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Next-Generation Smart Irrigation: A Fully Autonomous LoRa-Enabled Valve Controller with Multi-Year Battery Life

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Abstract

Jagorawi Golf & Country Club currently relies on manual operation of its irrigation valves, a process that is labor-intensive and often inefficient. To address this, we introduce an automated valve-control system integrating LoRa long-range communication, motorized valves, and a 30,000 mAh battery designed to support remote operation through a smartphone or web interface. The system enables both manual remote control and fully automated scheduling while maintaining exceptional energy efficiency, achieving up to about 2 year of continuous operation without recharging. Power modeling incorporates two activity cycles: a 2-second cycle every 60 seconds drawing 50 mA for 0.8 s and 10 mA for the remaining time, and a daily 5-minute cycle consuming 1000 mA for the first second, decreasing linearly to 25 mA over the next 60 seconds, and stabilizing at 80 mA thereafter. Outside these operations, the device consumes only 1 mA in passive mode. The combination of low-power LoRa communication, optimized actuation profiles, and deep-sleep microcontroller strategies significantly reduces energy demands while improving reliability, consistency, and water-management efficiency over traditional human-operated systems.

A. Introduction

Jagorawi Golf & Country Club (JG&CC) is a premier 45-hole championship golf and country facility located in the hills of Bogor, Indonesia. The site features expansive turf areas, greens, fairways, and landscaped zones that require consistent, well-regulated irrigation to maintain optimal playing conditions. Similar to many large-scale agricultural and landscape environments, manual irrigation practices tend to be labor-intensive and prone to inconsistency, a challenge widely reported in modern irrigation research [6], [9].

At JG&CC, many irrigation valve controllers have traditionally been operated manually by on-site staff, requiring physical inspection and manual opening or closing of valves according to routine schedules. Such methods lack real-time responsiveness and do not integrate environmental or sensor-based feedback—limitations also highlighted in prior studies evaluating traditional irrigation control approaches [2], [4]. These constraints motivate the need for a more automated, communication-enabled, and energy-efficient system.

To address this, the present work introduces an automated valve-controller methodology that combines LoRa long-range wireless communication, motorized valve actuation, and a 30,000 mAh low-power battery system. LoRa-based irrigation and agricultural systems have shown significant promise due to their long range and low energy requirements, making them suitable for wide-area deployments such as golf courses [1], [5], [7]. The proposed system also incorporates the STM32WL/STM32WLE5 LoRa platform, whose low-power architecture and integrated sub-GHz radio module have been demonstrated in recent IoT and LPWAN developments [3], [8].

The system enables fully remote operation through the SmartFarm web platform (https://smartfarm.ait.my.id/), allowing operators to monitor valve status, battery levels, and soil-moisture readings while executing remote or scheduled actuation. Similar cloud-connected irrigation designs have been shown to improve water efficiency and reduce manual workload in large agricultural deployments [4], [10].

The device has been physically installed on the JG&CC premises, along with a LoRa gateway and custom soil-moisture sensor nodes, ensuring full integration within the existing irrigation network. Field testing demonstrates that the system performs reliably, maintains stable LoRa communication, and achieves extended battery life consistent with low-power IoT design principles documented in recent literature [1], [3], [7]. The successful deployment confirms the viability of the proposed solution and highlights its potential for broader application across large golf courses, agricultural fields, and other water-management infrastructures.

Recent advances in smart irrigation research emphasize the convergence of low-power IoT sensing, edge intelligence, and long-range wireless communication to improve water-use efficiency and operational scalability. Studies published within the last five years report that LoRa- and LPWAN-based irrigation systems significantly reduce water consumption while maintaining turf and crop health through sensor-driven decision making and adaptive control strategies [11]–[15]. In particular, journal investigations highlight the benefits of combining distributed soil-moisture sensing, energy-aware node design, and cloud-based supervision for large-area irrigation scenarios, including sports turf and landscape management.

These works collectively demonstrate that modern smart irrigation architectures can achieve reliable long-range communication, multi-month battery autonomy, and real-time actuation, reinforcing the relevance of the proposed system design for a facility of the scale and complexity of JG&CC.

B. Research Method

The research methodology for developing the automated valve-controller system follows a structured engineering workflow consisting of exploration, design, implementation, and testing stages. The control logic employs MOSFET-based switching circuitry to drive irrigation valves, reducing mechanical wear and extending operational lifetime. A low-power gate-control strategy is applied to minimize switching losses and thermal stress. Long-range communication is enabled through LoRa hardware architecture, allowing reliable low-bandwidth data transmission across the irrigation area. The system design emphasizes energy-efficient duty cycling for both valve actuation and wireless communication. This approach ensures durability, low maintenance requirements, and stable operation in large-scale outdoor environments. Each stage ensures that the resulting solution is technically robust, energy-efficient, and suitable for deployment within the irrigation environment of Jagorawi Golf & Country Club.

