Optimized Agricultural Water Regulation Through Through IOT Systems and Terrain Modeling using Miniatures

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Abstract

This study aims to develop and evaluate an Internet of Things (IoT)-based optimized water distribution system for palay (rice) agriculture in Sitio Sapa, Barangay Tamboilan, Municipality of Dumangas, Province of Iloilo, the Philippines.. The research addresses critical challenges in agricultural water management, including uneven distribution between upstream and downstream users, water wastage, and the need for precise irrigation based on crop growth stages. The proposed system integrates real-time monitoring through a layered architecture comprising sensor, data communication, cloud, automation, and user layers. The system utilizes LoRa transceivers for reliable long-distance data transmission while minimizing power consumption. Environmental parameters including soil moisture, humidity, temperature, and rainfall are monitored through sensors. The system employs solenoid valves and a positive displacement pump controlled by microcontrollers to automate water distribution. The study will evaluate the system's performance through analysis of water use efficiency, energy consumption, and system responsiveness. This research contributes to sustainable agriculture by promoting efficient water resource management while ensuring equitable distribution among farmers.

Keywords: Internet of Things, Wireless sensor networks, Real-time systems, Embedded systems, Agricultural applications, Water resources, Automation, Precision agriculture, LoRa communication

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Chapter 1

Introduction

1.1 Overview

Agriculture plays a vital role in the Philippines' economy, with rice farming being particularly significant as it contributes approximately 20% of the country's Gross Value Added (GVA). While irrigation systems are crucial for enhancing rural development and agricultural productivity, many areas face persistent challenges in water management. Despite significant progress in expanding irrigated areas through the National Irrigation Administration (NIA) and substantial government budget allocations for irrigation infrastructure, the quality of existing irrigation services remains limited due to several factors.

The aging infrastructure of many irrigation canal systems requires frequent maintenance and rehabilitation, while improper resource management has hindered timely system upgrades. A critical issue is the uneven distribution of water between upstream and downstream users, resulting in some farms experiencing water shortages while others have excess water that goes to waste. These challenges are further compounded by the impacts of climate change, including increased droughts and floods, making it difficult to maintain a reliable water supply to farmers, particularly in vulnerable areas. Furthermore, conventional irrigation systems supply water without considering specific crop needs, soil conditions, or weather parameters, leading to inefficient water use.

Recent studies have shown that modernizing traditional designs and operation schemes can significantly improve efficiency and fairness in water distribution. The implementation of precision agriculture techniques, smart water irrigation systems using the Internet of Things in particular, have emerged as promising solutions to the aforementioned agricultural challenges.

1.2 Problem Statement

The current irrigation system in the Municipality of Dumangas, Iloilo faces several critical challenges that affect agricultural productivity and resource sustainability:

1. Inefficient Water Distribution:
   - Upstream farms often receive excessive water while downstream farms experience shortages
   - Lack of real-time monitoring leads to improper water allocation
   - Traditional irrigation methods fail to account for varying crop water requirements
2. Limited Technology Integration:
   - Absence of automated systems for water distribution control
   - Insufficient data collection for informed decision-making
   - Manual intervention requirements increase operational inefficiencies
3. Resource Management Issues:
   - High energy consumption due to unoptimized pump operations
   - Water wastage from improper timing and distribution
   - Limited ability to adapt to changing environmental conditions
4. Monitoring and Control Challenges:
   - Lack of real-time feedback on soil moisture and environmental conditions
   - Difficulty in maintaining optimal water levels across different growth stages
   - Inability to respond quickly to changing weather patterns

These problems result in reduced crop yields, increased operational costs, and unsustainable water usage, highlighting the need for an intelligent, automated irrigation system.

1.3 Research Objectives

1.3.1 General Objective

To develop and implement an IoT-based smart irrigation system that optimizes water distribution for rice farming in Dumangas, Iloilo through automated monitoring, control, and distribution mechanisms.

1.3.2 Specific Objectives

1. To design and implement a sensor network system that monitors soil moisture, humidity, temperature, and rainfall in real-time
2. To develop a LoRa-based communication infrastructure for reliable data transmission across agricultural areas
3. To implement an automated control system for water distribution using solenoid valves and positive displacement pumps
4. To develop a web-based interface for farmers to monitor and control irrigation parameters
5. To evaluate the system's performance in terms of water use efficiency, energy consumption, and system responsiveness

1.4 Scope and Limitations of the Research

The study will focus on:

- Development of the IoT-based irrigation system within selected rice farms in Dumangas, Iloilo
- Implementation of sensor networks for environmental monitoring
- Creation of automation algorithms for water distribution
- Development of a user interface for system control and monitoring

