

**WIRELESS SENSOR NETWORKS FOR AUTOMATING
IRRIGATION IN RWANDA**

MASTER'S DISSERTATION

**Submitted in partial fulfillment of the Requirements for the award of
Master of Science in Information and Communication Technology
Option : Operational Communication (Msc. SoICT).**

Submitted by

NTAKIRUTIMANA Elie

REF. N^o: 221028512

Supervisor: Dr. KABANDANA Innocent

August, 2024

**WIRELESS SENSOR NETWORKS FOR AUTOMATING
IRRIGATION IN RWANDA**

MASTER'S DISSERTATION

**Submitted in partial fulfillment of the Requirements for the award of
Master of Science in Information and Communication Technology
Option: Operational Communication (Msc. SoICT).**

Submitted by

NTAKIRUTIMANA Elie

REF. N^o: 221028512

August, 2024

DEDICATION

I, **Mr. NTAKIRUTIMANA Elie**, hereby that this thesis is my original work and has never been submitted before for any academic award either in this or other institutions of higher learning for academic publication or any other purpose. To the best of my knowledge and brief, the thesis contains no material previously published or written by another person except where the references used here from other journal are indicated in the references section.

Names: NTAKIRUTIMANA Elie

REG. No: 221028512

Signature:

Date: / /2024

CERTIFICATE

This is to certify that the project entitled “Wireless Sensor Network for Automating Irrigation in Rwanda” is a record of original work done by Elie NTAKIRUTIMANA 2210280512 MSc. Degree student in Information and Communication Technology (Option: Operational Communication). This work has been submitted under the guidance of Dr. Innocent KABANDANA.

Signature:



Date: 22 / 10 / 2024

Head of Department

Dr. HARELIMANA Dominique

ACKNOWLEDGEMENT

Our praise and sincere thanks to our God Almighty who blessed us with His grace and blessing throughout our lives.

We deeply offer our sincere thanks to all of management of the College of Science and Technology (CST) for their helpful guidance and unlimited support. I'm grateful to all lectures and all the persons supported me during my study as well as this thesis preparation.

I sincerely have deep recognition to my supervisor **Dr. KABANDANA Innocent** who guided me in the accomplishment of this work, especially for their substantial advice, professional assistance, guidance, and precious ideas.

I am grateful thanks to the management of **STES Group Ltd** for their cooperation and efforts to provide me needed information to the achievement of goals of this work.

A big and sincere thanks to our dear beloved parents **Mr. RWAMAKUBA David** and **MUKAKARIBANYI Elianne** who have helped and supported me during my study to the completion of this work, my brothers **NDAMUKUNDA Ismaël**, **NAYITURIKI Joseph**, and **MUHAYITETO Ruben**, for their support and encouragement.

No one is truly self-made, a cordial thanks to my colleagues and friends, especially to my best friend **Claudine MUKAMANZI** for their encouragement and invaluable assistance.

May the Almighty God bless you abundantly.

ABSTRACT

The irrigated area in Rwanda is Over 27 000 Ha and has been tremendously increasing. The irrigation facilities that supply agricultural water are distributed at low density across areas, these facilities experience higher water demand and require efficient maintenance operations. Traditional irrigation systems encounter numerous critical limitations, such as dependence on human presence, inaccurate water distribution, time consuming and inconsistency irrigation timing, this system is very difficult due to the scarcity of water which is primarily caused by rapid growth of population and climate. Internet of Things (IoT) is a new Technique to support the modernization of agriculture. Since through automation IoT can make agriculture and all farming processes more efficient by reducing the need for human interventions and required irrigation to field. So, due to this, it is proposed wireless sensor network for automation irrigation system using IoT devices to save water wastage and time. In this methodology it is planned to use the soil moisture sensors to measure the parameters of the soil based on the value of soil moisture automatically make the microcontroller to relay a signal to a distant location where the pumping and well system for irrigation system located to turn on or off the water pump. The soil moisture level will be displayed on a web application and the system sends a short message (SMS) to the farmer's mobile phone regarding the level of water required for crops vary by type, climate, growth stage, soil, and method of irrigation. Cereals like maize, wheat, rice, and need 450-2000 mm of water; vegetables like potatoes and tomatoes, require 300-1200 mm; fruits like apples and oranges need 500-1200 mm; legumes like beans, lentils, and peas are require 300-500 mm. Dry climates and sandy soils increase water required, while cool, humid climates and clay soils reduce them. Efficient irrigation methods, such as drip irrigation, can lower water usage. Soil moisture monitoring and weather forecasts help enhancing irrigation schedules and water use efficiency.

This study therefore presents a prototype for an Internet of Things (IoT) devices to improve the technology in agriculture production and thus increase the productivity by using the wireless sensor networks (WSNs) to collect data in real time, storing the data into the cloud, monitoring the status of crops according to the climate changes in the light. Finally, the result showed that this technology performed best with an accuracy of 91.7% and the famers are satisfied with this method.

Keywords: Automated irrigation, soil moisture, micro-controller, NodeMCU,

Wireless sensor network (WSN).

TABLE OF CONTENTS

DEDICATION	i
CERTIFICATE	ii
ACKNOWLEDGEMENT	iii
ABSTRACT	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
LIST OF TABLES	viii
ABBREVIATIONS	ix
CHAPTER 1: INTRODUCTION	1
1.1. Background of study	1
1.2. Motivation	4
1.3. Problem Statement	4
1.4. Research Questions	5
1.5. Hypothesis	5
1.6. Objectives	6
1.7. Challenges	6
1.8. Structure of the study	7
CHAPTER 2: LITERATURE REVIEW	8
2.1. Wireless Sensor Network in Irrigation	8
2.2. The Soil Property	10
2.3. Soil Moisture Content	10
2.4. Methods of measurement of soil moisture sensors	11
2.4.1. Oven drying method.	11
2.4.2. Gravimetric method.	11

2.4.3. Tensiometer Method	11
2.4.4. Neutron Method	12
2.4.5. Gamma-Ray Method.....	12
2.4.6. Remote sensing method.....	12
CHAPTER 3: RESEARCH METHODOLOGY	14
3.1. Research Process.....	14
3.2. Research Design.....	15
3.3. Baseline Survey	15
3.4. Data Collection	16
3.4.1. Interview	16
3.4.2. Observation.....	17
3.4.3. Documentation.....	17
4. System Design.....	17
4.1. Hardware components.....	18
4.2. Software of proposed system	20
5. Proposed System	23
6. Developed New System	23
CHAPTER 4: RESULT AND DISCUSSION.....	25
4.1. Graphical presentation	25
4.2. Real-time gathering of soil data Hardware implementation	26
CHAPTER 5: CONCLUSION AND RECOMMENDATION	30
5.1. Conclusion	30
5.2. Recommendations.....	31
REFERENCES	33
APPENDIX I: QUESTIONNAIRE	36
APPENDIX II: CODE IN ARDUINO IDE.....	39

LIST OF FIGURES

Figure 1. 1: Map of Central Africa Continent.....	1
Figure 3. 1: Research Process	15
Figure 3. 2 :Block diagram for automating irrigation system.....	18
Figure 3. 3: ESP8266 NodeMCU	19
Figure 3. 4: Soil Moisture Sensor	19
Figure 3. 5: Rely Module.....	19
Figure 3. 6: Mini water pump.	20
Figure 3. 7: Power supply	20
Figure 3. 8: Program in Arduino IDE.....	21
Figure 3. 9: Flowchart for NodeMCU	22
Figure 3. 10: Proposed system architecture design.....	23
Figure 4. 1: Irrigation systems the farmers used in this research (%).....	25
Figure 4. 2: Picture shows complete System.	26
Figure 4. 3: Login Page.....	27
Figure 4. 4: Level of moisture on dashboard.	28
Figure 4. 5: Graphics of Soil Moisture Level Measurement	28
Figure 4. 6: SMS notifications in mobile Phone.....	29

LIST OF TABLES

Table 1.1: Agriculture Season and crops grow in Rwanda [10].	3
--	---

ABBREVIATIONS

CST	College of Science and Technology
FDR	Frequency Domain Reflectometry
GDP	Gross Domestic Product
GPIO	General Purpose Input/Output
ICT	Information Communication and Technology
IDE	Integrated Development Environment
IoT	Internet of Things
MINAGRI	Ministry of Agriculture
NISR	National Institute of Statistics of Rwanda
NPK	nitrogen (N), phosphorus (P), and potassium (K)
PCB	Printed Circuit Board
SAS	Seasonal Agricultural Survey
SMSs	Soil moisture sensors
STES	Seed Technology Engineering and Science
TDR	Time Domain Reflectometry
Wi-Fi	Wireless Fidelity
WSN	Wireless sensor network

CHAPTER 1: INTRODUCTION

1.1. Background of study

The Republic of Rwanda is a nation that know as landlocked discover in Central Africa continent (see Figure 1.1). Its borders are as follows : Burundi to the South, Tanzania to the East, Uganda to the North and Democratic Republic of the Congo to the West. The country is located 120km south of the equator, the land area of approximately 26,000km² , and is mainly hilly, it is referred to as “ The Land of a Thousand Hills ”, through there are also swamps and extensive mountainous areas and marshes [1][2]. Currently, the total population of 12 million, the current trends indicates that in 2100, this number will triple. Population projections are necessary for a country to manage its infrastructure and plan its policies. From the perspective of economics, the young population portends considerable workforce in the future for supporting the goals and strategies for national development. Despite the benefits of population growth, every economic strategy must carefully assess the burden that rising numbers would place on the country's natural assets in terms of pollution, food production, sustainable energy generation, ecosystem integrity, and biodiversity [3].

Several areas of government policy and strategy are critical for the agricultural sector to make its full potential contribution to the economy. Such a population growth has been recognized to become one of the government's major obstacles to achieving national food security [4].

The figure 1.1 below shows the country of Rwanda as a landlocked in central Africa continent.



Figure 1. 1: Map of Central Africa Continent

According to government Rwanda vision's economic policy discovers that the agriculture sector will continue to be the most significant industrial sector in the future, maintaining its leading position in GDP shares and creating jobs while taking up a large portion of all other sectors. The government anticipates taking the country away from its reliance on agriculture for self-sufficiency closer to a middle-income status by reducing the GDP share of the agriculture sector from its peak of 48% in 2006 to 33% in 2020. Rwanda has ranked among the top three countries in Africa throughout the previous 20 years due to its remarkable record of nearly 8% annual economic growth (and over 5% per capita growth). Academics generally agree that in terms of agricultural development, Rwanda has been successful in increasing the volume of its total agricultural production, mostly due to significant yield growth. An often-cited summary states that production volumes of beans doubled, rice and Irish potato output increased by 30%, and cassava, maize, and wheat tripled between 2007 and 2011 [5] [3].