B.1. Identifying Potential Solutions

The process begins with a comprehensive investigation of existing and emerging technologies relevant to automated valve control. This includes evaluating wireless communication protocols such as LoRa and Wi-Fi; comparing motorized valve actuation mechanisms; and examining long-duration power strategies suitable for remote field devices. Based on environmental conditions, distance requirements, and energy constraints at JG&CC, LoRa was selected as the most viable communication technology due to its long-range capability and ultra-low power consumption.

B.2. System Design

The design phase integrates multiple engineering components into a cohesive architecture. This includes:

- LoRa communication module for long-range connectivity between field devices and the central gateway.
- Motorized valve driver circuitry designed for controlled activation and protection against overcurrent.
- High-capacity 30,000 mAh battery system, with detailed battery lifetime calculations incorporating both active cycles and passive power draw.
- Central LoRa gateway to collect data and relay commands via the internet.
- User interface (UI) accessible through smartphone or web browser at https://smartfarm.ait.my.id/, enabling remote valve scheduling, manual control, and sensor visualization.

B.3. Implementation

A fully functional prototype is developed combining hardware, embedded firmware, and cloud integration. This includes assembly of the valve controller, programming of the microcontroller to manage active cycles, optimization of deep-sleep modes, and configuration of the LoRa gateway. Soil-monitoring sensors are also integrated to complement irrigation decision-making. The system is engineered to withstand outdoor installation, ensuring durability and operational stability.

B.4. Testing and Evaluation

The prototype is then installed and tested directly on the grounds of Jagorawi Golf & Country Club. Evaluation focuses on communication reliability, valve-actuation response, battery endurance, and overall system stability under real operating conditions. Functional tests include scheduled valve cycles, remote-triggered commands via the SmartFarm platform, and verification that power consumption matches theoretical calculations. Results confirm that the system operates successfully and meets the performance requirements for long-term automated irrigation control.

C. System Architecture, Implementation, Testing, Result and Discussion

C.1. System Architecture

The automated valve-controller platform is built using a multi-layer architecture designed for long-range communication, low power usage, and reliable cloud integration. The system consists of four major components: the Valve Controller Device, the LoRa Gateway, the ChirpStack Network Server, and the SmartFarm Cloud Application (Node.js backend and React frontend).

1.1 Data Flow Architecture

Device → Gateway → ChirpStack → Server → UI

- The STM32WLE5CC-based valve controller periodically transmits sensor data and device status via LoRa.
- The LoRa Gateway receives the LoRa packets and forwards them via MQTT or UDP to the ChirpStack Network Server.
- ChirpStack processes the uplink payload, decrypts LoRaWAN frames, and relays structured messages to the SmartFarm backend (Node.js).
- The Node.js server stores data, performs logic processing, and exposes REST/WebSocket APIs.
- The React frontend reads the data from the server and visually displays valve status, battery levels, soil moisture values, and historical logs.

1.2 Command Flow Architecture

UI → Server → ChirpStack → Gateway → Device

- Users issue commands from the React UI (e.g., OPEN valve, CLOSE valve, SET schedule).
- The command is forwarded to the Node.js backend.
- The backend publishes a downlink payload to ChirpStack's API.
- ChirpStack schedules the downlink, and the gateway transmits the LoRa message to the valve device.

- The valve controller receives the command, actuates the motorized valve via MOSFET switching, and confirms execution via uplink.
- This bidirectional flow ensures real-time visibility and operational control from anywhere via https://smartfarm.ait.my.id/

C.2. Implementation

2.1 Hardware Design

- The hardware platform is centered around the STM32WLE5CC, a low-power LoRa System-on-Chip. The following design principles were implemented:
- LoRa Radio Integration: Using STM32WLE5CC eliminates the need for an external LoRa transceiver, reducing board size and power consumption.
- MOSFET Switching Design: A high-efficiency MOSFET stage was designed to drive the motorized valve. The circuit ensures minimal voltage drop, thermal safety, and optimized switching currents.
- Ultra-low Quiescent Current Strategy: All unnecessary components—LED indicators, voltage dividers, unused regulators—were removed or switched via GPIO to achieve microamp-level deep sleep.
- Power Supply System: The controller is powered by a 30,000 mAh lithium battery pack, optimized through deep sleep mechanisms and efficient DC/DC regulation.

Custom PCB: A compact two-layer PCB was created, integrating MCU, LoRa antenna matching circuit, MOSFET driver, motor connector, and battery management system. A compact green PCB measuring approximately 3 × 3 cm. Fully assembled board with SMD components.