Limitations include:

- The system will be tested on a limited number of farm plots
- Weather conditions during the testing period may not represent all possible scenarios
- The study will not address policy-related irrigation management issues
- Economic analysis will be limited to direct operational costs and savings

1.5 Significance of the Research

This research contributes to the advancement of agricultural technology and sustainable farming practices through:

Technical Contributions:

- Development of an integrated IoT architecture for precision irrigation
- Implementation of LoRa-based communication for agricultural applications
- Creation of optimization algorithms for water distribution in rice farming
- Integration of real-time monitoring with automated control systems

Societal Impact:

- Enhanced water resource management for agricultural sustainability
- Improved farming efficiency through automated irrigation
- Reduced operational costs for farmers through optimized resource usage
- More equitable water distribution among farming communities
- Contribution to food security through improved rice farming practices

Environmental Benefits:

- Reduced water wastage through precise irrigation control
- Lower energy consumption through optimized pump operations
- Decreased environmental impact of agricultural practices

Chapter 2

Review of Related Literature

Spatial and temporal variations in soil properties, hydraulic characteristics in particular, influence water retention, nutrient availability, and ultimately, crop water demand, yield, and quality. Variability in field conditions that can stem from either natural processes or human-induced factors, in this case irrigation management and supply, can significantly impact crop performance. In the local context, water scarcity, inequitable distribution, and climate change are pressing concerns for Filipino farmlands relying on a steady supply of irrigation water.

The uneven distribution of water in canal irrigation systems, where upstream farmers often receive more water than they need while downstream farmers suffer from shortages, results in significant water wastage and reduced agricultural productivity. Conventional irrigation systems also supply irrigation water without considering the destination's crop, soil, and weather conditions, among other things (Vories et al., 2021).

2.1 Water Use Efficiency

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) are key metrics for evaluating how effectively water is used in agriculture. These metrics are often calculated as the ratio of crop yield to the amount of water applied through irrigation and rainfall (Rai, Singh, & Upadhyay, 2017). While these definitions are commonly used at the farm level, IWUE and WUE can also be assessed at larger scales, such as irrigation districts or river basins (Qureshi, Grafton, Kirby, & Hanjra, 2011).

As several studies show, higher levels of efficiency and fairness are achieved by altering traditional designs (Ghumman, Ahmad, & Usman, 2012; Rezapour Tabari, Hosseinzadeh Talaee, & Aghamohammadi, 2014) and operation scheme (Bhadra, Ozger, & Sen, 2010; Fele, Gorla, et al., 2014; van Overloop, van der Krogt, & De Schutter, 2014) of the irrigation systems. Implementation of fair water allocation and policies in irrigation canal management also ensures agricultural productivity and sustainability (Gany, 2019).

2.2 Precision Irrigation

Precision agriculture is a data-driven approach to managing farms and food production. Its sub-branch, precision irrigation (PI) which deals with supplying plants with precisely calculated amounts of irrigation water directly to the plants' roots at designated time intervals, is slowly gaining traction as a solution to overarching agricultural problems (Abioye et al., 2020). The overall goal of PI is to optimize water use and boost crop yields, while reducing strain on natural water resources. PI is comprised of two major components: the physical pathway for the irrigation water and the control and management system that regulates the irrigation system. When all conditions are met, the technique eliminates both fertilizer leaching and deep percolation from irrigation runoff, as well as any plant stress from lack of water.

Literature showed that a time domain transmission (TDT) PI system can use up to 53% less water compared to a fixed irrigation system, potentially cutting down a great amount of production cost for irrigators (Blonquist, Jones, & Robinson, 2006). In humid climates, where water scarcity is less of an issue, another study with PI also displayed a 23% reduction in CO2 emissions, along with a 22.6% reduction in water consumption, compared to a conventional irrigation system (El chami, Knox, Daccache, & Weatherhead, 2019). PI systems, specifically surface drip and sub-surface drip systems, have also been tested to perform better than a sprinkler-based system in an arid environment, saving 35.7% and 29.2% more water, respectively (Almarshadi & Ismail, 2011).

The success of the system is dependent on an accurate understanding of all spatial and temporal variables involved in the crop's growth (Anjum, Cheema, Hussain, & Wu, 2023). This requires closely monitoring plant responses to changes in their environment, such as soil moisture and plant water stress, then recursively optimizing irrigation schedules using this information.