Rwanda is a country in central Africa with geographic coordinates between 1004' and 2051' latitude South and between 28045 and 31015 longitude East [6]. Rwanda's economy is greatly impacted by the agricultural sector, as 90% of total population work in this field of agriculture. Considering national agriculture accounted for 91% of food production, 36% of GDP, and 70% of revenue, poor performance of the agricultural industry has an impact on development from those various levels. Rwanda is a country with a diverse landscape that includes several lakes, beautiful valleys, and rolling hills with its capital city, Kigali located in central part of the country [7].

In agriculture, irrigation is critical to feeding a growing population and will surely play a significant role in the future. In regions with short growing seasons, it not only expands the season but also increases yields and income. Rwanda has three seasons of agriculture, Season A, B and C respectively where season "A" starts in September and ends in February of the following calendar year, the season "B" starts in March and ends in July of the same calendar year, and season "C" which starts in August and ends in September of the same calendar year [8]. Rwanda also has an abundance of natural water resources such as lakes, wetlands, rivers, run offs and groundwater [7]. With an approximate irrigable surface of 580,000ha, Rwanda's internal natural water resources total $31,9 \times 10^9 \text{m}^3/\text{year}$; however, only about 2% of these resources are currently being utilized. The major economic sector in Rwanda is the agriculture industry, which employs over 66% of the population and provides about 31% of nation's income [9].

The Rwandan government advice the Ministry of Agriculture and Animal resources to promote irrigation, specifically during the season's dry conditions period, realizing the importance of promoting

irrigated agriculture to reduce poverty, accomplish nutrition security and minimize a shortage of water caused by the impact of climate change because during this time the country received a little rainfall [7].

Table 1.1: Agriculture Season and crops grow in Rwanda [10].

Season	Crops	Percentage(%)
Season A: Starts in September and ends in February of the following calendar year	Beans	27
	Cassava	12.6
	Bananas	19.7
	Maize	11.9
Season B: Starts in March and ends in July of the same calendar year	Bananas	17.9
	Sorghum	14.6
	Beans	17.4
	Cassava	15.9
Season C: Which starts in August and ends in September of the same calendar year	Beans	14
	Vegetables	12
	Irish potatoes	71

For the goal of cultivating and producing crops, agricultural irrigation is constantly regarded as an essential application. Both agricultural productivity and water conservation can be greatly increased with a dependable and appropriate irrigation water supply. Traditional irrigation obviously uses a lot of water, but depending on the geographical area, it may also need a lot of electrical energy. Applying water as evenly as possible throughout the entire field is the typical irrigation method, which ignores the variety of soil and crop water requirements. This causes uneven irrigation in different areas of the field; some areas are over- irrigated while others are under- irrigated [11] [12].

Automated irrigation system is defined as the supply of the appropriate quantity of water during irrigation to maximize crop production, and efficient operations that control the system to work effectively [13] [14]. The desirable quantity of water is required to enhance crop cultivation using irrigation facilities and aqueducts in the irrigated area. Today’s agriculture is not just about crop production or livestock farming and associated activities due to different challenges brought by environmental factors such as climate, soil properties and soil water that would devastate the crop production unless they are controlled . Farmers need to address the environmental impact due to climate change and this is where modern technology comes to the rescue. The use of wireless sensor networks

(WSNs) for automating irrigation has the potential to address these issues, by providing real-time monitoring and control of irrigation systems [15].

Wireless Sensor Networks (WSN are also called Wireless Sensor and Actuator Network(WSAN) these are wireless network that consist of autonomous sensors that are spatially distributed to monitor physical or environmental conditions, such as temperature, soil water level, humidity, and pressure [15]. Irrigation facilities and irrigation trenches face different technical problems during operations including but not limited to collapses and leaks [15] . These technical problems require regular maintenance by the irrigation facility staff during periods of irrigation. This study of wireless sensor networks for automating irrigation in Rwanda was address the environmental factors affecting irrigation and upgrade the daily monitoring system of irrigation facility. Therefor it was complement the implementation smart agriculture in Rwanda through proper irrigation [16] [13].

1.2. Motivation

As a master's student, it is with great pressure to work with Information Technology based organization and working in an international organization gives me the hope to increase my knowledge and skills. For academic reasons, this research will meet the requirement for a student to complete the master's degree in University of Rwanda; it is used to help me applying the knowledge gained during studies. For the community, this study will improve agricultural productivity and livelihoods for small-scale farmers while promoting green agriculture and sustainable water used and will help people to irrigate their crops consistently.

1.3. Problem Statement

Nowadays, Agricultural sector employs over 80% of the total population and contribute 33% of the country's GDP. Thus, makes it a backbone of Rwanda's economy. Most of the Rwandan farmers rely on rain-fed agriculture, which is sometime unpredictable and often leads to lack crop production, particularly during drought seasons and can lead to famine [9].

Most of the irrigated area is the hillsides which depend on rain season, while in dry season the productivity decreases, due the lack water which eventually leads to wetland degradation as the only productive area during dry periods, All these facts natural resources degradation [9] [18].

Furthermore, many farmers use traditional irrigation methods such as flooding, which is not only inefficient but also leads to water wastage, soil erosion, and reduced soil fertility. In addition to that

manual irrigation system requires high labor costs, many small-scale farmers are unable to irrigate their crops, leading to low yields and income. For this reason, if the wireless sensor networks for automating irrigation system is put in place in agricultural fields, it will irrigate the crop only when it needs to prevent over-or under-watering of the plants. This research is proposed to employ the wireless sensor networks for automating irrigation in Rwanda to address all those challenges faced by farmers [15].

The use of wireless sensors in irrigation will enable small and large-scale farmers in Rwanda to monitor their crops water needs in real-time, adjust water supply system when needed, and reduce water wastage. This technology is more efficient and will reduce labor costs. Farmers will gain more time to focus on other activities [19]. Overall, the implementation of wireless sensor networks for automating irrigation in Rwanda could significantly improve agricultural productivity and livelihoods for small-scale farmers while promoting green agriculture and sustainable water use. Also, the benefit of employing this system is that they minimize human intervention while yet assuming appropriate irrigation [20].

1.4. Research Questions

1. How can a wireless sensor network for automating be designed and how do you monitor the soil moisture in real-time effectively?
2. How can the automated irrigation prototype be developed for estimated quantity of water used and distributed to the plants in the irrigation system?
3. What tools did the farmer use to store the data on soil moisture and the cost associated with the farmers in irrigation period?

1.5. Hypothesis

1. Wireless sensor networks provide accurate and timely data measurements in monitoring soil moisture.
2. There is reduction water wastage and accurate distribution of water to plants when using wireless sensor network automated irrigation systems.
3. There is low cost associated with the use of wireless sensor networks in irrigation.
4. Short time is required by the Wireless sensor network automated irrigation systems to irrigate specific areas of land compared to traditional irrigation methods.

1.6. Objectives

1.6.1. General Objective

The general objective of this research is to improve the production by providing farmers with a low cost and effective means for monitoring farm conditions through the design, develop wireless sensor networks for automating irrigation system in Rwanda for the farmers so as increase yields. This goal is based on the hypothesis that there is water wastage distributed to plants and to continuously sense the moisture level of the soil on the farms. The system will respond appropriately by watering the soil with the exact amount of water required and then turning off the water supply when the required amount of soil moisture is achieved.

1.6.2. Specific objectives

1. To design wireless sensor network for automating irrigation system to provide accurate and timely data measurements in monitoring soil moisture.
2. To develop a prototype IoT device for wireless irrigation system.
3. To input in place online cloud database for to store the data of soil moisture collected from the farmers by using an IoT devices.

1.7. Challenges

Challenges to bring this work to an end may be defined as difficulties which can prevent the system working efficiently. Developing automated irrigation systems is not a simple task, even for a small organization. The process demands you to be very attentive and having sufficient time and experience to meet all customer needs.

The biggest challenge that may be faced in developing the web application is the lack of sufficient experience in developing the application.

For collecting data, it requires some method such as interview, consulting documentations, observations and here the research project may not meet its objectives when an interviewee provides incomplete or wrong information.

1.8. Structure of the study

This project is subdivided into **five** chapters:

Chapter 1: Introduction

Introduces the design and implementation of irrigation in Rwanda where some points will be discussed concerning why and for what I have chosen this project. This chapter also deals with the introduction, Motivation of the study, the problem of statement, the research questions, the hypothesis, objectives of the project, the challenge, Structure of the project.

Chapter 2: Literature review

The second chapter deals about relevant literature reviews on the problem of automating irrigation in Rwanda, proposed solution, technology used which is focusing on previous similar studies done. This aids to identify the gaps and improve the technology that motivate in conducting the current study.

Chapter 3: Research methodology

This third chapter will be coming to highlight in detail how the study was undertaken to answer the research problem, this involves the description of the techniques that will be used, and tools applied in data acquisition, the analysis and processing of data.

Chapter 4: Result and Discussion

This chapter presents a description of the findings of the study. This come to highlight the technical realization of the application and the interpretation of the results, where we will explain the new system and how the application has been conceived, as well as the technologies used to build the system.

Finally, **Chapter 5:** Will come up with the conclusion and recommendations related to results of the project.

CHAPTER 2: LITERATURE REVIEW

This chapter analyses earlier studies which are relevant to this study conducted by various researchers, based on the problem statement, suggested solution, technology utilized, and suitability of the results found. This supports the current study's motivation of discovering the gaps and advance in technology.

2.1. Wireless Sensor Network in Irrigation

The study of P.Pamkumar¹, and his colleagues “Smart water Irrigation System Using IoT” stipulated that precision agriculture that uses Wireless Sensor Networks that my research was based, enables remote and real time monitoring of soil fertility and other parameters namely soil moisture. The study of P.Pamkumar¹, and his colleagues demonstrates the effectiveness of IoT and WSN in managing and monitoring soil conditions, it does not address potential challenges in data accuracy, sensor consistency, and the integration of these technologies in diverse agricultural environments. Moreover, the study may not provide insights into the cost implications and scalability of the proposed method for small-scale farmers or large agricultural operations, to fill this gap is for conducting experiments to evaluate the accuracy and reliability of different sensors in various environmental conditions. The data obtained is automatically sent to the cloud and the corresponding values are displayed on a mobile application. Internet of things (IoT) based software system is normally programmed to recommend the quantity of water and other soil inputs which improves the quality of the soil and ensures optimum growth of the crop [21].