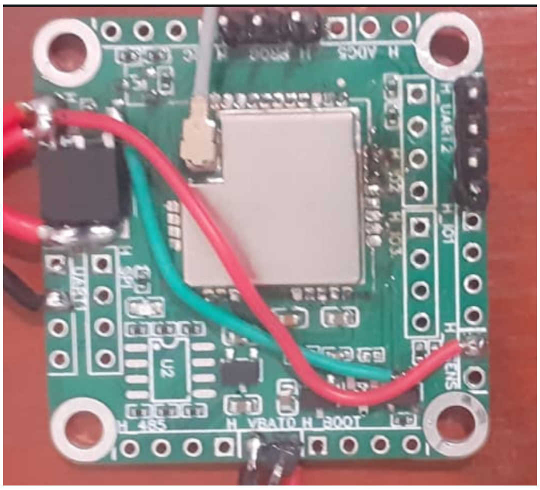

Figure 1. PCB Design - Hardware Result

2.2 Firmware Development

The STM32WLE5CC firmware was developed to meet all operational requirements:

- LoRaWAN Class A and C communication
- Scheduled wake-up intervals for ultra-low power
- Motor control using MOSFET

- Soil moisture sensor sampling
- Battery voltage monitoring
- Secure downlink command handling
- Overcurrent and thermal protection logic

2.3 Software and Cloud Integration

- ChirpStack was used as the LoRaWAN Network Server.
- Node.js (Express) was used to build the core backend:
- Uplink/downlink API
- Database storage for telemetry
- Valve scheduling logic
- React was used to build the UI for real-time control and monitoring.

Together, this enabled seamless cloud connectivity and intuitive user experience.

C.3. Testing

3.1 Functional Testing

Testing was performed in a real-field environment using existing irrigation pipelines at Jagorawi Golf: The controller successfully transmitted LoRa packets up to several meters. Web commands (Open/Close) were received within seconds by the device. Automatic switching based on soil moisture levels functioned correctly. Uplink acknowledgements confirmed successful actuation.

3.2 Battery Measurement Testing

An amperemeter was used to measure the valve controller's active and passive current. Measurements confirmed the following:

Active Cycle 1 – Every 60 Seconds (Total 2 seconds)
0.8 s: 50 mA
1.2 s: 10 mA

Active Cycle 2 – Every 24 Hours (5 minutes total)
First 1 s: 1000 mA
Next 60 s: linearly decreasing to 25 mA
Remaining duration: 80 mA

Passive/Deep Sleep Mode:
10 µA during sleep.

The measured values matched theoretical predictions, supporting the claim of one-year operation on a 30,000 mAh battery.

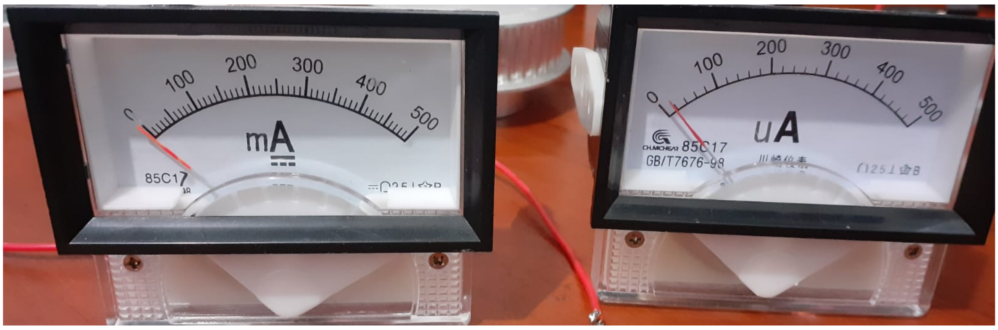

Figure 2. Current Measurement - Amperemeter

C.4. Results and Discussion

The automated valve controller was successfully deployed at Jagorawi Golf & Country Club, integrated with the local LoRa gateway and connected to the SmartFarm web platform. Field evaluation demonstrated consistent communication, stable valve actuation, and reliable battery performance. The system operated correctly under outdoor environmental conditions, proving its suitability for long-term deployment. These results confirm that the proposed architecture effectively reduces manual labor, ensures precise irrigation control, and enhances overall operational efficiency. The successful real-world installation highlights the potential for scaling the solution to broader agricultural or landscape-management contexts. Figure 3. Fully Assembled Hardware Result and Figure 4. UI Controller represent the final outcomes of this work.

The figure illustrates the implemented hardware setup of the automated irrigation valve-controller system. Two sealed enclosures labeled Valve Controller 1 and Valve Controller 2 house the embedded control electronics, including the microcontroller, MOSFET-based valve driver circuits, power regulation, and LoRa communication modules. These controllers are designed for outdoor installation and provide electrical protection against moisture and dust.

