Simulation-Driven Optimized Agricultural Water Regulation Through IOT Systems

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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 P.D. Monfort North, 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 WiFi connection for reliable data transmission while being cost effective. Environmental parameters including water level, humidity, temperature, and rainfall are monitored through sensors. The system employs servo motors and a 5v water pump controlled by microcontrollers to automate water distribution based on the environmental parameters observed. The study will evaluate the system's performance through analysis of water use efficiency 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 agricultural technologies and operational procedures being used in the irrigation system in the Municipality of Dumangas, Iloilo are outdated and riddled with issues. In its current state, the major problem is the unequitable water distribution, with upstream farms receiving excess water while downstream farms suffer from shortages. Both the reliance on traditional methods, which don't collect real-time data nor consider the varying crop growth levels, water requirements, and watering schedules, in addition to the lack of real-time monitoring of environmental and meteorological conditions also lead to inefficient water distribution and water wastage. The absence of any automated system requires the irrigation control and other mechanisms to be manually managed, which is highly inefficient. Pump operations, aside from costing a lot of energy to operate, needs to be manually operated.

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 water level, humidity, temperature, and rainfall in real-time

2. To develop a WiFi-based communication infrastructure for reliable data transmission across irrigation systems

3. To implement an automated control system for water distribution using servo motors and submersible 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 and system responsiveness

1.4 Scope and Limitations of the Research

The study will focus on the development of an IoT-based irrigation system for selected rice farms in Dumangas, Iloilo. This system will involve the implementation of sensor networks to monitor environmental conditions, the creation of automation algorithms to optimize water distribution, and the development of a user interface for system control and monitoring.

The system will be tested on only a limited number of farm plots, and the weather conditions during the testing period may not encompass all possible scenarios. The system will primarily use surface irrigation methods to apply water to the tested plots. Additionally, the study will not delve into policy-related irrigation management issues, and the economic analysis will be confined to direct operational costs and savings.

1.5 Significance of the Research

The significance of the study extends to various stakeholders:

Farmers: The developed IoT-based irrigation system will enhance farming efficiency by automating water distribution, leading to improved crop yields and reduced labor costs. Additionally, the system will help farmers optimize water distribution and usage, resulting in lower operational costs.

Residents of Dumangas, Iloilo: The research contributes to more equitable water distribution among the local farming community. By improving the quality of rice farming, the study also contributes to food security. Furthermore, optimized pump operations will lower energy consumption, minimize the negative environmental impact of agricultural irrigation, and help lessen the effects of climate change on the local residents.

Future Researchers: The implementation of precision irrigation techniques will reduce water wastage, leading to more sustainable water resource management. The study establishes a valuable reference for researchers interested in developing efficient and equitable water distribution schemes for irrigation systems, providing them with a scalable basis for implementation.

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. Conventional irrigation systems also supply irrigation water without considering the destination's crop, soil, and weather conditions, among other things (Vories et al., 2021). In the local context, water scarcity, inequitable distribution, outdated technologies, and climate change are pressing concerns for Filipino farmlands relying on a steady supply of irrigation water.

2.1 Irrigation Water Use Efficiency

Philippine rice production needs to be strengthened to keep up with the growing population. However, the declining water availability due to climate change and pollution keeps hampering agricultural progress efforts. Thus, the necessary approach is threefold: save water, increase water productivity, and increase rice production using less water.

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).

2.1.1 Equitable Irrigation

The uneven distribution of water in community canal irrigation systems, where upstream or head-end farmers often receive more water than they need while downstream or tail-end farmers suffer from shortages, is a significant cause of water wastage and reduced agricultural productivity for the affected farms. In the Philippines specifically, despite undergoing major rehabilitation projects spearheaded by NIA, irrigation services have failed to improve due to inequitable water distribution (Wongprasittiporn, 2007).

Equitable irrigation schemes are necessary for shared irrigation networks to ensure sustainability, especially for areas where water scarcity is a frequent issue. One study shows that tail-end community irrigation farmers who are actively participating in local irrigation operations can even outperform head-end farmers in an effective and equitable irrigation water allocation setup, with 30% of tail-end farmers being able to produce more than 18 tons of produce during the dry season compared to only 26% of head-end ones and 64% of tail-end farmers producing more than 19 tons annually as opposed to only 52% of their counterparts (Kosanlawit, Soni, & Shivakoti, 2017). This shows that flexible, reliable, and equitable water distribution leads to greater paddy yields for rice farmers even in subpar conditions.

2.2 Optimized Irrigation Management

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, usually directly to the plants' roots, at designated time intervals, is slowly gaining traction as a solution to many 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 PI system, particularly one using time domain transmission (TDT), 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 22.6% reduction in water consumption, along with a 23% reduction in CO2 emissions, 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 ultimately 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, and then recursively optimizing irrigation schedules using this information.