Thanwamas Kassanuk¹ et al. Say in [22] the majority of irrigation water is wasted due to free flow irrigation. Water should be used efficiently in irrigation by employing modern technology. It is essential to be aware of new advances to combat the free flow of water in irrigation and regulate it via using smart irrigation techniques. As a result, a review of the existing literature was conducted to investigate current advancements in making irrigation automated and obtaining the necessary nutritional content of the crop that is produced.

Water irrigation is one of the most common ways for famers use to supply water in their farms but on some occasion it might be wasted. The traditional water irrigation technique is very difficult due to the scarcity of water which is primarily caused by rapid growth of population and climate. Using wireless sensor in agriculture is a new methodology to empower the modernization of agriculture. Since through automation irrigation system can make agriculture and all sorts of farming process in an efficient

way by reducing human interventions. So, due to this, it is proposed automation of water irrigation system using wireless sensor to save time and water wastage [23].

Sumalatha and Kumar's [24], the automate irrigation system is supported by solar energy, and a GSM system is utilized to maintain contact between the farmer and agriculture. Temperature sensors and soil moisture sensors are used to provide the precise value of moisture, depending on which the valve in the system is Start or Stop. In the book titled “ Information and communication technology for competitive strategies (ICTCS 2021)”, Dinesh Kumar Kalal and Ankit Bhavsar focusing on the efficient use of water resource in the agriculture sector which is in actuality a larges consumer of water resource. There are so many mechanisms for water management like automation of irrigation systems, development of decision support system for judicious utilization of rain, surface, and groundwater resources, minimizing the gap between water supply and water demand out of the mention methods, and this study focusses on the automation of irrigation system. Wireless sensors are very good watering concept [25].

According to the study done by Jin-Yong Choig and his colleagues entitled “A Wireless Sensor Network (WSN) application for irrigation facilities management based on Information and Communication Technologies (ICTs)” they have demonstrated that it could be more effective and efficient if information system for irrigation facilities management are conveyed by wireless sensor network (WSN) that uses information and communication technologies (ICTs) [15].

In the paper entitled “Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques: A Review of the Aeroponic System” published that during the plant cultivation, several steps including temperature, humidity, light intensity, water nutrient solution level, CO₂ concentration, atomization time, and atomization interval time require proper attention for flourishing plant growth. Using automated wireless sensor network in irrigation farmers could monitor all paraments without using laboratory instruments, and the farmer could use their smart phone and computers to control the entire system remotely and it this can work in the aeroponic system as one of the techniques of the soilless culture thus reduce labor costs associated with irrigation [26].

The irrigation is the process of supplying water to the root zone at the appropriate time. Plants draw water from wet soil, and by the mechanism of Evapotranspiration (ET), plants transpire water into the atmosphere while drawing nutrients available in soil with water for root zone development. When the supply amount of water in the root zone falls below a certain threshold, plants are unable to draw nutrients and water for nourishment. Therefore, it is important to irrigate high quantity of water

to the root zone before the threshold limit is reached. This limit is determined by the species of plant, soil, and climate [22].

According to the report of Ministry of agriculture and animal resources in Rwanda. In the fiscal year of 2020, the irrigated area reached 63 742 ha (37 273 ha of marshlands, 8 780 ha of hillsides[27]. Most practiced irrigation method used in Rwanda is flood irrigation methods. The furrow, basin, and border irrigation methods[8]. The average annual precipitation in Rwanda is 1200 mm, and around 6.8 billion m³ per year of water is usable[28]. The recent report of NISR Seasonal Agricultural Survey(SAS) has shown that the modern irrigated land in season A,B and C of 2022 where 27000Ha, 211000Ha and 1100 respectively[29]. According to report of the world bank, The increase of public investments in rehabilitating Hillside and wetland Irrigation technology lead Projects in Rwanda will raise the productivity [30].

2.2. The Soil Property

Based on the mix of mineral particles in the soil various types of retrieval systems, soil textures are classified into four categories(sand, silt, lay-loam, and clay) and 13 levels by the international classification system which affect air and water movement in the soil and soil's ability to function. The physical and electrochemical properties of soil are different from its electrochemical properties. These characteristics consist of the soil's dielectric, electroosmosis, resistance, and natural electric field[31].

These particles can be classified into four main categories such as: silt, clay, sand, and gravel. Each of these categories has unique properties that influence the behavior and use of the soil. Particles greater than 2.0 mm in size give gravel drainage and stability but lack nutrients. Sand with a particle size range of 0.05 to 2.0 mm provides moderate aeration and good drainage, but it also contains less nutrients. With a greater potential to hold nutrients than sand, silt particles, which range in size from 0.002 to 0.05 mm, balance drainage and water retention. Clay offers excellent nutrient and water retention because to its smaller particle size of less than 0.002 mm; yet, it has poor drainage and aeration, which may impede root growth. Given that soil texture has a major impact on nutrient availability, aeration, and water retention, an understanding of these qualities is essential for applications in agriculture, building, and environmental management [32] [33].

2.3. Soil Moisture Content

Soil moisture is referred to the amount of water content that present in the soil. It is an essential factor that affects various environmental processes, such as soil erosion, plant growth, and nutrient

availability. The soil's moisture content is crucial to support the ecosystem and maintaining plant life. In the agricultural sector, crop productivity depends on the timely and appropriate irrigation of sufficient moisture which is determined by the soil moisture and plant environment [31].

2.4. Methods of measurement of soil moisture sensors

2.4.1. Oven drying method.

Soil moisture sensors (SMSs) are the devices that are used to measure the water contents in soil. In the field of smart agriculture, there are various methods used for evaluating the status of soil moisture include gravimetric (oven Drying method), tensiometer, neutron, Gamma-ray (*y-ray*), remote sensing, and dielectric methods[31] [34] .

A soil sample is gathered, and its wet weight is recorded in a moisture container. The soil sample is dried at 105 degrees Celsius (105°C) in a hot air oven until a constant weight is obtained at which level the sample's dry weight is recorded[35].

$$\text{Moisture content (on weight basis)} = \frac{\text{Wet weight} - \text{Dry weight} \times 100}{\text{Dry weight}}$$

2.4.2. Gravimetric method.

The Gravimetric method is also referred to as drying method, is the most commonly and oldest method currently used for determining the amount of a substance or soil moisture content contained within a sample by determining the mass of solid after it has been burned to eliminate volatile components [36] [37]. This method provides an exact measurement of the moisture content based on the type and salt content of the soil. In gravimetric method, the principle is used as the basic conservation of mass. By means of a particular chemical reaction or physical technique, this method removes the component of interest from the sample and the resultant product is analyzed by weight to determine the component's mass. [31] [16].

2.4.3. Tensiometer Method

The tensiometer method is used for measuring the amount of water content in soil by estimating the energy contained in soil moisture via monitoring of the flow of water in porous components that come direct contact with the soil [38] [37]. A variation in resistivity between the two electrodes that were placed was utilized as an alternative for the moisture content of sensor. However, the small spatial variabilities within this system are its limitation including time consuming process, susceptible to errors

from contamination or incomplete drying, it requires careful handling and precise measurements. It requires taking a soil sample at the desired depth, weighing it, drying it in an oven (at 220° Fahrenheit for 24 hours), and then reweighing the dry sample to determine the amount of water that was lost [16], [31]. Tensiometers are made of a porous ceramic cup that is buried in soil at any depth and filled with moisture. A vacuum gauge attached to a tube is connected to the ceramic cup, the moisture tends to equilibrate with the soil moisture. The vacuum gauge indicates that there has been a decrease in the hydrostatic pressure of water filled barrel tensiometer due to this moisture loss [39] [40].

2.4.4. Neutron Method

The neutron method refers to a method that uses neutron probes to measure the moisture content and the nutrients levels in the soil. Neutron probes are devices that identify the presence of neutrons in the soil, from the data regarding the composition of nutrients and moisture content can be obtained. This method is especially helpful in agriculture because it provides farmers useful information to optimize crop management, fertilizer application and irrigation techniques [41], [38].

Neutron probes operate based on the principle that water molecule's hydrogen atoms slow down neutrons. It measures the rate in which neutrons are absorbed or slowed down by the soil to estimate how much water present in the soil. In order to prevent both overwatering and underwatering which can have a negative effects on crops yield, the farmers should have this information to help them to determine when and how much to irrigate their crops [41], [42].

2.4.5. Gamma-Ray Method

Gamma-ray methods can be used in many different industries to determine a material's moisture content. Accurate measurement of moisture content using these methods depends on the interaction of gamma rays with the materials being evaluated [16].

The attenuation of gamma rays as they pass through materials, which is mainly influenced by the density and composition of the material, is used in gamma-ray moisture measuring techniques. The assessment of soil moisture is a particular field in which this principle is commonly utilized, particularly in environmental and agriculture [43] [37].

2.4.6. Remote sensing method

Remote sensing techniques are a useful method for determining the moisture content of many factors in different field such as environments monitoring, urban planning, disaster management, and agriculture. These are various methods to sensing that utilizes different technologies. Dielectric method

The dielectric method is a favorite technique for determining the moisture content of soil. This method is based on the principle that a material's dielectric constant is affected by several factors, such as temperature, salinity, soil density, soil volumetric water content, soil particle shape, ratio of bound water to total soil, and moisture content which influence the dielectric constant of the soil [31] [44].

There are many techniques used to measure the dielectric properties of soil to estimate the moisture content. Two commonly used techniques are Time Domain Reflectometry (TDR), which measures the dielectric properties of soil by measurement of the time needed for an electromagnetic pulse to travel through a waveguide inserted into the soil, and Frequency Domain Reflectometry (FDR), which measures the impedance of the soil at different frequencies [45] [16].

CHAPTER 3: RESEARCH METHODOLOGY

To conduct research, we need data collection as the one most important stage in conducting research. For achieving the objective, the data used in this research was collected by using library research by reading technical and methodological the surveys report for secondary data collection. There are many methods to collect data, depending on research design and methodologies employed. Some of the common methods used in this research are survey research, and interview were used to collect primary data, field observation and measurement, and questionnaires.

3.1. Research Process

To provide solutions for internet of things (IoT) farming systems to maximize production and evaluate the feasibility as well as effectiveness of wireless sensor networks of automated irrigation in Rwanda, the research conducted in this study used an integrated modeling and technology approach. The research was using a mixed strategy of both quantitative and qualitative method approaches to achieve the objective of this work. These two approaches work well together because one may test assumptions using quantitative methods and discover the unknown with ease using qualitative ways. Whenever feasible, tests were conducted to validate the concepts and models.

The phase taken to design a prototype device are the follows:

Problem identification: this phase consists of identifying specific needs and the goals of the irrigation system. Consider factors such as the size of the area to be watered, water sources, the environmental climate and the types of crops or plant involved.

User requirements: This phase is used to collect information concerning the system to be developed where the project requirements are gathered from stakeholders and it involves understanding the problem domain, defining the scope of object, and identifying the user needs as well as end users.

