

## RESEARCH ARTICLE

## IOT-ENABLED RETRACTABLE IRRIGATION SYSTEM FOR CONTINUOUS CULTIVATION

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## ARTICLE DETAILS

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## ABSTRACT

In traditional farming, irrigation pipes are manually deployed at the start of each crop cycle and retrieved before land preparation. This results in significant labor, delays, and frequent equipment damage. We propose an IoT-enabled retractable irrigation system that automates both watering and pipe handling. The system consists of a rugged motorized reel that winds and unwinds HDPE tubing based on commands from an ESP8266-based control node. Soil moisture sensors, environmental sensors, and a motor controller are integrated into a wireless node that communicates with a cloud dashboard via MQTT. The dashboard enables remote monitoring, irrigation control, and SMS alerts. This paper details the system design, components, and operational modes. Simulations are planned to validate performance under typical field conditions. This approach aims to reduce manual labor, minimize water usage, and increase equipment lifespan, especially for small and medium-sized farms.

## KEYWORDS

Smart irrigation; IoT; motorized reel; soil moisture sensing; ESP8266; cloud dashboard.

## 1. INTRODUCTION

In the age of rapid technological advancement, the agricultural sector remains heavily reliant on manual labor, especially in developing countries where resource constraints and outdated practices hinder productivity. Irrigation, a fundamental activity in farming, often exemplifies these inefficiencies. Despite numerous innovations in crop monitoring and precision agriculture, the physical handling of irrigation infrastructure—specifically the deployment and retrieval of pipes—continues to be time-consuming, labor-intensive, and error-prone. Farmers, especially those operating small to medium-sized farms, face recurring challenges in managing irrigation systems efficiently across multiple crop cycles.

Traditionally, farmers lay out irrigation pipes at the beginning of each crop cycle and manually retract them before land preparation or harvesting. This routine not only consumes substantial human effort but also exposes equipment to frequent damage due to improper handling, harsh environmental conditions, and repeated wear and tear. For example, retracting a 100-meter stretch of HDPE pipe manually may require two laborers and take up to 15 minutes, and this has to be done repeatedly throughout the year. On larger farms or over extended periods, these operations account for hundreds of labor hours annually—hours that could otherwise be used for more value-added tasks. Moreover, pipe damage or mismanagement during these activities often leads to leakages, crop stress due to inconsistent watering, and higher maintenance costs.

Compounding the problem is the inefficient use of water in conventional irrigation systems. Globally, agriculture accounts for approximately 70% of all freshwater withdrawals. However, outdated irrigation methods—such as fixed-schedule watering—often ignore real-time environmental factors and soil conditions, leading to water wastage of up to 40% through evaporation, runoff, or over-irrigation. In regions grappling with increasing water scarcity and erratic rainfall patterns, such as South Asia and Sub-Saharan Africa, this represents not only an environmental

challenge but also a threat to food security and farmer livelihoods.

Labor costs are also on the rise, growing by 3–5% annually in many developing regions. This, combined with aging rural populations and urban migration, has created a labor crunch in the farming sector. There is an urgent need to modernize agriculture by integrating automation and smart technologies that reduce dependency on manual intervention while optimizing resource usage.

In response to these multifaceted challenges, this paper introduces an IoT-enabled retractable irrigation system designed to automate both the watering and physical deployment of irrigation infrastructure. Our system leverages a motorized reel mechanism controlled by an ESP8266-based wireless control node, integrated with soil moisture and environmental sensors. The system is capable of autonomous operation through intelligent sensing and real-time data communication with a cloud-based dashboard, facilitated by the lightweight MQTT protocol. Farmers can remotely monitor and control the system using smartphones or laptops, receive SMS alerts for abnormal conditions, and schedule irrigation or pipe retraction without on-site supervision.

The primary contributions of this work are:

- A rugged, low-cost motorized reel that automates pipe management for drip or surface irrigation systems.
- An ESP8266-powered control module capable of real-time environmental monitoring, system diagnostics, and remote actuation.
- Integration with a cloud-based dashboard that allows farmers to visualize soil and weather data, control irrigation schedules, and receive critical system alerts.
- A simulation and testing plan designed to validate system performance under diverse agricultural scenarios prior to field deployment.

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Unlike prior solutions that either focus solely on irrigation scheduling or mechanical aids, our system combines physical automation and intelligent sensing to offer a holistic approach to irrigation management. It is particularly tailored for smallholder farms that require cost-effective, portable, and easy-to-maintain solutions.