2.3 Smart Irrigation Systems

Providing accurate real-time data on environmental conditions and subsequent timely analysis of the data collected are needed for any precision system to achieve its fullest potential (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. IoT-based smart irrigation systems have the capacity to improve an irrigation 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.

2.3.1 IoT-based Prototypes

IoT-based irrigation systems are still limited mainly due to their novelty. There are relatively few software platforms that are capable of simplifying and automating IoT data processes. Consequently, existing middleware and available sensors on the market are also heterogeneous and not standardized. This delays the development of any potential pilot application for smart water management. Prototype systems such as Smart Water Management Platform (SWAMP) and Smart Water-Irrigated Management System (SWIMS) are still in development and far from being widely adapted (Estomata et al., 2024; Kamienski et al., 2018).

Locally, the Water Advisory for Irrigation Scheduling System (WAISS), an irrigation decision support tool which aims to optimize crop water application and provide more effective and efficient water management, is in development (Luyun Jr et al., 2023). The monitoring system field unit, accompanied by a software monitoring interface, sends a short message service (SMS) irrigation advisory to the end-user using the real-time data gathered. The system's capacitance sensors have a comparable accuracy to a calibrated METER EC-5 sensor unit while being cheaper. However, the system only uses soil moisture sensors to provide irrigation advice.

Eggplant and tomato plants were raised using an IoT-based irrigation system that 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 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.

2.3.2 Cost and Calibration

The main IoT cost components described by Ciuffoletti (2018) are infrastructure, development, sensors, energy, and network. The prices of IoT system components are steadily decreasing, thus is it not difficult to reduce expenditure for a single component. However, the main financial challenge in IoT lies with finding a balance that makes the whole system affordable.

Low cost IoT systems generally use controllers that are programmable using the Arduino Integrated Design Environment (IDE), with AVR and ESP8266 boards being two of the most popular categories in this regard (Ciuffoletti, 2018). Other notable examples include Raspberry Pi line and STM32 based boards.

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 condition monitoring sensors are for air temperature and humidity. The sensors used tend to be the low-cost ones as opposed to commercial sensors, implying that most projects give a greater emphasis on reducing the sensor cost component.

Calibration plays a huge role in ensuring the 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. The majority also did not mention the sensors' specifications.

Most IoT systems are hosted over traditional networks such as WiFi and 3G. Low Power Wide Area Network (LPWAN) technologies such as LoRaWan are also slowly gaining popularity as dedicated IoT networks. However, they come with their own drawbacks such as increased development and financial costs since they are relatively new (Ciuffoletti, 2018).

Chapter 3

Research Methodology

This chapter lists and discusses the materials and methodologies used to develop and evaluate the optimization level of the IoT-based miniature water irrigation system prototype for palay (rice) agriculture in P.D Monfort North, Municipality of Dumangas, Province of Iloilo, the Philippines used in this study. In providing detailed descriptions of each component, we aim to ensure a comprehensive understanding of the development and research processes involved in the creation of the irrigation system prototype.

3.1 Research Activities

3.1.1 Materials

This section outlines the development requirements and software utilized in the study, including the frameworks, physical components, and software used.

IoT Components

This study employed an extensive set of information system components to implement a smart irrigation system. Key components for environmental conditions and plant monitoring include HW-038 water level sensors for water level monitoring, DHT22 Temperature and Humidity sensors for measuring the surrounding temperature and humidity, and MH Rain Drop sensors for measuring rainfall. ESP8266 controllers were connected to the sensors via battery clips and configured to handle the sensors' raw data, issuing gate commands to MG90S servo motor gates accordingly over a WiFi connection. One mini submersible pump supplied the system with irrigation water coming from a water source. System information was monitored via a Flutter-based application.

For the initial prototype, the miniature consisted of one HW-038 analog water level sensor, one DHT11 Temperature and Humidity sensor, one MH Rain Drop sensor, one Arduino Nano ATMega328 microcontroller, one NodeMCU V3 ESP8266 ESP-12E Arduino microcontroller, three MG90S servo motors, and one mini submersible pump.

The interaction of each component with other components in the system is depicted in Figure 3.1.