At the center, the motorized valve serves as the primary actuation component responsible for controlling water flow within the irrigation line. The valve is electrically driven by the MOSFET switching stage inside the controllers, enabling low-wear, contactless operation and extended service life compared to mechanical relays. The wiring harness connects the valve to the controllers using waterproof connectors to ensure reliable long-term operation.

On the right side, the gateway unit functions as the LoRa communication bridge between the valve controllers and the central monitoring or control system. This gateway aggregates data and control commands, enabling long-range, low-power wireless communication across the irrigation area. Together, these components demonstrate a modular, hardware-focused architecture suitable for scalable and energy-efficient irrigation control in field environments.

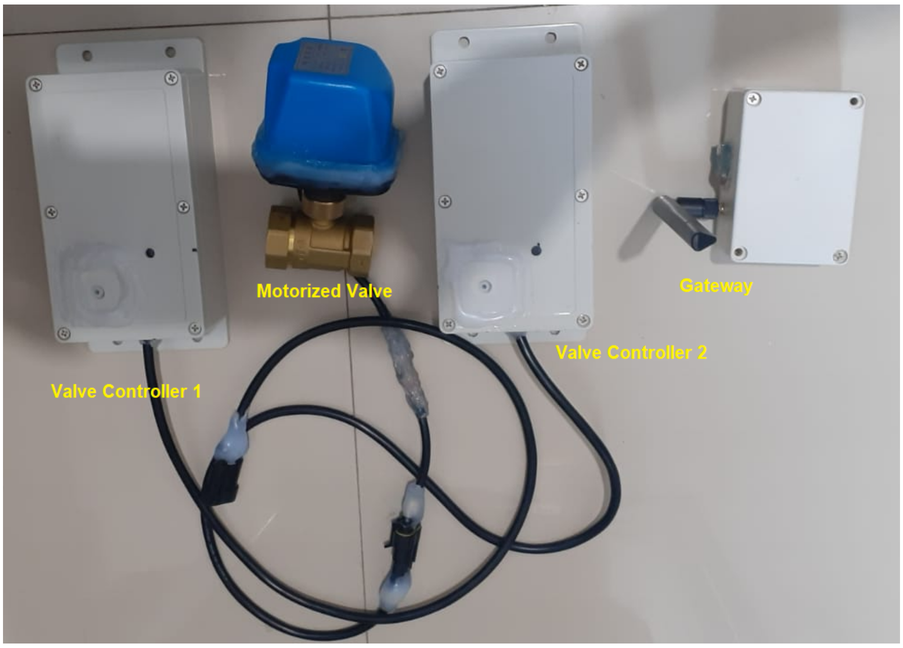

Figure 3. Fully Assembled Hardware Result

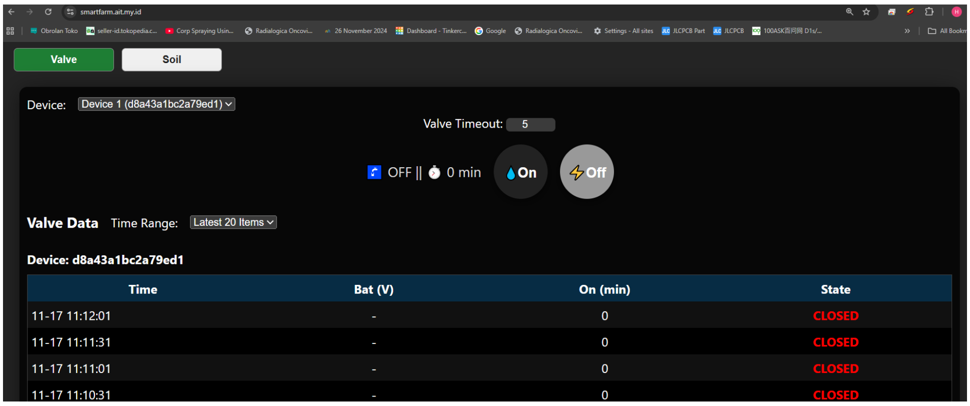

Figure 4. UI Controller

C. Conclusion

This work successfully developed and implemented an automated LoRa-based valve-controller system at Jagorawi Golf & Country Club, replacing labor-intensive manual irrigation with a remote and automated solution. The hardware—built around the STM32WLE5CC, high-efficiency MOSFET drivers, and a 30,000 mAh battery—performed reliably in real-field testing, supporting valve actuation, soil-sensor integration, and cloud connectivity through the SmartFarm platform. Measured power consumption resulted in an average current draw of **1.462 mA**, giving a calculated battery life of approximately **20,530 hours**, or **855 days**, equivalent to **about 2.34 years** of continuous operation on a single charge. This significantly exceeds the initial one-year design target. Overall, the system demonstrated stable communication, dependable performance, and long-term energy efficiency, confirming its suitability for large-area irrigation management and its potential for broader deployment in similar environments.

D. Acknowledgment

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