System design: This phase consists of system architecture of irrigations system, including components such as communication modules, controller, interfaces, sensors, actuators and define how these components will interact with each other to achieve the desired functionality.

System Development: This phase focuses on the actual programming or coding and integration of various system components.

Testing: This phase of evaluating the functionality of the prototype and adjusting it to meet the requirement of wireless sensor network system. The process was repeated until the expectation result satisfied the needs of the users.

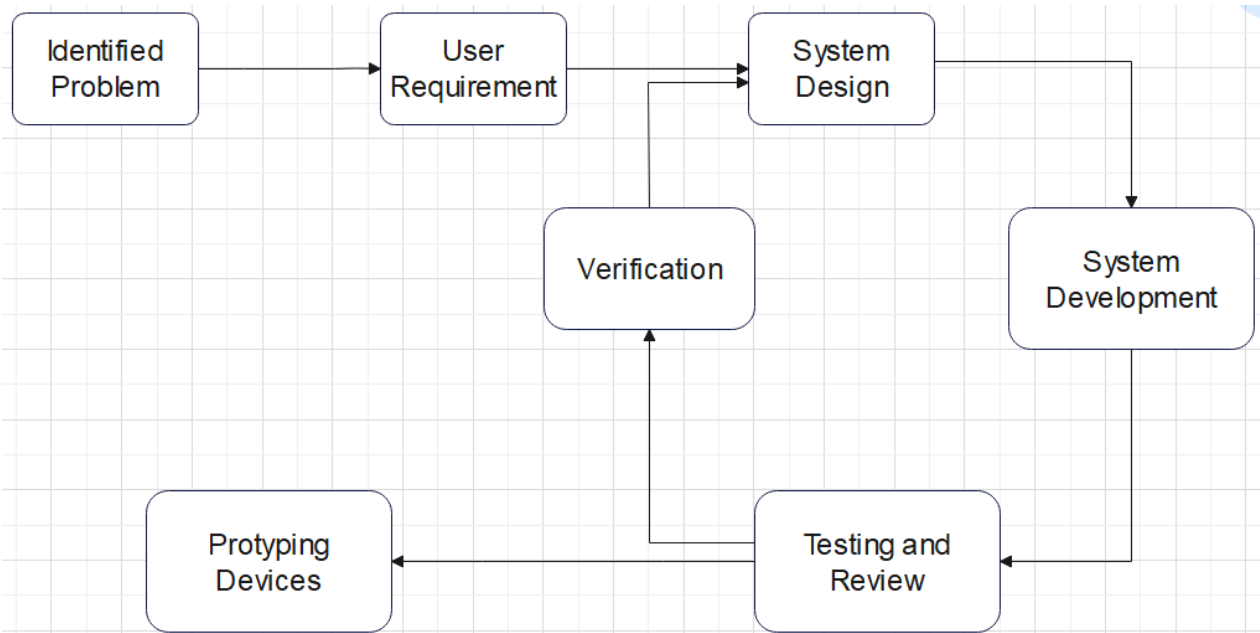


Figure 3. 1: Research Process

3.2. Research Design

The types of data were necessary for the design of wireless sensor networks for automating irrigation systems, the project location, the participants involved in the design process, and the methods that was used to collect the data using in the design project was all taken for consideration to produce a good research design.

3.3. Baseline Survey

This is the first action a researcher takes to assess the present situation where this research was conducted before implementing the project into execution. This type of primary research involves asking people questions on paper, over the mobile phone, or online and person by person to get data directly from resources. The survey for this study will use online, in-person, and questionnaires. The survey will be conducted in KAGITUMBA wetland of maize, beans, and soybeans at Nyagatare District.

The study at this location aims to gather as much data as possible regarding the quantity of water used and distributed to the crops by sensor network during irrigation. The interviews with local irrigation technicians and farmers from Seed Technology Engineering and Science Group Ltd (STES Group Ltd), was performed by person and the initial baseline survey that I was doing involve face-to-face interviews.

3.4. Data Collection

The selection of data gathering techniques was used for this research study, including questionnaires, interviews, observation, and literature review on wireless sensor networks automating irrigation system design. To collect primary data, surveys, interviews, and observation was used. The second data was collected from literature reviews of books, websites and journal or articles.

This research procedures were based on data collection by conducting with irrigation technicians and farmers from Seed Technology Engineering and Science Group Ltd (STES Group Ltd), in KAGITUMBA wetland of maize, beans and soybean, located in Nyagatare District, to estimated quantity of water used and distributed to the plants/ crops and to examine the human and time resources associated with the use of wireless sensor network in irrigation.

The data was collected from August 2023 to December 2023 it takes a period of 4 months. This data was collected from KAGITUMBA wetland owned by STES GROUP Ltd where they cultivate maize, soja and beans. Kagitumba irrigation wetland where 35 devices are installed in about 70ha with 6pivots for irrigation the crops. The data were collected and analyzed according to the protocol and timeline set, and sampling areas for research was selected based on presence of wireless sensor network. The data was formatted using Microsoft Excel and the fields that were not necessary for our solution were removed.

The data from participants was treated with a high level of privacy and confidentiality throughout the research project. After analyzing aal the data, conclusions and recommendations were drawn. In this project the following techniques were used in collecting data:

3.4.1. Interview

Interview is verbal questioning in research is defined as a two-person conversation, initiated by the interviewer for the specific purpose of obtaining research relevant information and focused by him on the content specified by research objectives of description and explanation. During my research, two types of interviews were conducted:

Structured interview: This is a set of predefined questions directed at respondents. The main respondents to these interviews were both the technicians and farmers from Seed Technology Engineering and Science Group Ltd.

Unstructured interview: Here, the interviewer is allowed much greater freedom to ask supplementary questions, change the sequence of questions or omit certain questions if the situation so requires.

3.4.2. Observation

Observation is a process of recording the behavior of people, objects, and occurrences without questioning or communicating with them. The main advantages of it are that, if done accurately, the researcher looks at him/herself instead of asking respondents. Moreover, the information obtained under this method relates to what is currently happening. So, I went so many times to KAGITUMBA wetland, and I observed what was going on.

3.4.3. Documentation

Documentation involves systematic data collection from existing records, such as books, statistics reports, websites and so on. To develop my project, I had read and researched various project documents from several sources, like some statistics reports of Ministry of Agriculture, the website of Ministry of MINAGRI, NISR report and so on. The ideas and concepts gained have influenced and helped shape the development of my project.

4. System Design

An overview of the architecture of the system implemented through this study is provided in this section, which also describes each component used and its function in the circuit. The different hardware and software components were used during the design process and implementation of this research project. Additionally, the web and mobile applications are mentioned in this study.

The main components of wireless sensor network for automated irrigation system are shown in figure 3.2

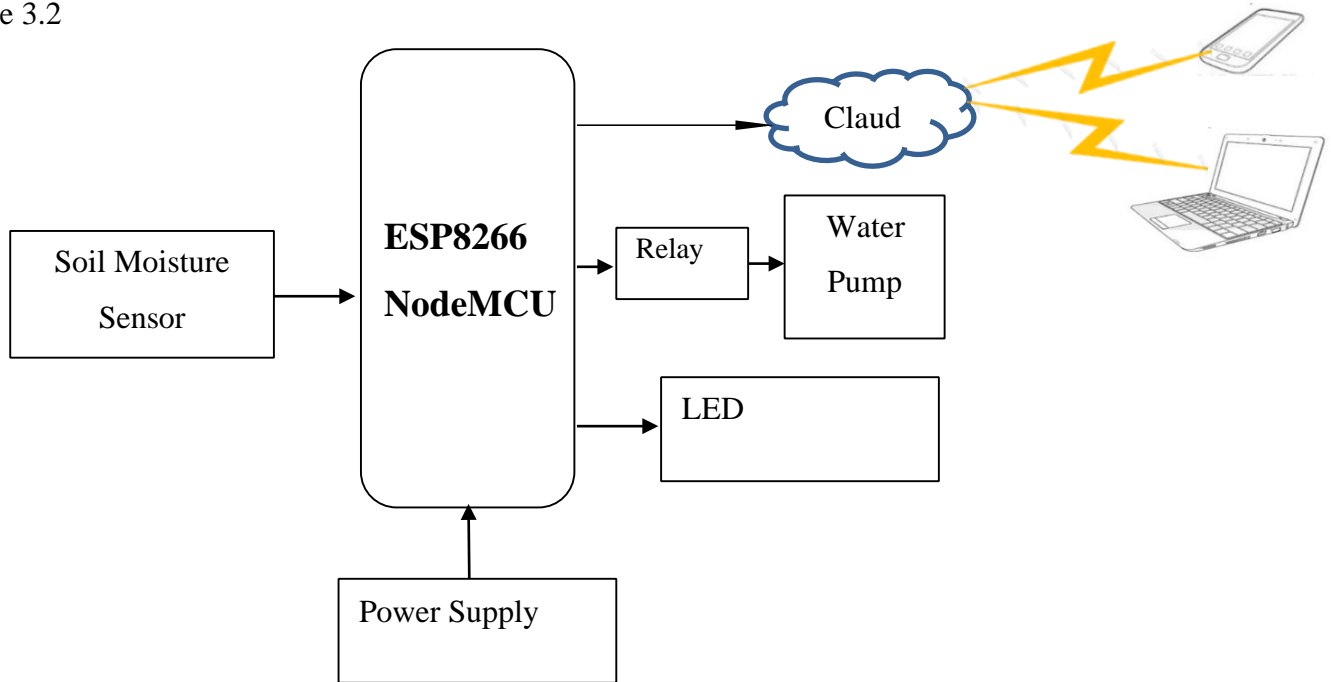


Figure 3. 2 :Block diagram for automating irrigation system.

4.1.Hardware components

The proposed system was composed of various components including, NodeMCU ESP8266, moisture sensor, 5v relay module, 6v Mini water pump with small pipe, connecting wires, 5v battery to supply power to the microcontroller. It provides a complete and self-contained Wi-Fi network solution, enabling it to either host the application or to transfer all Wi-Fi networking functions from another application processor.

1. **ESP8266 Node MCU:** This is a microcontroller, where all system components are interconnected such as soil moisture sensor, relay, water pump. NodeMCU is equipped with ESP8266 which is an integrated chip developed to meet the needs of the connected world. ESP8266 NodeMCU has powerful on-board processing and storage capabilities that allow it to be integrated with the sensor's specific devices via its GPIOs with minimal development up-front and minimal loading during runtime.



Figure 3. 3: ESP8266 NodeMCU

- 2. Moisture sensor with the electric module:** This component was used in this system to detect the level of moisture in the soil . This sensor is connected to Node MCU and is used for detecting levels of moisture from time to time.