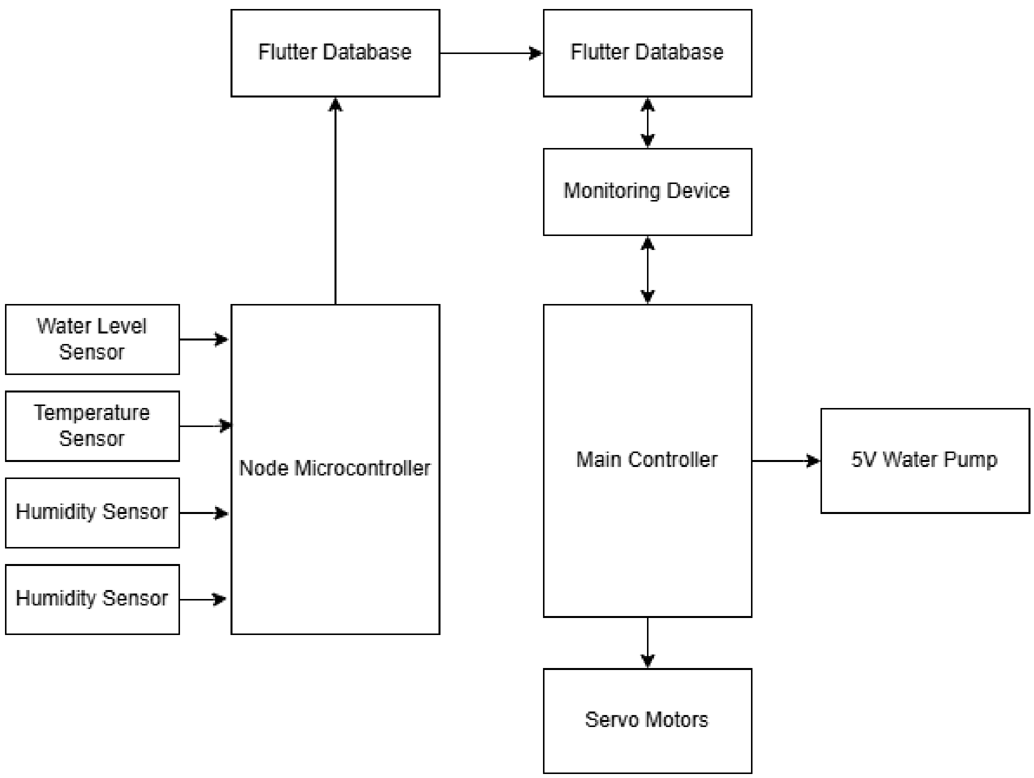

Figure 3.1: System Architecture of the Irrigation System

Miniature Model Materials

The miniature used PVC foam boards for it's base. PVC Foam Board was the primary choice for the miniature irrigation pathway because it is lightweight, waterproof, and resistant to warping. PVC foam board is also used to sculpt and model the main cement waterway that cuts across the farms along a straight line. Real soil is used on top taken from rice fields to ensure accuracy of the model.

3.1.2 Methods

This section presents the methods and procedures followed throughout the study.

Environmental Conditions Monitoring

Each cluster contained a set of one water level sensor and one temperature and humidity sensor, with an additional rainfall sensor shared by all clusters. The water level sensor was placed along the irrigation path while the temperature and humidity was elevated through a pole. Each set had a dedicated microcontroller responsible for collecting data from the water level and the temperature and humidity sensors. The shared rainfall sensor was also elevated and connected to each dedicated microcontroller.

Water Path

The system will simulate the existing water paths in the rice fields of P.D. Monfort North, Dumangas, Iloilo, Philippines. Unity 3D was used to create a 3D model of the real-life irrigation system. The terrain was manually sculpted using a Google Maps image of the area as an outlined reference. The image was then used as texture for the 3D model to give it a realistic look.

The primary waterway was replicated using a long piece of PVC foam board. The upper layer of the miniature was modeled with layers of real soil with canals dug into it to model the surface irrigation that branches off from the main waterway.

Irrigation Gate Control

The system control was programmed through NodeMCU ESP8266, an open-source IoT software development environment. NodeMCU ESP8266 is a common choice for IoT-based systems because of its simplicity, built-in modules, and the abundance of community-provided support for it.