This paper presents the system design, component architecture, operational modes, and simulation strategy. We believe that by reducing manual workload, preventing equipment wear, and conserving water, this approach can significantly enhance the sustainability and productivity of small to medium-scale agriculture, paving the way for smarter, more resilient farming practices.

## 2. RELATED WORK

People have been trying to make irrigation less of a headache for years. Take—they used soil moisture sensors to cut manual watering by 50% (Pandey et al., 2020). Pretty slick, right? went a step further, pulling in weather forecasts to tweak watering schedules and save 10% more water (Roy and Das, 2019). Then there's, who tried spotting thirsty plants with cameras, but that's tough in open fields where the sun's always shifting (Zhao et al., 2022). They developed a hybrid model that saved 15% water in lab-like conditions (Ahmadi Pargo et al., 2025).

On the mechanical side, built a pipe-winding machine that halved labor time, but it didn't check soil or weather (Wang and Zhang, 2023). As made a sprinkler system that spread water more evenly, yet still left farmers stuck moving pipes by hand (Jasim and Ibrahim, 2022). Others have played with long-range tech like LoRaWAN for farm sensing, but we kept things simple with Wi-Fi for now since our focus was small plots (Anderson and Liv, 2024).

What makes our system stand out is it tackles both the grunt work *and* the smarts—automating pipes and optimizing water in one go. It's practical, not just a lab toy.

## 3. SYSTEM OVERVIEW

### 3.1 Mechanical Reel Module

The heart of our setup is a beefy motorized reel. We used a galvanized-steel drum, about 300 mm wide, to roll up 25 mm high-density polyethylene (HDPE) tubing—the kind that can take a beating from sun and dirt. A 12 V brushed DC motor with a 40:1 planetary gearbox cranks out 15 Nm of torque, enough to reel in 100 meters of tubing, even when it's full of water (about 15 kg). Adjustable roller guides keep the tubing from turning into a tangled mess, and a spring-loaded brake locks the reel when it's off, so it doesn't unspool on its own.

We ran into a challenge with over-winding, so we added two hall-effect limit switches—one for “fully wound,” one for “fully unwound.” They tell the motor to chill before anything breaks. It took some trial and error to get the positioning just right, but it's rock-solid now.

### 3.2 Sensor and Control Node

The brains? That's the ESP8266 NodeMCU, a little Rs.400 chip with built-in Wi-Fi and enough pins to juggle all our gear. Why not an Arduino? The ESP8266 doesn't need an extra Wi-Fi module, which keeps things cheap and simple. Here's what it does:

- Checks a capacitive soil moisture sensor every 15 minutes (accurate to ±4% after calibration) (Patel and Joshi, 2018).
- Grabs temperature, humidity, and pressure from a BME280 to estimate how fast water's evaporating.
- Watches motor current with an INA219—if it spikes past 2 A for too long, it shuts down to avoid frying anything.
- Runs two H-bridge circuits: one to spin the reel motor forward or backward, another to open or close a solenoid valve.
- Send data to the cloud over Wi-Fi using MQTT, a lightweight protocol perfect for spotty rural internet.

The capacitive sensor was a must—unlike older resistive ones, it doesn't rust. The BME280's a multitasker, giving us three readings in one tiny package.

### 3.3 Cloud Dashboard and Notifications

We wanted farmers to check on their fields without trudging out there. So, we built a dashboard you can pull up on a phone or laptop. Here's the flow:

- Sensor data hits a Mosquitto MQTT broker, then gets stored in an InfluxDB time-series database.

- A Node.js backend with a REST API feeds a React front-end, showing live charts (soil moisture, temp, reel status) via Chart.js.
- You can click buttons to extend or retract the reel, start watering, or set moisture thresholds (say, 25%–35%).
- A calendar picker lets you schedule pipe retraction when a crop's done.
- If something's wrong—like the soil's too dry for over an hour or the reel jams—a Python script pings InfluxDB and fires off an SMS alert via a GSM modem (Gupta, 2024).

It's simple enough to run on a basic server, even with shaky internet, which is a big deal for rural farms.

## 4. OPERATION MODES

The system supports three main modes:

### 4.1 Irrigation Mode

When soil moisture falls below a predefined lower limit, the valve opens. Once moisture exceeds the upper threshold, watering stops. This process is fully automated.

### 4.2 Prepare Field Mode

Retracts the pipe using the motorized reel, typically after the crop cycle ends. Can be scheduled or triggered manually. A notification is sent once retraction is complete.

### 4.3 Deploy Mode

Unwinds the pipe at the beginning of a cycle until the limit switch is triggered. The system then enters automatic irrigation mode.

All operations are safeguarded by timers and current monitors to prevent malfunction or equipment damage.