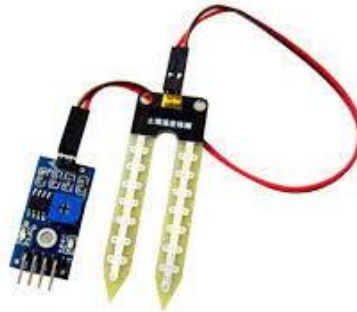


Figure 3. 4: Soil Moisture Sensor

- 3. 5v relay module:** A relay is an electromechanical switch that's controlled by a relatively small current-controlled. Large electrical phenomenon operational devices are also controlled by a little quantity of electrical current during switching. The Arduino is unable to control high voltages or currents. A relay module ensures proper irrigation of the field by turning on the supply when the moisture content is below turning ON and shutting it off when the moisture content is adequate for the crop or plant for preventing under or over irrigation.



Figure 3. 5: Rely Module.

4. **6v Mini water pump with small pipe:** This pump was used to pump the water to the plant, it will be controlled by relay which will turn it off or on according to the optimum value read by soil moisture sensor. The pipe will be used to carry water from the container to the plant.



Figure 3. 6: Mini water pump.

5. **5v battery or Power supply:** A device that supplies an electrical power component that provides a load a source of electricity. The main purpose of power supply is to convert electrical current from a source into the appropriate voltage, current, and frequency needed to load. Therefore, power supplies are sometimes referred to as electric power converts. Some power supplies are built into the load appliances they power, others are standalone units.



Figure 3. 7: Power supply

All the described components will interconnect together to give full function of the system and be able to provide real time plant irrigation.


4.2. Software of proposed system

The software development methodology for designing of wireless sensor networks for automating irrigation in Rwanda and providing alert to the farmers.

A. Arduino IDE

The Arduino Integrated Development Environment(IDE) or Arduino Software consists of a text editor for writing code, a text console, a message area, a toolbar with buttons for frequently used functions

and other menus. It connects to the Arduino hardware to communicate and upload programs with them. The writing code is shown on appendix II.



```
code2 | Arduino 1.8.19
File Edit Sketch Tools Help

code2
Serial.println(value);

dataFunction(value);

if(value>800){
  Serial.println("Water is low, system is pumping!");
  digitalWrite(ledPin, LOW);

  // scan from 0 to 180 degrees
  for(angle = 45; angle < 180; angle++) {
    servo.write(angle);
    delay(10);
  }

  // now scan back from 180 to 0 degrees
  for(angle = 180; angle > 45; angle--) {
    servo.write(angle);
    delay(10);
  }
  delay(2000);
}else if(value<100){
  digitalWrite(ledPin, HIGH);
  Serial.println("Soil Moisture is not connected well!");
}else{
  digitalWrite(ledPin, HIGH);
}
```

Figure 3. 8: Program in Arduino IDE

B. Software Algorithm of proposed System

- Step 1: Power On the system which includes the NodeMCU ESP8266, power supply, relay module, soil moisture sensor and other peripherals.
- Step 2: Initialize the system which consists of Wi-Fi, Sensors, and User Interface.
- Step 3: Reading the instruction from the configuration file and the operation of system based on file's configuration.
- Step 4: Reading and analyzing the data from the sensors to check if it is required to alert the user or continue monitoring the system.
- Step 5: Sending data to the user of the system upon request by using NodeMCU ESP8266 and waiting for the response from the user.
- Step 6: If the response is YES then the state of sprinklers and irrigation pumps, activate the state and save the current state in the system configuration file.

Flowchart

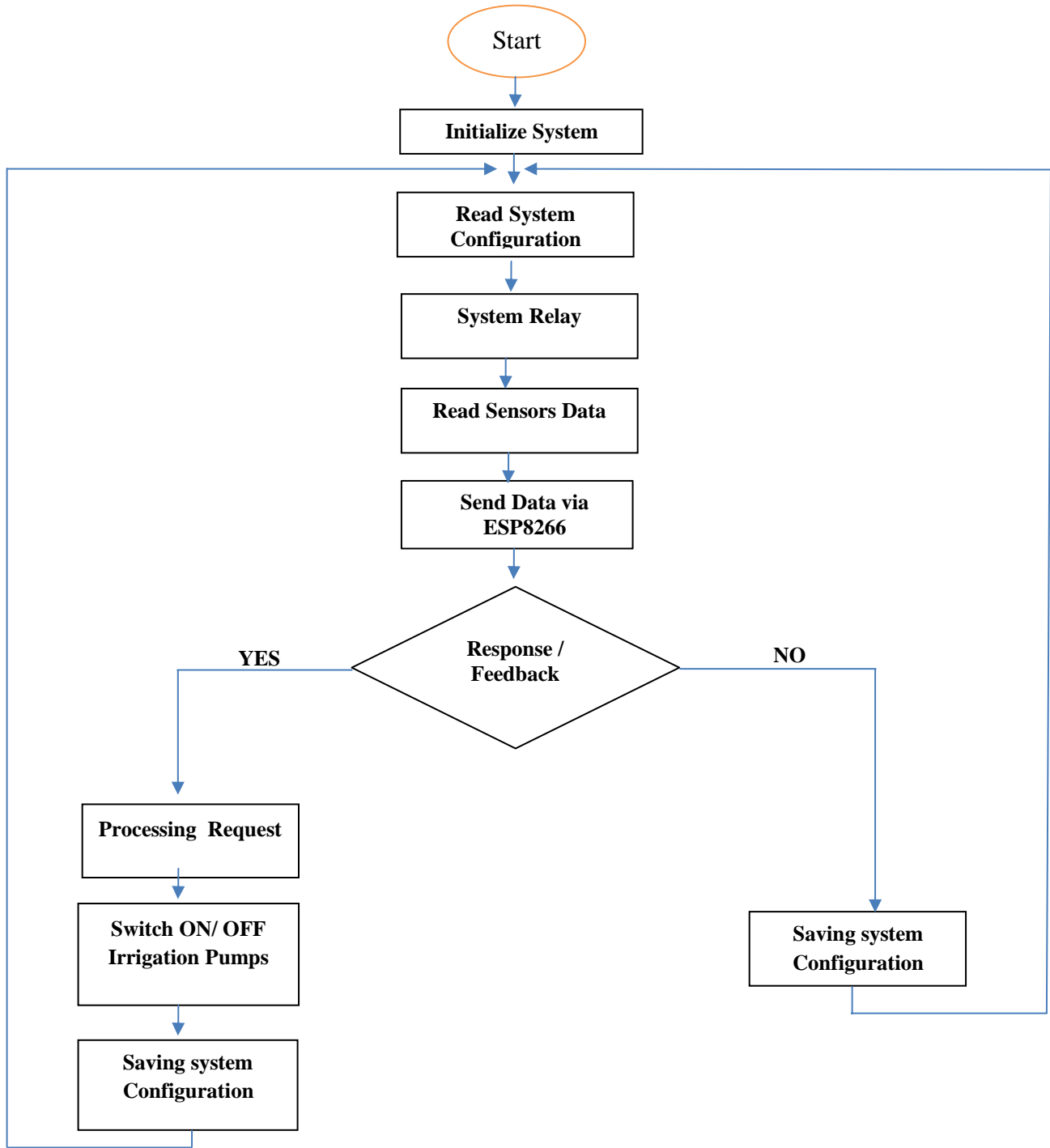


Figure 3. 9: Flowchart for NodeMCU

5. Proposed System

The overall proposed wireless sensor network for automated irrigation system contained soil moisture sensor, Node ESP 8266, 5v relay module, 6v Mini water pump with small pipe, connecting wires, 5v battery to supply power to the microcontroller is designed as shown in Figure 3.10

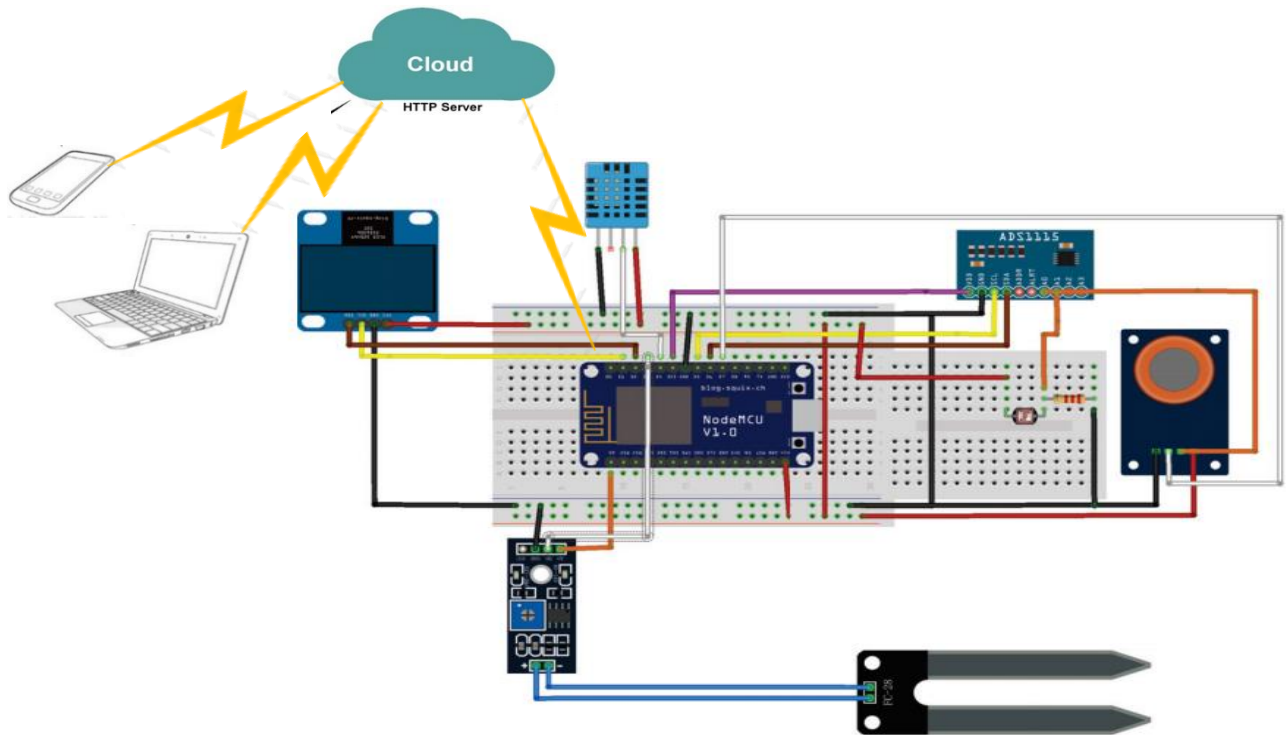


Figure 3. 10: Proposed system architecture design

The challenges faced in designing a sustainable water resource system are causing many issues for agriculture at this time. A wireless sensor networks for automating irrigation system has been proposed to help farmers in overcoming their everyday struggles. In this system design, we expect to automate the irrigation of the mint by providing monitoring on the soil conditions of the plant. We have integrated soil moisture with the input pins of the Arduino and the relay module connected to the water pump.