Real-time water level, temperature, and rainfall data provided by the respective

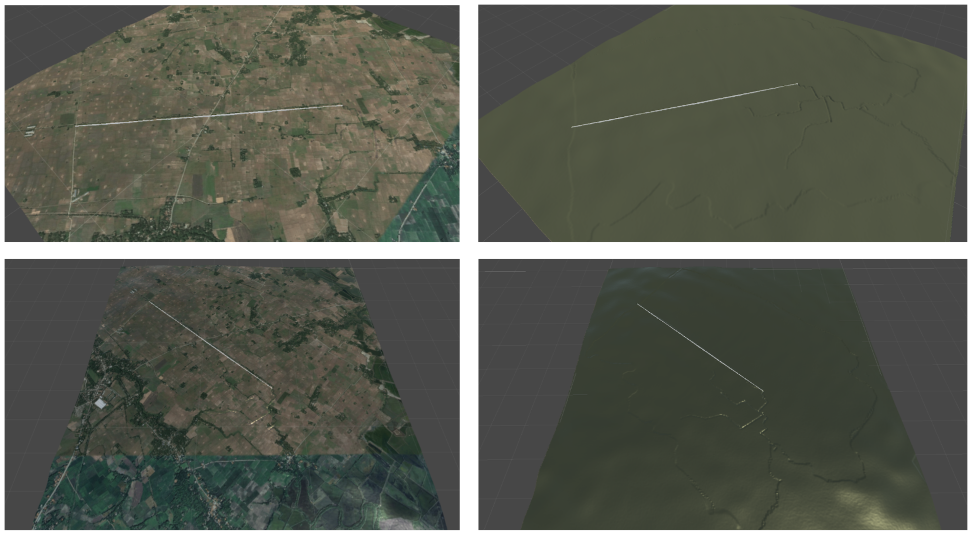

Figure 3.2: 3D Model of the Target Area

sensors are collected by a dedicated microcontroller, which in turn is connected to a central microcontroller responsible for computing the needed water allocation and controlling the system's gates. The amount of water supplied to the farms is calculated based on the standard crop water requirement equation used by FAO (Howell, 2001), which is a simplified version of the Penman-Monteith equation, and the observed data from the node sensors.

Interface

System information was displayed through a Flutter-based mobile app connected to Firebase. Flutter, an open source framework for building cross-platform apps, was used as data visualization and IoT functionality libraries were the main considerations for the system interface, all of which Flutter provides, in conjunction with Firebase for offline mobile support.

3.1.3 Price Comparative Analysis

Three sets of infrastructure and sensor components were considered for this study. All three sets were compared according to the total of the lowest prices of each individual component taken from Shopee, one of the leading online shopping platforms in the Philippines.

3.1.4 Functionality Tests

The functionality test for the prototype irrigation system involved a comprehensive evaluation of each chosen component to ensure both accuracy and reliability. Each sensor's accuracy was assessed individually. Water level sensors were assessed by changing the water level of the container around it. Temperature and humidity sensors were tested by introducing change to the surrounding conditions via a lighter. Rainfall sensors were exposed to differing amounts of water droplets. The microcontrollers were tested for accurate and stable downstream and upstream communication over the WiFi connection. The water pump and servo motors were also tested to ensure they function correctly and activate appropriately. Data processes were observed via changes to the Firebase database and ESP8266 development environment.

3.2 Calendar of Activities

Table 3.1 shows a Gantt chart of the activities. Each bullet represents approximately one week worth of activity.

Table 3.1: Timetable of Activities

Activities	**Sep**	**Oct**	**Nov**	**Dec**
Review of Existing Irrigation and IoT Systems	••	• • •		
System Designing and Component Deliberation		•	• • •	
Component Programming			••	•
System and Miniature Creation			••	•
Functionality Tests and Results				•
Documentation			••	•

Chapter 4

Preliminary Results/System Prototype

This chapter presents the preliminary functionality test results and the system prototype of the study.

4.1 Price Comparative Analysis

Different sets of physical components were considered to be used for the initial prototype. Tables 4.1, 4.2, 4.3 list different sets of physical IoT devices and their respective observed prices.

Table 4.1: Node Set Option A

Hardware Name	**Qty**	**Price**	**Total**
9V Battery Clip with DC Plug	2	75	150
HW-038 Water Level Sensor	3	39	117
DHT22 Temperature and Humidity Sensor Module	3	195	585
Arduino Nano ATmega328P CH340G CH340 Soldered Unsolder Board	1	399.75	399.75
NodeMCU V3 ESP8266 ESP-12E Arduino CH340 WiFi Board	1	159	159
Mini Submersible Pump Water Pump Fish Tanks Aquarium Fountain DC 5V	1	69	69
SX1278 LoRa Module Ra-02 433MHz Wireless Spread Spectrum	2	275	550
Rain Water Sensor Module	3	55	165
Servo Motor Metal Gear	3	195	585
2 x 6dBi 2.4GHz 5GHz Dual Band WiFi RP-SMA Antenna + 2 x 35cm U.fl / IPEX Cable	2	112	224
		TOTAL	**3003.75**

Table 4.2: Node Set Option B

Hardware Name	**Qty**	**Price**	**Total**
9V Battery Clip with DC Plug	2	75	150
HW-038 Water Level Sensor	3	39	117
DHT22 Temperature and Humidity Sensor Module	3	195	585
NodeMCU V3 ESP8266 ESP-12E Arduino CH340 WiFi Board	4	159	636
Mini Submersible Pump Water Pump Fish Tanks Aquarium Fountain DC 5V	1	69	69
Rain Water Sensor Module	3	55	165
Servo Motor Metal Gear	3	195	585
		TOTAL	**2307**