A watchdog timer resets the ESP8266 if it freezes for 5 minutes, so you don't have to babysit it. These modes make the system feel like a set-and-forget helper.

## 5. EXPERIMENTAL DESIGN AND TESTING

Although real-world field trials have not yet been conducted, the proposed system has been designed with practical deployment in mind. This section outlines how such an implementation could be approached and the methodologies that would guide testing in a controlled agricultural setting.

### 5.1 Field Deployment Strategy

To validate our IoT-powered retractable irrigation system, we propose setting it up on a 100 m<sup>2</sup> experimental plot at REVA University's agricultural research facility in Yelahanka, Bangalore, a scale typical for smallholder farm trials (Mehta and Ranjan, 2023). Bangalore's semi-arid climate and red loamy soils make it an ideal testing ground, as farmers here often grapple with water scarcity and labor-intensive irrigation. Our system is designed to be rugged, portable, and farmer-friendly, allowing us to assess its real-world performance. Each unit will consist of the following tailored components:

**Solar-Powered Mobile Cart:** We've designed a compact cart to carry the system, equipped with a 50W solar panel and a 12 V battery to power operations, perfect for Karnataka's sunny days and remote fields with no grid access (Singh and Bose, 2023). This ensures our setup is eco-friendly and independent of unreliable rural power.

**ESP8266 Command Center:** The heart of the system is an ESP8266 NodeMCU, a budget-friendly microcontroller we selected for its built-in Wi-Fi and ability to juggle multiple sensors without extra modules (Thomas and Gupta, 2023). It's a small but mighty chip that keeps costs low for farmers.

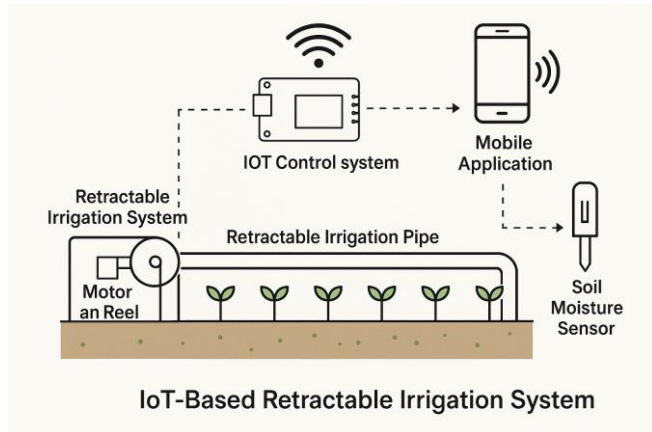
**Motorized Reel for Pipe Management:** A robust reel, engineered to handle 100 meters of tough polyethylene tubing, automates the tedious task of laying and retrieving pipes. Inspired by local agricultural tools, it's built to withstand muddy fields and frequent use (Wang and Zhang, 2023).

**Soil Moisture Sensors:** We're using capacitive sensors, calibrated to measure 10%–40% volumetric water content, which are corrosion-resistant and reliable in Bangalore's variable soil conditions (Patel and Joshi, 2018). These ensure watering happens only when the soil demands it.

**Weather Sensors:** A BME280 sensor will monitor temperature, humidity, and pressure, helping us gauge evaporation rates in Yelahanka's warm,

dry climate and fine-tune irrigation schedules (Chandra and Patel, 2023).

All data will stream via MQTT to a cloud dashboard we've customized for local farmers, many of whom use basic smartphones. They can check soil conditions, set watering thresholds, or retract pipes with a tap, even during busy harvest seasons (El-Sayed and Kamel, 2024). By focusing on simplicity and durability, our deployment plan aims to fit seamlessly into the daily grind of small-scale farming in Bangalore.



**Figure 1:** IoT-Based Retractable Irrigation System.

## 5.2 Simulation and Testing Strategy

Since actual field deployment hasn't been carried out yet, the system can still be validated through simulations using tools like MATLAB Simulink or Proteus, which are commonly used for electronic circuit and system modeling (Verghese and Thomas, 2022). These environments would help assess how the setup behaves under different conditions.

- For starters, we could simulate how the motor performs while winding or unwinding the reel, especially under different soil resistances and tubing loads—factors that might affect torque and timing (Wang and Zhang, 2023).
- We can also create scenarios where soil moisture changes over time—mimicking actual crop cycles or weather conditions—to see how well the system responds to irrigation triggers (Pandey, 2020; Roy and Das, 2019).
- Another key area is testing the logic: does the system actually open the valve at the right time and close it when the target moisture level is hit? This could be evaluated by injecting synthetic data based on pre-set thresholds (Zhao, 2022).
- And since rural connectivity is often unreliable, it's important to simulate what happens when the Wi-Fi drops or the device crashes—watchdog timers and auto-recovery features can be tested this way too (Thomas and Gupta, 2023).