2.3 IoT Based Smart Irrigation Systems

Effective implementations of precision irrigation rely heavily on accurate and timely data collection and analysis. IoT-based smart irrigation systems have the capacity to improve a PI system's performance with a modern technological backbone. Integrating sensors, actuators, and cloud connectivity can enable real-time monitoring of soil moisture, plant health, and weather conditions necessary for an optimum PI system while being low-cost and easy to set up.

Eggplant and tomato plants raised using an IoT-based irrigation system was able to save a total of 44% in water expenditure (Palconit et al., 2020). In addition to having consumed less water, their tomato plants significantly increased in height, grew more leaves, and looked better appearance-wise compared to the control group after 4 weeks, while the eggplant plants also looked better appearance-wise and grew more leaves but only by a slight margin compared to their respective control group after week 4.

There are many similar studies showcasing how IoT-based irrigation systems can potentially improve water management by optimizing water distribution, reducing waste, and preserving soil quality (Abioye et al., 2020; Bwambale, Abagale, & Anornu, 2022; Obaideen et al., 2022). Their prototypes are relatively user-friendly and simple, which would be very helpful for small-scale farmers who might not be proficient with technology. However, most of these studies are mostly prototypes implemented in miniature plots or nurseries or are likely designed with independent small-scale farms in mind. Multiple farms using a shared irrigation system can sometimes have problems arising from multiple agents having conflicting interests.

2.3.1 Irrigation Monitoring

A PI system requires accurate real-time data of environmental conditions vital to the plant's health and subsequent analysis of the data collected at regular intervals (Abioye et al., 2020). Specialized sensors can track crop conditions in real-time, assisting farmers in determining when and how much water to apply while avoiding over- or under-irrigation.

In a review (García, Parra, Jimenez, Lloret, & Lorenz, 2020) of precision irrigation systems, among all environmental variables, soil moisture is the most utilized parameter. Other frequently used weather conditions monitored are air temperature and humidity. The sensors used tend to be the low-cost ones as opposed to commercial sensors. Calibration plays a huge role in ensuring accuracy of the received data in low-cost sensors (Hojaiji, Kalantarian, Bui, King, & Sarrafzadeh, 2017). However, most of the studies reviewed did not include how each sensor was calibrated. Majority also did not mention the sensors' specifications.

2.4 Chapter Summary

Chapter 3

Research Methodology

This chapter lists and discusses the specific steps and activities that will be performed to develop and evaluate the IoT-based optimized water distribution system for palay (rice) agriculture in Sitio Sapa, Barangay Tamboilan, Municipality of Dumangas, Province of Iloilo, the Philippines.

3.1 Research Activities

The research will employ a framework based on IoT and automation to address the following research questions:

1. How can IoT-based smart irrigation systems aid in maximizing the reach of irrigation water distribution in Sitio Sapa, Barangay Tamboilan, Dumangas, Iloilo?
2. How can IoT-based smart irrigation systems reduce the water loss in water distribution?

The methodology will follow these steps:

System Design and Development:

1. **Sensor Layer:** Sensors will monitor soil moisture, humidity, temperature, and rainfall, providing real-time data to the automation layer.

2. **Data Communication Layer:** LoRa transceiver devices will be utilized to facilitate the transmission of data from the sensors to the central controller.

3. **Automation Layer:** Two types of microcontrollers will be used - a sensor microcontroller responsible for data collection and a central controller for processing and decision-making.

4. **Actuators:** Actuators such as a 5V pump and servo motors will be used for water distribution and path control.

5. **Cloud Layer:** A cloud-based system will process the collected data, store it in a SQLite database, and refine irrigation schedules to balance soil moisture levels and water conservation.

6. **User Layer:** Farmers will access a web-based interface to view sensor data, control irrigation manually or automatically, and receive alerts for anomalies.

Water Distribution Algorithm Implementation: A fuzzy logic algorithm will be used to process the sensor data in the cloud layer, optimizing irrigation schedules based on crop water needs and energy consumption. This algorithm will refine water distribution strategies such as the amount of water and the duration of pump operation.

Data Collection:

1. **System Performance Data:** Real-time sensor data on soil moisture, humidity, temperature, and rainfall will be collected and used to inform the automation layer's irrigation decisions.

2. **Energy Consumption Data:** Power meters will track energy use by the water pumps and other components, supporting the optimization algorithm's goal of reducing operational costs.

3. **User Interaction and System Responsiveness:** Metrics on farmer interactions and alert response times will be collected to assess the system's effectiveness in assisting decision-making and responding to environmental changes.

Data Analysis:

1. **Water Use Efficiency Analysis:** Sensor data will be analyzed to determine if the fuzzy logic algorithm maintains optimal soil moisture levels

across different growth stages, and the results will be compared to traditional irrigation schedules.