Table 4.3: Node Set Option C

Hardware Name	**Qty**	**Price**	**Total**
9V Battery Clip with DC Plug	2	75	150
HW-038 Water Level Sensor	3	39	117
DHT22 Temperature and Humidity Sensor Module	3	195	585
Arduino Nano ATmega328P CH340G CH340 Soldered Unsolder Board	1	399.75	399.75
Raspberry pi PICO	1	399	399
NodeMCU V3 ESP8266 ESP-12E Arduino CH340 WiFi Board	3	159	477
Mini Submersible Pump Water Pump Fish Tanks Aquarium Fountain DC 5V	1	69	69
SX1278 LoRa Module Ra-02 433MHz Wireless Spread Spectrum	2	275	550
Rain Water Sensor Module	3	55	165
Servo Motor Metal Gear	3	195	585
2 x 6dBi 2.4GHz 5GHz Dual Band WiFi RP-SMA Antenna + 2 x 35cm U.fl / IPEX Cable	2	112	224
		TOTAL	**3720.75**

Node Set A consists of various sensors and electronic components, including battery clips, water level and rain water sensors, temperature and humidity modules, an Arduino Nano board, a NodeMCU WiFi board, a mini submersible pump, LoRa modules, servo motors, and WiFi antennas, with a total cost of ₱3,003.75. Node Set B is similar but with a reduced configuration, featuring fewer components and board types, primarily using multiple NodeMCU WiFi boards, and costing ₱2,307.00. Node Set C represents the most populated option, incorporating additional components like a Raspberry Pi PICO, maintaining the core sensor and communication elements of the previous sets, and reaching a total cost of ₱3,720.75. As shown in tables 4.1, 4.2, 4.3, each set includes multiple sensors for environmental monitoring, communication modules, and control components, having variations in board types and quantities that impact the overall system configuration and price.

Table 4.4: Comparison of Node Set Options

Feature	Node Set Option A	Node Set Option B	Node Set Option C
Total Cost	₱3,003.75	₱2,307	₱3,720.75
Key Advantages	Reliable long-range communication, potential for lower power consumption	Lower cost in terms of price and development	More powerful processing capabilities, flexibility in communication protocols
Key Disadvantages	More complex setup and configuration, potential interference issues	Limited range, higher power consumption	Higher cost, more complex system

Node Set Option A, utilizing LoRa for long-range communication, offers reliable connectivity but requires more complex setup and configuration. While it potentially consumes less power, it is also susceptible to interference. Node Set Option B, relying on WiFi, is simpler to set up and more cost-effective, but its projected power consumption is higher. Node Set Option C, combining LoRa and WiFi, provides a balance between the two, offering versatility with long-range and short-range connectivity and powerful processing capabilities, but with increased cost and complexity.

After deliberation, the proponents of the study decided to adapt Node Set Option B as the set of initial prototype components.

4.2 Functionality Tests

To ensure that each component in the system is working, the researchers created a checklist if that specific component is working or not as shown in Table 4.5.

Table 4.5: Functionality Test of the Prototype Components

No.	Components	Yes	No
1	9V Battery Clip with DC Plug	/	
2	HW-038 Water Level Sensor	/	
3	DHT22 Temperature and Humidity Sensor Module	/	
4	NodeMCU V3 ESP8266 ESP-12E Arduino CH340 WiFi Board	/	
5	Mini Submersible Pump Water Pump Fish Tanks Aquarium Fountain DC 5V	/	
6	DHT11 Temperature and Humidity Sensor Module	/	
7	Rain Water Sensor Module	/	
8	Servo Motor Metal Gear	/	

Table 4.6: Component Status at Initial and Final Stages

Component	Initial		Final	
	Indicator	**Output**	**Indicator**	**Output**
NodeMCU ESP8266	LED	Blink	LED	Blink
Arduino Nano	LED	Blink	LED	Blink
Water Level Sensor	Serial Display	None	Serial Display	Displays value in percent
Rainfall Sensor	Serial Display and LED	Display none, LED is OFF.	Serial Display and LED	Displays value, LED is ON.
Temperature and Humidity Sensor	Serial Display	Display none	Serial Display	Displays values for temperature and humidity
Firebase Real-time Database	Database	Empty	Database	Gets populated with sensor data

All physical components listed in Table 4.5 were found to be individually operational. Table 4.6 further describes each component's assessment after being connected to other components of the system. Overall, the functionality test results show that the prototype and its individual components are ready for further testing.