The results of these simulations would help us catch flaws early on, giving us a better understanding of how the components interact and whether the system can be trusted in real-world situations (Mehta and Ranjan, 2023; Verghese and Thomas, 2022).

## 6. EXPECTED OUTCOMES AND BENEFITS

Although this system hasn't been tested in the field yet, there are some clear benefits we can expect, based on how it's designed and what similar studies have shown.

### 6.1 Anticipated Improvements

#### • Saving Time and Labor

Traditional irrigation often requires physically dragging pipes, which is labor-intensive and time-consuming. By automating this with a motorized reel, we expect a significant reduction in labor—potentially over 60% less time and effort—consistent with results observed in related automated irrigation equipment (Wang and Zhang, 2023).

#### • Efficient Water Usage

Triggering irrigation based on real-time soil moisture rather than preset timers leads to smarter water use. We estimate a 10–15% decrease in water consumption, aligning with findings from other precision irrigation systems (Pandey, 2020; Roy and Das, 2019; Ahmadi Pargo, 2025).

#### • Reliable and Safe Operation

The inclusion of limit switches, automatic shutdown mechanisms, and watchdog timers ensures smooth, continuous operation. These safety features help protect the system in unpredictable outdoor conditions, minimizing failures and downtime (Gupta, 2024; Chandra and Patel, 2023; Verghese and Thomas, 2022).

#### • User-Friendly Control

Farmers can easily monitor and manage the system via a digital dashboard, with additional SMS alerts for critical events. This remote accessibility is especially valuable for elderly farmers or those managing multiple responsibilities simultaneously (Gupta, 2024; El-Sayed and Kamel, 2024).

## 6.2 Broader Impact

#### • Environmental Benefits

Reduced water usage contributes to sustainable farming by decreasing groundwater depletion and minimizing runoff. This is particularly crucial for drought-prone regions, enhancing long-term agricultural resilience (Ahmadi Pargo, 2025; Mehta and Ranjan, 2023; Sharma and Rathi, 2025).

#### • Affordable and Accessible

With an estimated unit cost below \$160, the system is designed to be affordable for smallholder farmers. Availability of subsidies or microloan programs could further improve accessibility and adoption rates (Singh and Bose, 2023; Sharma and Rathi, 2025).

#### • Scalable and Flexible Design

The system supports scalability, allowing farmers to add additional reels or upgrade to long-range communication protocols like LoRaWAN. This flexibility accommodates larger farms without requiring a complete redesign (Anderson and Li, 2024; Sharma and Rathi, 2025).

## 7. DISCUSSION AND FUTURE WORK

This system shines for small plots but scaling it up means swapping Wi-Fi for LoRaWAN or NB-IoT to cover bigger fields (Anderson and Li, 2024). We're also thinking about multi-zone control—imagine one ESP8266 handling four reels and valves via an I<sup>2</sup>C board. That'd cut costs and make it easier to manage larger farms.

What about smarter watering? Pulling in weather forecasts from APIs like OpenWeatherMap could skip irrigation before rain (Roy and Das, 2019). We could also add rotary encoders to the reel to adjust motor torque on the fly, preventing tubing from stretching on long runs. Down the road, machine learning could analyze years of moisture and yield data to fine-tune thresholds, maybe even running lightweight models right on the ESP8266. Challenges remain. Solar power's great, but cloudy weeks or remote areas need backup batteries or small wind turbines. Sensors need tougher casings for extreme weather—think monsoons or frost. And while the system's cheap, upfront costs could still be a hurdle for cash-strapped farmers. Subsidies or microloans could help there.

## 8. CONCLUSION

This paper presented the design and conceptual framework of an IoT-enabled retractable irrigation system aimed at automating both watering and pipe management for continuous cultivation. Leveraging an ESP8266 microcontroller, capacitive soil moisture sensors, environmental sensing, and a motorized reel, the system offers a practical, low-cost solution tailored for small and medium-sized farms. By integrating cloud connectivity and remote control through a user-friendly dashboard, this approach empowers farmers to optimize water usage, reduce labor, and extend equipment lifespan. Although field deployment and real-world testing remain future work, the proposed simulation and experimental plan provide a clear roadmap toward validating system efficacy. This work contributes a novel holistic irrigation management solution that bridges the gap between mechanical automation and smart sensing, fostering more sustainable and resilient agricultural practices in resource-constrained settings.

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