6. Developed New System

First, there's the Water Pump. This pumps water from wherever it's stored to your plants. Then there's the Relay module ensures proper irrigation of the field which tells the pump to turn on when the value of moisture is below the threshold value and turns off the supply when the moisture content is

sufficient for the plant or crops there by preventing over irrigation or under irrigation. The ESP8266 NodeMCU is a great option for building an automated and effective irrigation system because of its capacity to connect to Wi-Fi and control a variety of devices so you can manage your plants from anywhere. Then there's the Soil Moisture Sensor, his little device checks how wet the soil is. When it's dry, it tells the system to distribute the water to the plants. When the soil gets too dry, the Soil Moisture Sensor tells the system to turn on the Water Pump. It waters the plants until the soil is just right again.

With this system, you can take better care of your plants without all the guesswork. It's simple, smart, and helps your garden thrive.

Pump ready to splash water.

The moisture sensor provides data on the moisture level to the controller. There is no requirement for irrigation when the moisture content is higher than the maximum value that is necessary. The water pumping relay will turn on and irrigation will start if the controller detects a lower moisture level than the minimum needed. The controller will send a signal to the water pumping relay to stop the pump to stop the irrigation process if the moisture level reaches the maximum value during the irrigation operation.

Water Reservoir

The reservoir holds the precious water that will eventually nourish the soil and the plants it supports. The reservoir as the heart of the irrigation system and very important to meet the water security needs of the farmers, its draws water from here to distribute it across the field or garden as needed.

CHAPTER 4: RESULT AND DISCUSSION

4.1. Graphical presentation

In the survey related to the sociodemographic characteristics of the farmers and technician who participated in this study for the response where the famers are 126 and the technician are 12 in total are 138 peoples. The farmers were of various age groups, with most of them are between 31 and 50 years (52.1%) old. Most of the farmers in the study sampling were consisted of males 88 (63.8%) and females (36.2%). Two-thirds of the study sampling had an intermediate school level or less, total of 6 (37.6%) completed a secondary school level, while 6 (4.3%) had a university degree.

The results revealed that farmers mostly relied on groundwater for irrigation, while they also used other types of water. A total of 94 (68.1%) of participants utilized groundwater for irrigation, with canal water coming in second 17 (12.3%), groundwater and canal water combined 10 (7.2%), spring and river and groundwater combined with the total of 8 (5.2%), and river or spring water 7 (5.07%). 1.4% of respondents said they had bought water for irrigation. Most participants (53.6%) stated that they used deep wells, to irrigate their crops as their primary supply of water.

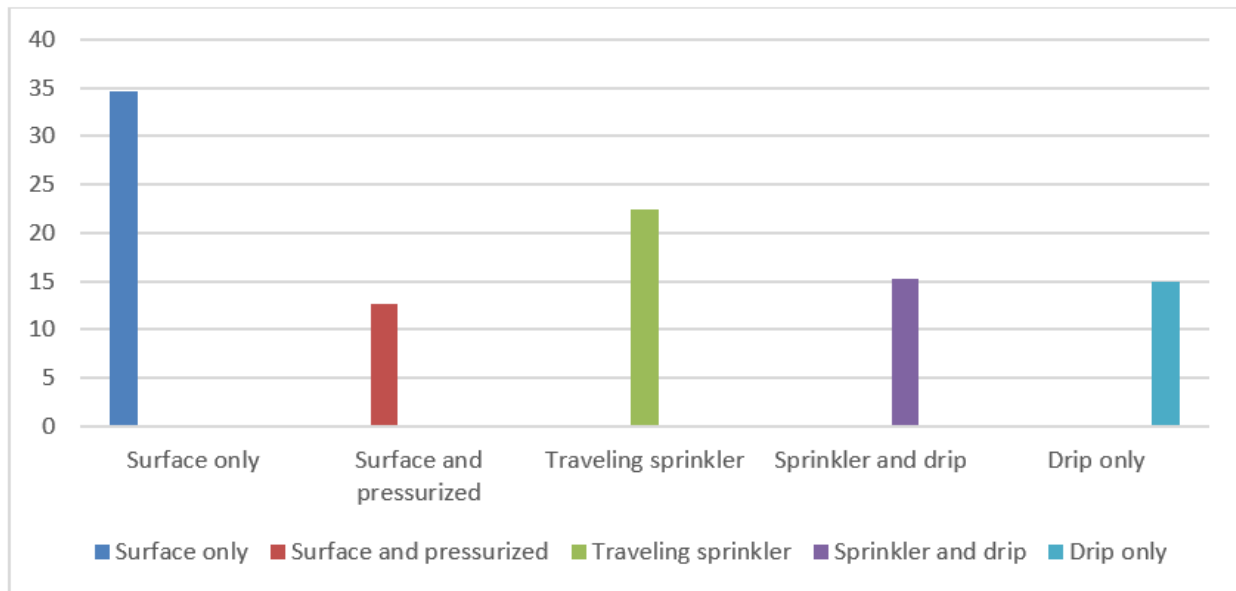


Figure 4. 1: Irrigation systems the farmers used in this research (%)

Farmers reported using various irrigation method with their irrigation systems, including surface and pressurized irrigation 15.2%, drip irrigation only is 34.7%, sprinkler and drip 13.7%, sprinkle only 22.5% , and surface irrigation only 13.8%. About 6.3% of the interviewees said they used timing or irrigation metering systems. Approximately two-thirds of the participants stated that they used

electricity, 12.6% said they used electricity, and 19.6% said they used both energy sources to irrigate their agricultural area.

The suggested system has reduced the amount of water wastage and accurate distribution of water to plants because all actions are carried out automatically. There is a handsome amount of money and time saving by benefiting from the proposed system. This system intends to save water and grid power and get more crop yields, improve crop quality, energy saving, labor efficiency, improved soil health, and beneficial effects on the environment.

Additionally, this proposed system it can be used by every non-professional and layman as there is nothing complex in the operating function of the system. To control Wireless Sensor Network for Automated Irrigation System using a mobile phone for irrigation makes it even better. The major advantage of this system is to remote control and monitoring capabilities, user can manage their irrigation systems precisely and conveniently. With its customization features and integration with weather data, smart irrigation system ensures effective watering for optimal growth of plant and reduced environmental impacts.

4.2. Real-time gathering of soil data Hardware implementation

Figure 4.2 shows the wireless sensor network for automated irrigation system designed to facilitate the automatic supply of adequate of water from reservoir to field in all agricultural seasons.

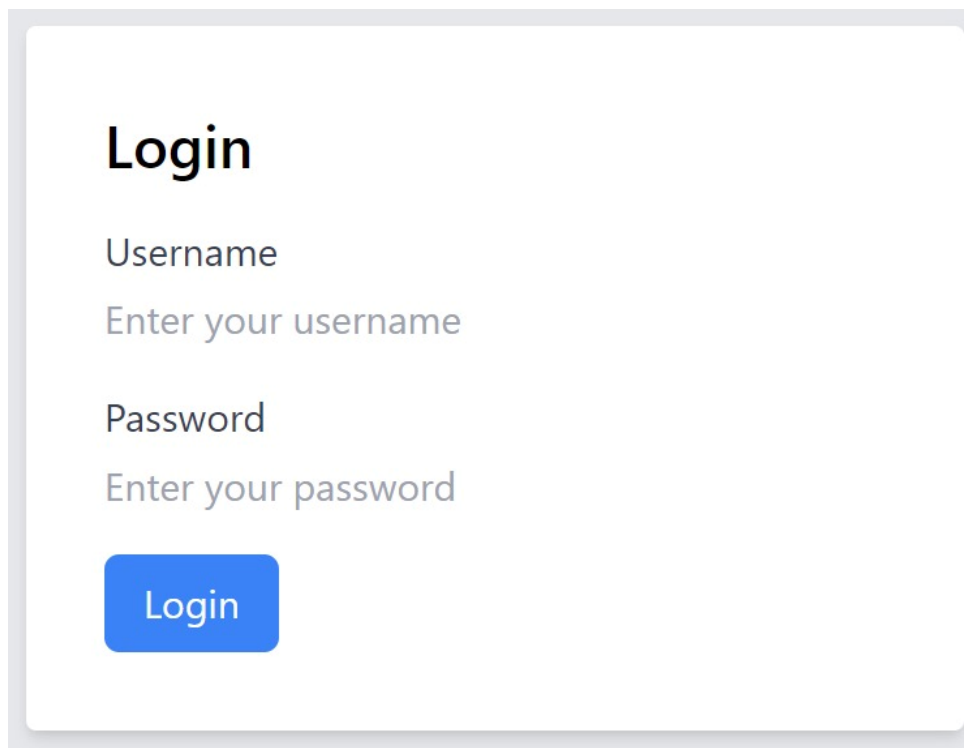


Figure 4. 2: Picture shows complete System.

The hardware implementation is composed by soil moisture sensor which responsible for collecting soil data and connect directly to the microcontroller (Arduino nano) for processing. Finally, after computation, the data processed sent to the cloud using http protocol.

Login Page

The login page allows the famers to enter to the web application system by viewing the variation of soil moisture level if there is a decreasing or increasing of moistures (Username and Password).Once it is validated, he can access the system.



The image shows a login form with a white background and a light gray border. At the top, the word "Login" is written in a large, bold, black font. Below it, there are two input fields. The first is labeled "Username" and has the placeholder text "Enter your username" in a light gray font. The second is labeled "Password" and has the placeholder text "Enter your password" in a light gray font. At the bottom of the form, there is a blue button with the word "Login" written in white text.

Figure 4. 3: Login Page

Moisture Level

The figure 4.4 below shown some sample outputs from the prototype, this show that the prototype was able to measure soil moisture level in different days, do the prediction and actuate the pump to irrigate the field.