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Appendix A

Wiring and Database Documentation

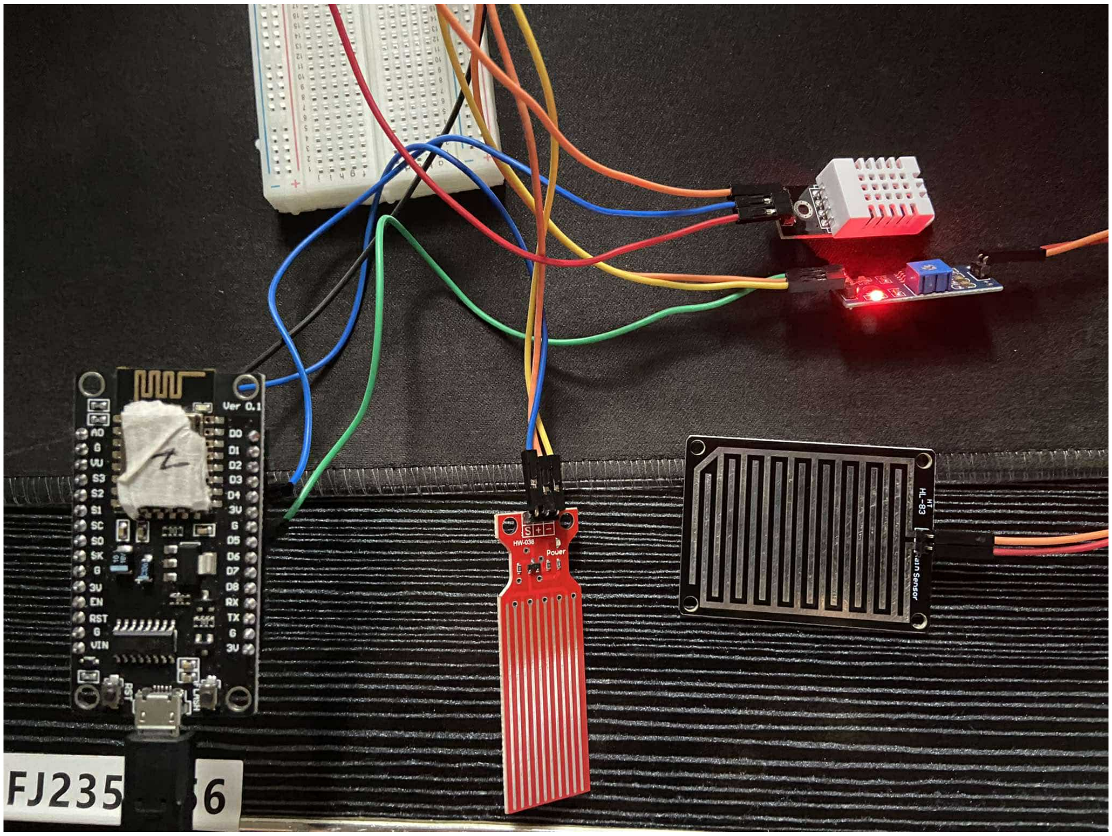

Figure A.1: Physical circuit design

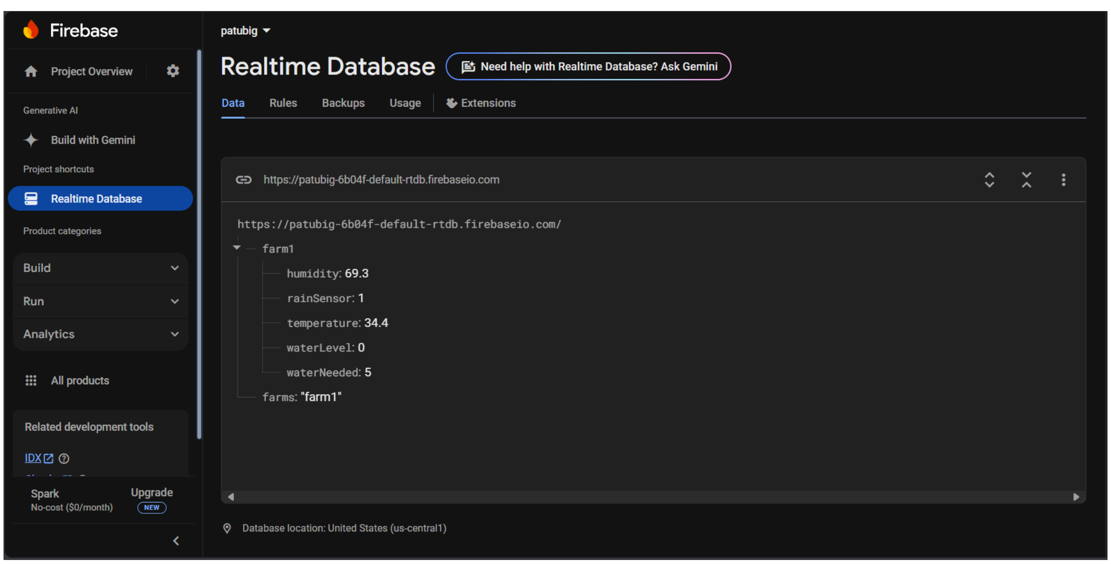