2. **Energy Efficiency Analysis:** Energy consumption data will be analyzed to assess the system's ability to optimize pump usage while maintaining effective irrigation.

3. **System Responsiveness Analysis:** User interface interaction and system alert data will be evaluated to determine the system's responsiveness and user-friendliness.

As the designers and developers of the system, the researchers will be responsible for implementing the hardware and software components, configuring data collection, and developing the optimization algorithm. The researchers will ensure the system's functionality, manage testing, and conduct field simulations to gather data for analysis.

3.2 Calendar of Activities

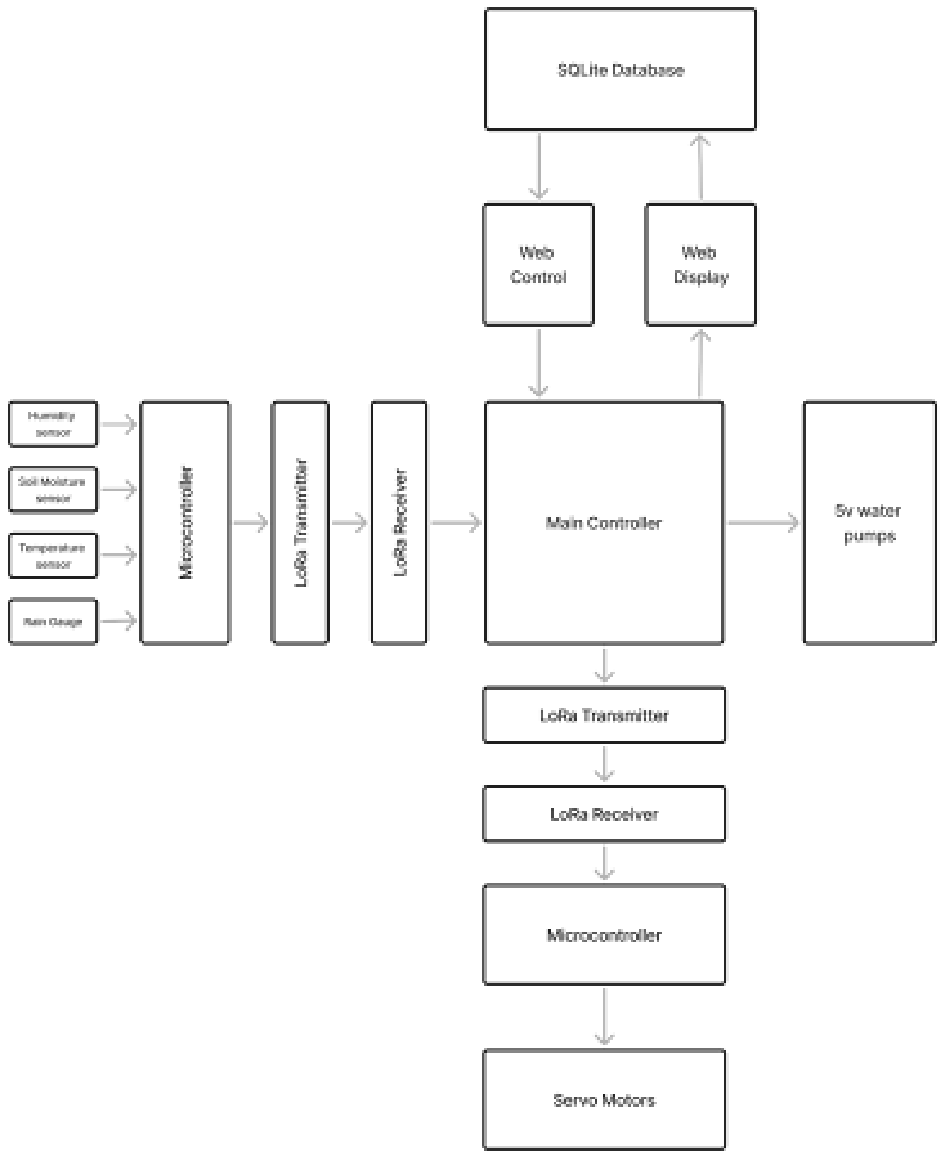

Figure 3.1: Figure 1: Subsystems Diagram for the IoT Based Irrigation System. This shows the connection of the different components of the system from the sensors to the valves.

Chapter 4

Preliminary Results/System Prototype

This chapter presents the preliminary results or the system prototype of your SP. Include screenhots, tables, or graphs and provide the discussion of results.

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Appendix A

Appendix Title

Appendix B

Resource Persons

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