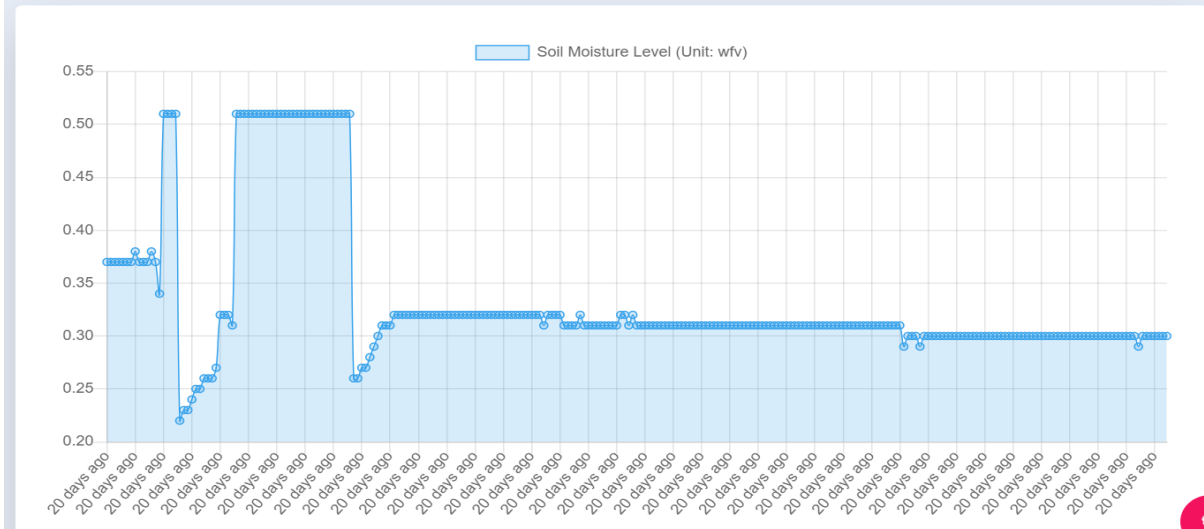


Figure 4. 4: Level of moisture on dashboard.

The figure 4.5. illustrate the measurements obtained from February 21, 2024, to February 26, 2024, and they demonstrate how the data was obtained and saved for more analysis. As the diagram shows, the temperature increases cause a decrease in moisture and high soil moisture levels cause a reduction in soil temperature.

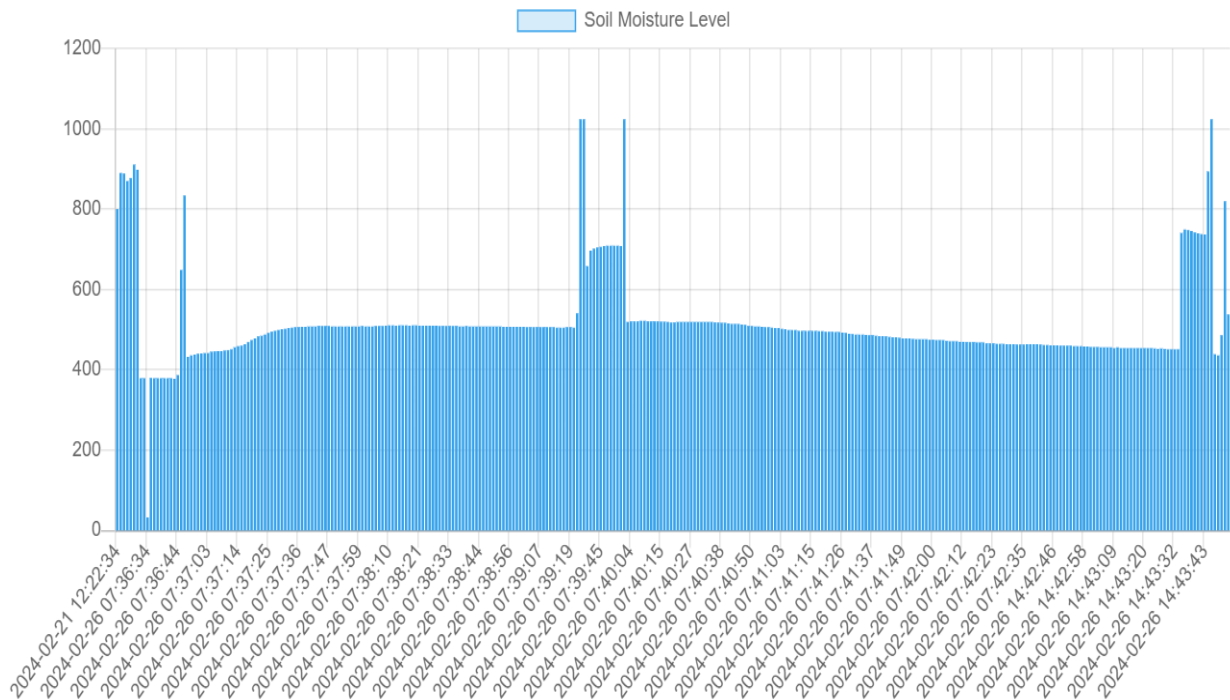


Figure 4. 5: Graphics of Soil Moisture Level Measurement

The Moisture Sensors would sense the corresponding values when there is lowest or highest soil moisture levels and alert the smart phone to display the values for the farmers.

The developed system can monitor the water level in the soil and show the data in the web application after sending the data to the mobile phone with SMS. The farmers do not need to use a smart phone or internet to know if the water pump is starting or stop to irrigate the system can control the water pump turning ON and OFF automatically by considering the data collected and ambient environment.

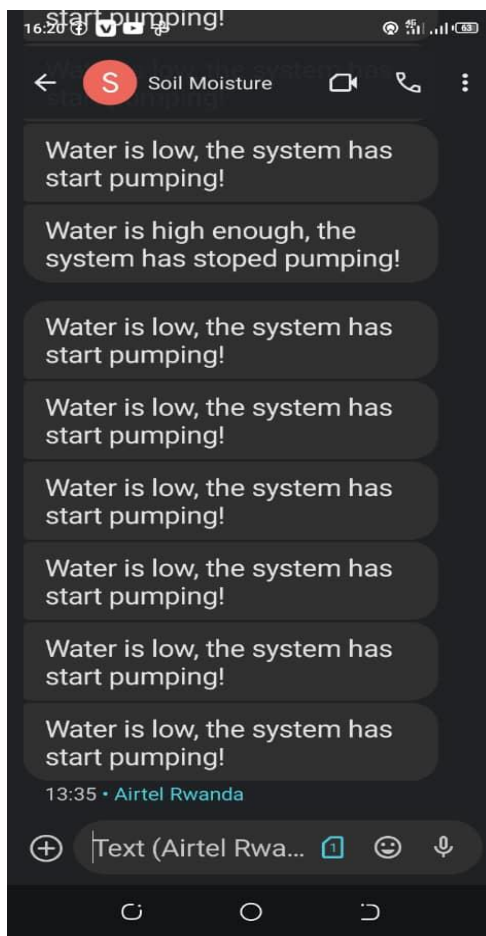


Figure 4. 6: SMS notifications in mobile Phone.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The aim's objective of the current project was to provide a solution to the problem of how the famers irrigate and control their plants by improving crop yields, conserving water resources, and increasing efficiency. This objective has been successfully achieved with a practical solution. By implementing the goal of this study which was to develop a prototype and web application that will be used as a tool which facilitates farmers for monitoring their plants and to reduce water wastage usage in agriculture.

A prototype of Irrigation System using the NodeMCU ESP8266 to run the water pumper and opening valves with a sensor is developed. It was successfully built and tested by integrating all the hardware components. The primary objective of the wireless sensor network for automating irrigation system was to replace the current traditional irrigation method such as flood with a better, more creative, effective and user-friendly techniques for agriculture. The farmer will check the irrigation status and moisture levels in the field to determine when irrigation is required by using a smartphone or web application. If the farmer does not have a smartphone, it is possible to register his phone number to receive an SMS notification for changes made to his field.

In this research a wireless sensor network for automated irrigation system was designed to irrigate and monitor the crops yields or plant for increasing the productivity in sector of agriculture. By using wireless sensor network for automated irrigation system will reduces water waste, helps to maintain a consistent water supply, and facilitates sustainable farming techniques. Additionally, it contributes with economic advantages including increased profitability and simplified access to markets for the famers.

5.2. Recommendations

This study presents a prototype for a wireless sensor network for automated system. It also appropriates for Rwandan famers to use wireless sensor network for automated instead of using manual irrigation because is greater way to efficiently water lawns, gardens, and landscapes while using less water and saving time. When the famers selecting automated irrigation system, the following recommendations are considered:

- 1. Climate and Weather:** When setting up the automated irrigation system, the local climate and weather patterns should be considered. In regions with frequent rainfall, you may not be needed to water regularly. But more frequent watering can be required in hot, dry regions.
- 2. Soil type and drainage:** Water absorption and retained in soil are influenced by the farm's soil type and drainage characteristics. Clay soil retains water longer but can become waterlogged, whereas sandy soil drains more quickly and needs more water watering. To avoid overwatering or underwatering, the irrigation system selected should be appropriate with the soil type.
- 3. Availability of water resources:** When selecting an automated irrigation system, the availability and level of water resources are important factors to take into consideration. Farmers need to determine if they have access to a reliable water supply, such as river, lake, a well, municipal water resource or reservoir. The type of water resource will affect the capacity and design of the irrigation system required.
- 4. Controlling and manipulating features:** Nowadays automated irrigation systems must have powerful monitoring and control parameters, to optimize water usage and irrigation scheduling the farmers need to look for systems that include weather sensors, moisture sensors, remote access control and automated components.
- 5. Etc..**

The implementation of this solution as it will indeed ensure the practice of data driven farming and thus help conserve the environment and ensure maximum irrigation of resources for the crops. This will also lead to reduced operation costs and thus increase profits.

The future researcher who will be interested to do their research on automated irrigation system to improve it by adding other functionality like automating fertilization crops which will help the farmers to get the information about plant fertilization at any time are encouraged.

This project can be also extended to notify the farmers and the technician the quantity of water status in the water storage to know if it satisfied in dry season period through cell phones and other visualization platforms.