Figure A.2: Data storing part 1

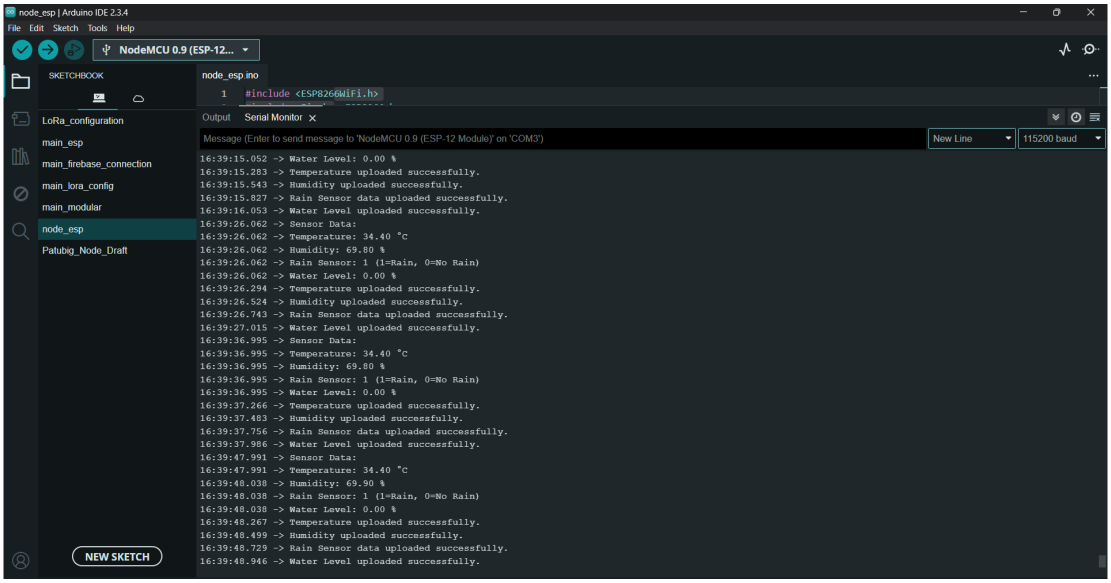

Figure A.3: Data storing part 2

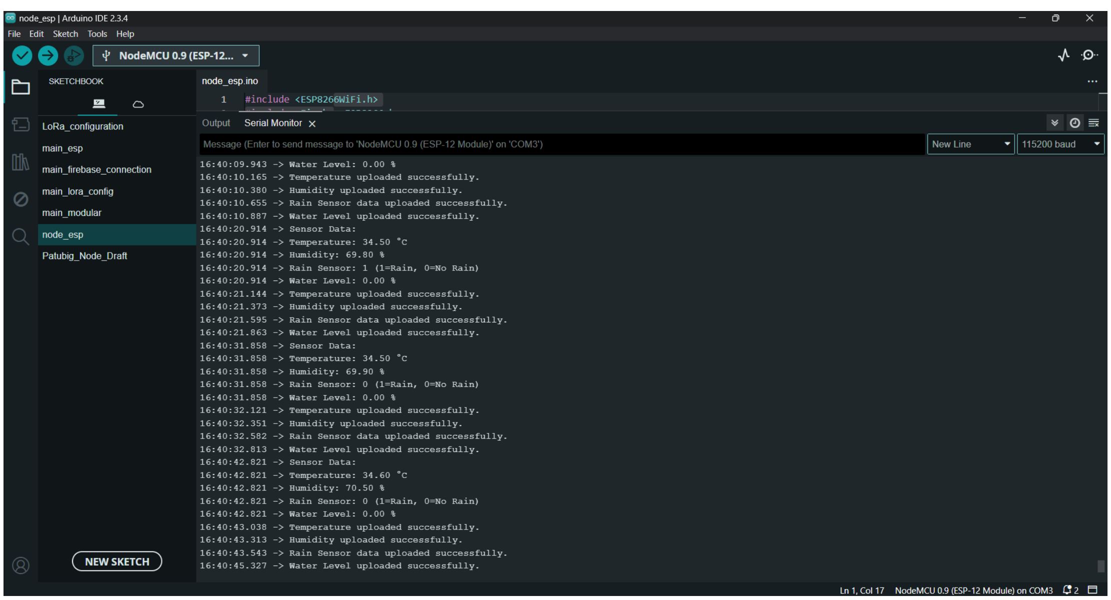

Figure A.4: Data storing part 3

