to the sensor’s ADC output, demonstrating a strongly linear

response across the tested range. The linear regression equation showing the relationship between the productions of the soil moisture sensor is given in (3).

$$Y = 2700X + 534 \tag{3}$$

Equation (3) indicates that the ADC reading increases proportionally with moisture content, with a slope of 2700 reflecting the sensor’s sensitivity and an intercept of 534 representing the baseline output at near-zero moisture. The model achieves an excellent coefficient of determination ( $R^2 = 0,9997$ ), confirming that nearly all variance in ADC values is explained by changes in soil moisture. This high linearity validates the reliability of the sensor’s electrical response and supports the use of the regression equation for accurate conversion from raw ADC readings to soil moisture estimates. Consequently, the calibration model provides a robust basis for implementing threshold-based control and quantitative monitoring in the proposed innovative irrigation system.

TABLE I  
TESTING THE SOIL MOISTURE SENSOR

Soil Moisture Meter	Soil Moisture Sensor					Average	Error (%)
	1	2	3	4	5		
9,2	9	9	10	10	9	9,4	2,17
53,3	52	51	51	52	52	51,6	3,19
47,1	46	44	47	46	47	46	2,34
71,2	69	69	70	70	70	69,6	2,25
40,4	39	39	40	40	40	39,6	1,98
60,2	58	58	59	58	60	58,6	2,66
54,8	55	55	55	56	54	55	0,36
50,3	50	50	50	50	50	50	0,60
60,8	61	61	61	60	59	60,4	0,66
44,5	43	44	44	43	44	43,6	2,02

*B. Testing Data Delivery*

Testing of data delivery to the Firebase web dashboard and Telegram was conducted to ensure that the values displayed on the interface are consistent with the values produced by the microcontroller. The validation method follows a common IoT verification strategy: comparing the displayed values across multiple endpoints (device display/LCD, cloud dashboard, and messaging application) and quantifying mismatch/error [5]. In the Koi fish quarantine monitoring system, Telegram notification delivery was verified by comparing Telegram data with LCD data, resulting in 0% error and no missing messages during the tests [5].

In this innovative irrigation system, the delivered data test was performed through repeated updates, and the results show that all uploaded values were displayed identically on the dashboard and Telegram, resulting in 0% error as shown in Table II. This indicates that real-time synchronization from the microcontroller to Firebase and Telegram can be considered reliable for monitoring and user notification purposes.

Additionally, the system’s periodic update behavior is aligned with the embedded logic implementation, where the device refreshes sensor readings and updates the database at a

defined interval (every 2 seconds), supporting near real-time visualization and interaction.

TABLE II  
DELIVERED DATA TESTING

NO	Data on LCD	Data on Website	Data on Telegram	Website Error %	Telegram Error %
1	30	30	30	0	0
2	31	31	31	0	0
3	32	32	32	0	0
4	66	66	66	0	0
5	68	68	68	0	0
6	90	90	90	0	0

*C. Testing the Entire System*

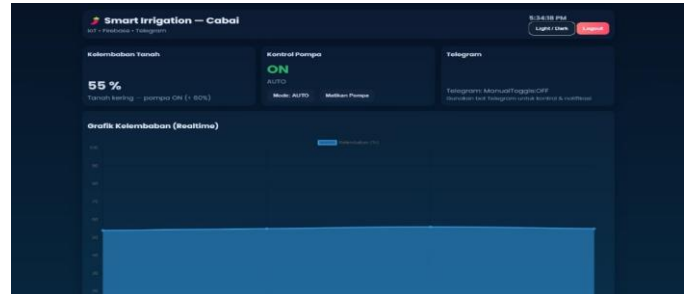


Figure 5. Web Dashboard Firebase

End-to-end testing was conducted to verify that the proposed innovative irrigation system operates reliably as an integrated platform, encompassing soil moisture sensing, decision-making, actuation, and user interaction. The test validated that moisture readings captured by the sensor were successfully transmitted to the backend, visualized in real-time on the web dashboard through the moisture trend graph, and used to drive pump control. Figure 5 shown the website dashboard and Figure. 6 shown the telegram chatbot. In parallel, the Telegram Bot interface was assessed to confirm that user commands and system feedback were delivered correctly, and that manual actuation could override the pump state when required.



Figure 6. Telegram Chatbot

TABLE III  
TESTING THE ENTIRE SYSTEM OF SMART IRRIGATION

NO	Soil Moisture	Pump Condition	Responses Time	
			Auto Mode from Website	Manual Mode from Telegram
1	30	ON	5,6	4,8
2	31	ON	5,3	4,6
3	32	ON	5,7	4,7
4	66	OFF	5,4	4,3
5	68	OFF	5,3	4,6
6	90	OFF	5,2	4,6

The experiment was conducted using six representative soil-moisture conditions, spanning from dry to wet media. System performance was evaluated under autonomous operation (Auto Mode via the website control logic) and manual operation (user commands issued through Telegram). The leading performance indicator was the pump time-to-response. For Auto Mode, this was defined as the elapsed time from when the ESP32 completed a sensor acquisition and threshold decision until the relay switched and the pump changed state, as confirmed by observing the physical pump and the status update on the web dashboard. For Manual (Telegram) Mode, the response time was measured from the moment the Telegram command was sent by the user until the relay-switching event was observed and the updated pump status appeared in both Telegram and the web dashboard. The measured intervals, therefore, include network propagation delay (Wi-Fi and Telegram API round-trip), Firebase update latency, and relay switching time. A stopwatch-based timestamp method was used for all measurements, with each condition recorded once during a single continuous test session.

The results show that the control logic behaved consistently with the intended irrigation rule. When soil moisture levels were low (30–32%), the system activated the pump (ON); however, at higher moisture levels (66–90%), the pump remained deactivated (OFF). This confirms that the sensing, threshold-based decision process, and relay actuation were functionally correct across the tested range. In terms of responsiveness, Auto Mode exhibited an average response time of 5,42 seconds, while Telegram commands achieved a faster average response time of 4,60 seconds across all trials. Telegram-based actuation was approximately 0,82 seconds more rapid than the autonomous pathway. The response times also remained stable when separated by pump state, with similar values observed for ON and OFF transitions, indicating repeatable actuation performance and consistent communication latency. It should be noted that the current evaluation used six discrete moisture conditions over a single test session. Extended field testing with actual chili plants, varied soil types, and long-duration operation would be required to fully characterize system reliability and irrigation effectiveness under practical farming conditions.

The observed difference between autonomous and Telegram control is plausibly attributed to system overhead in Auto Mode, where sensor acquisition cycles, data synchronization, and dashboard updates may occur concurrently with or precede final actuation. In contrast, Telegram commands trigger a more direct route from command to actuation. Nevertheless, the overall latency of 4,3–5,7 seconds is still suitable for irrigation applications, as soil moisture changes occur gradually and do

not require a sub-second response. Collectively, the end-to-end test demonstrates that the proposed system provides dependable real-time monitoring, accurate pump control decisions, and responsive REMOTE-CONTROL capability, supporting its suitability for deployment in practical and innovative irrigation scenarios.

#### IV. CONCLUSION

This study successfully developed and validated an IoT-based smart irrigation system for chili cultivation, integrating soil moisture sensing, automatic pump actuation, cloud data logging, web dashboard visualization, and Telegram-based remote monitoring and control. The system supports both automatic threshold-based irrigation and manual override via Telegram commands, achieving a sensor accuracy of 98,57% and precision of 99,93% relative to a reference meter, zero data synchronization errors across all interfaces, Telegram notification latency of approximately 1,0–1,8 seconds, and pump actuation response times of 5,3–5,9 seconds, collectively demonstrating reliable, real-time, end-to-end performance in reducing dependence on manual watering. For future work, the system can be enhanced through multi-point sensor calibration for diverse soil types, adaptive control strategies such as fuzzy logic or PID, and the integration of additional environmental parameters including temperature, humidity, and rainfall, while long-term outdoor reliability testing, expansion to distributed multi-zone architectures, and full growing-season field trials with actual chili plants would further strengthen the agronomic validity, scalability, and generalizability of the proposed irrigation framework.

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