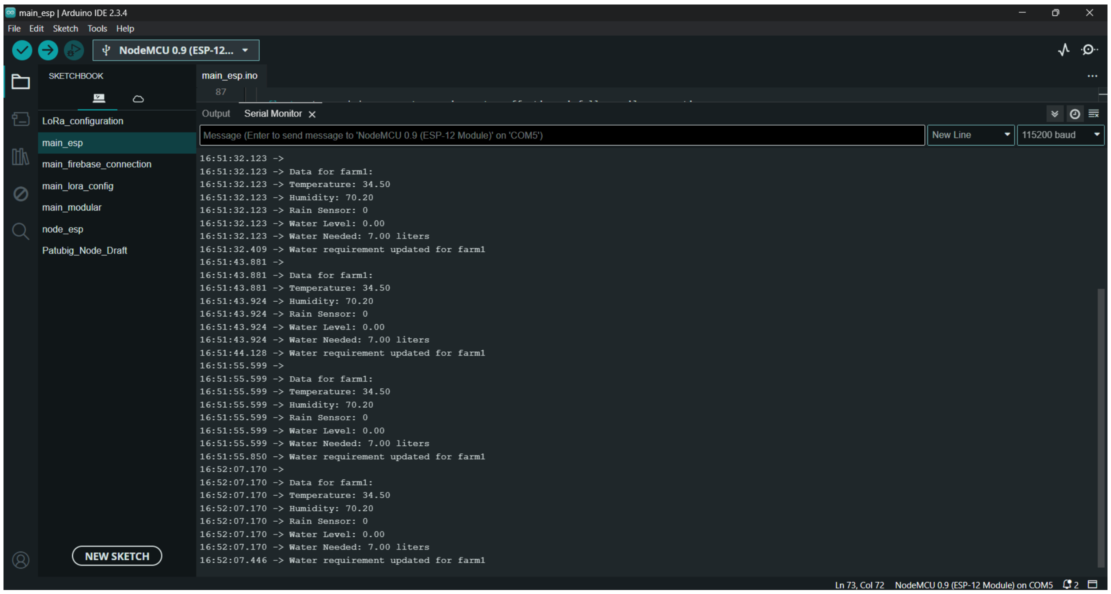

Figure A.5: Data storing part 4

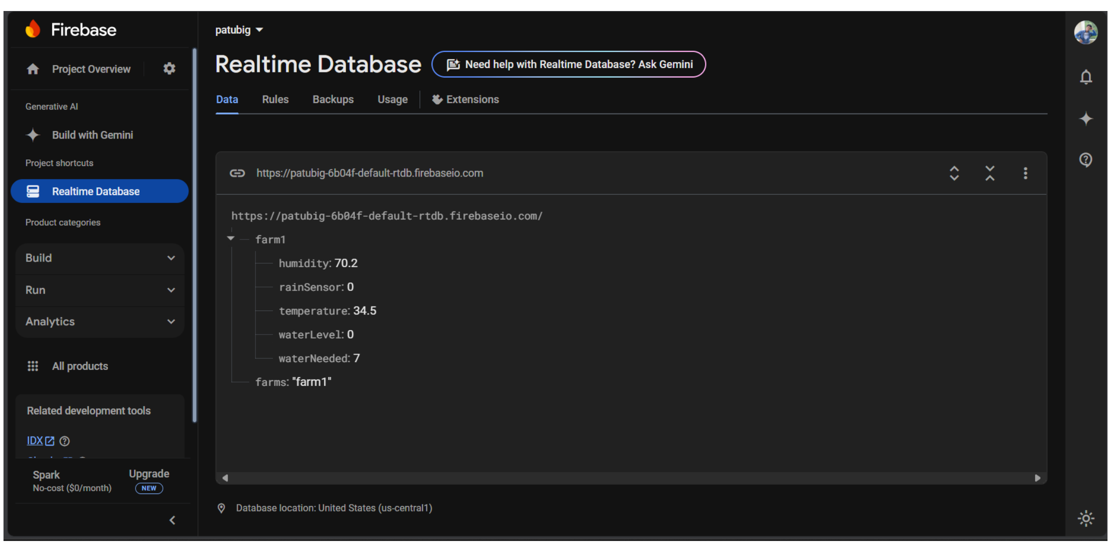

Figure A.6: Data storing part 5

Appendix B

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