REFERENCES

- [1] O. Rudahigwa and G. M. Tombola, “The Influence of East African Community’s Cargo Clearance Procedures on Trade Facilitation in Rwanda,” *Eur. J. Bus. Manag. Res.*, vol. 6, no. 3, pp. 61–68, 2021, doi: 10.24018/ejbmr.2021.6.3.828.
- [2] A. Mehler, “Central Africa,” *Africa Yearb.*, vol. 16, pp. 192–208, 2020, doi: 10.1163/9789004430013_021.
- [3] M. Ag and N. Bolson, “Evaluation of Rwanda ’ s Energy Resources Evaluation of Rwanda ’ s Energy Resources,” pp. 1–14, 2022.
- [4] M. H. Ehlers, R. Huber, and R. Finger, “Agricultural policy in the era of digitalisation,” *Food Policy*, vol. 100, no. December 2020, p. 102019, 2021, doi: 10.1016/j.foodpol.2020.102019.
- [5] S. Heinen, “Rwanda’s Agricultural Transformation Revisited: Stagnating Food Production, Systematic Overestimation, and a Flawed Performance Contract System,” *J. Dev. Stud.*, vol. 58, no. 10, pp. 2044–2064, 2022, doi: 10.1080/00220388.2022.2069494.
- [6] L. E. Richter, A. Carlos, and D. M. Beber, *Fifth Rwanda Population and Housing Census, 2022*. 2022.
- [7] R. A. Shema and L. Lanhai, “A geo-spatial analysis of precipitation distribution and its impacts on vegetation in Rwanda,” *Adv. GIS*, vol. 4, no. 1, pp. 24–30, 2024.
- [8] E. HAKIRUWIZERA, E. TOPÇU, and Y. UÇAR, “Ruanda’da Sulama Potansiyeli için Tarımsal Su Kaynakları,” *Türk Bilim ve Mühendislik Derg.*, vol. 4, no. 1, pp. 42–49, 2022, doi: 10.55979/tjse.1054181.
- [9] J. NGANGO and S. HONG, “Adoption of small-scale irrigation technologies and its impact on land productivity: Evidence from Rwanda,” *J. Integr. Agric.*, vol. 20, no. 8, pp. 2302–2312, 2021, doi: 10.1016/S2095-3119(20)63417-7.
- [10] A. McCauley, C. Jones, and J. Jacobsen, “Basic Soil Properties,” *Soil Water*, pp. 1–12, 2005, [Online]. Available: http://landresources.montana.edu/SWM/PDF/Final_proof_SW1.pdf
- [11] C. Jamroen, P. Komkum, C. Fongkerd, and W. Krongpha, “An Intelligent Irrigation Scheduling System Using Low-Cost Wireless Sensor Network Toward Sustainable and Precision Agriculture,” vol. 8, 2020, doi: 10.1109/ACCESS.2020.3025590.
- [12] S. Khriji, D. El Houssaini, I. Kammoun, and O. Kanoun, “Precision Irrigation : An IoT-Enabled Wireless Sensor Network for Smart Chapter 6 Precision Irrigation : An IoT-Enabled Wireless Sensor Network for Smart Irrigation Systems,” no. August, 2020, doi: 10.1007/978-3-030-49244-1.
- [13] M. M. Nugraheni, “Automatic Plants Watering System for Small Garden,” pp. 200–207, 2021.
- [14] S. Sakthivel, V. Vivekanandhan, and M. Manikandan, “Automated Irrigation System Using Improved Fuzzy Neural Network in Wireless Sensor Networks,” 2023, doi: 10.32604/iasc.2023.026289.
- [15] A. B. Amin, G. O. Dubois, S. Thurel, J. Danyluk, M. Boukadoum, and A. B. Diallo, “Wireless

- sensor network and irrigation system to monitor wheat growth under drought stress,” *Proc. - IEEE Int. Symp. Circuits Syst.*, vol. 2021-May, pp. 7–10, 2021, doi: 10.1109/ISCAS51556.2021.9401545.
- [16] M. W. Rasheed *et al.*, “Soil Moisture Measuring Techniques and Factors Affecting the Moisture Dynamics: A Comprehensive Review,” *Sustain.*, vol. 14, no. 18, 2022, doi: 10.3390/su141811538.
- [17] N. Lamek *et al.*, “Agricultural impact on environment and counter measures in Rwanda,” *African J. Agric. Res.*, vol. 11, no. 25, pp. 2205–2212, 2016, doi: 10.5897/ajar2016.10899.
- [18] A. Z. A. Naji and A. M. Salman, “Water saving in agriculture through the use of smart irrigation system,” *ACM Int. Conf. Proceeding Ser.*, pp. 153–160, 2021, doi: 10.1145/3456146.3456170.
- [19] S. S. K. Pokala and A. A. Bini, “A low cost iot enabled device for monitoring agriculture field and smart irrigation system,” *Lect. Notes Networks Syst.*, vol. 145, no. December 2020, pp. 923–932, 2021, doi: 10.1007/978-981-15-7345-3_78.
- [20] J. M. K S and D. P. Savant, “A Research paper on Auto Controlling Irrigation System Using Arduino UNO,” *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 10, no. 4, pp. 1207–1212, 2022, doi: 10.22214/ijraset.2022.41401.
- [21] S. Munusamy, S. N. S. Al-Humairi, and M. I. Abdullah, “Automatic irrigation system: Design and implementation,” *ISCAIE 2021 - IEEE 11th Symp. Comput. Appl. Ind. Electron.*, pp. 256–260, 2021, doi: 10.1109/ISCAIE51753.2021.9431829.
- [22] T. Kassaruk, M. Mustafa, K. Phasinam, and T. Santosh, “An Internet of Things and Cloud Based Smart Irrigation System,” *Ann. R.S.C.B.*, vol. 25, no. 4, pp. 1583–6258, 2021, [Online]. Available: <http://annalsofrscb.ro>
- [23] P. Ramkumar, U. Ranganathan, and V. Mathi, “SMART WATER IRRIGATION SYSTEM USING IoT,” no. January, 2021, doi: 10.47750/cibg.2021.27.03.232.
- [24] C. Padmaja, N. Swathi, E. Sudarshan, V. Srinivas, and P. Anuradha, “IOT based solar powered smart irrigation system,” *AIP Conf. Proc.*, vol. 2418, pp. 49–55, 2022, doi: 10.1063/5.0081783.
- [25] A. Das, *Redefining Text-to-SQL Task as a Machine Translation Problem*, vol. 401, no. Ictcs. 2023. doi: 10.1007/978-981-19-0098-3_14.
- [26] I. A. Lakhari, G. Jianmin, T. N. Syed, F. A. Chandio, N. A. Buttar, and W. A. Qureshi, “Monitoring and control systems in agriculture using intelligent sensor techniques: A review of the aeroponic system,” *J. Sensors*, vol. 2018, 2018, doi: 10.1155/2018/8672769.
- [27] RAB, “Rwanda irrigation master plan,” *Rwanda Irrig. Master Plan*, no. March, p. 240+xii, 2020.
- [28] I. Nzeyimana, “Farmer-Led Irrigation Development in Rwanda”.
- [29] N. (National I. of S. of Rwanda), “Seasonal Agricultural Survey(Sas) 2022 Annual Report,” no. December, p. 81, 2022, [Online]. Available: www.statistics.gov.rw
- [30] W. Bank, “ANNUAL,” 2023.
- [31] L. Yu *et al.*, “Review of research progress on soil moisture sensor technology,” *Int. J. Agric. Biol.*

- Eng.*, vol. 14, no. 4, pp. 32–42, 2021, doi: 10.25165/j.ijabe.20211404.6404.
- [32] A. D. S. Al-Hamad, M. A. H. Alnajjar, and M. A. Ibrahim, “The effect of alternating salinity of irrigation water and cultivation level on some soil properties and growth of date palm (*Phoenix dactylifera* L.) offshoots of Hillawi cultivar in clay soils,” *Int. J. Agric. Stat. Sci.*, vol. 17, no. 1, pp. 63–72, 2021.
- [33] A. Mohammed and W. Mahmood, “Estimating the efficiency of the sandy soils-cement based grout interactions from Particle size distribution (PSD),” *Geomech. Geoengin.*, vol. 16, no. 2, pp. 81–98, 2021, doi: 10.1080/17486025.2019.1645361.
- [34] D. K. Liyanage, I. Chathuranga, B. A. Mori, and M. S. Thilakarathna, “A Simple, Semi-Automated, Gravimetric Method to Simulate Drought Stress on Plants,” *Agronomy*, vol. 12, no. 2, 2022, doi: 10.3390/agronomy12020349.
- [35] T. Tensiometer, “04.soil moisture measurement”.
- [36] C. Durga, V. Ramulu, M. Umadevi, K. Suresh, and E. Sathyanarayana, “Correlation between the Soil Moisture Reading Obtained with Soil Moisture Sensors and Gravimetric Method for Scheduling of Irrigation in Maize,” *Int. J. Plant Soil Sci.*, no. March, pp. 72–80, 2021, doi: 10.9734/ijpss/2021/v33i130416.
- [37] S. S. Garusingha and D. T. Udagedara, “A Review- Comparison of Methods of Soil Water Content Estimation,” *Sri Lankan J. Appl. Sci. Vol.2.1*, vol. 2, no. 1, pp. 69–80, 2023.
- [38] A. A. Abdelmoneim, R. Khadra, B. Derardja, and G. Dragonetti, “Internet de las cosas (IoT) para la automatización del tensiómetro de humedad del suelo,” *Micromachines*, vol. 14, no. 2, 2023.
- [39] S. Kumar, “Indian Farming Automation in drip irrigation for increasing the water productivity of cereals in India,” no. October, 2023.
- [40] Y. Gamal, A. Soltan, L. A. Said, A. H. Madian, and A. G. Radwan, “Smart Irrigation Systems: Overview,” *IEEE Access*, vol. PP, p. 1, 2023, doi: 10.1109/ACCESS.2023.3251655.
- [41] Y. Lai and Y. Yang, “A Design for the High Yield Photoneutron Source Target Station,” *Materials (Basel)*, vol. 15, no. 21, 2022, doi: 10.3390/ma15217674.
- [42] Z. Pang, Y. Jia, X. Peng, X. Ju, and L. Gao, “Applicability of cosmic-ray neutron sensing for measuring soil water content to heterogeneous landscapes under subtropical hydroclimatic conditions,” *J. Hydrol.*, vol. 596, no. September 2020, p. 126068, 2021, doi: 10.1016/j.jhydrol.2021.126068.
- [43] E. Zare, J. Wang, D. Zhao, M. Arshad, and J. Triantafilis, “Scope to map available water content using proximal sensed electromagnetic induction and gamma-ray spectrometry data,” *Agric. Water Manag.*, vol. 247, no. January, p. 106705, 2021, doi: 10.1016/j.agwat.2020.106705.
- [44] D. Radočaj, M. Jurišić, and M. Gašparović, “The Role of Remote Sensing Data and Methods in a Modern Approach to Fertilization in Precision Agriculture,” *Remote Sens.*, vol. 14, no. 3, 2022, doi: 10.3390/rs14030778.
- [45] M. H. M. Roslim *et al.*, “Using remote sensing and an unmanned aerial system for weed management in agricultural crops: A review,” *Agronomy*, vol. 11, no. 9, pp. 1–15, 2021, doi: 10.3390/agronomy11091809.

APPENDIX I: QUESTIONNAIRE

Section I: Demographic characteristics of respondents

1. What is your age?

- A. 21-30
- B. 31-40
- C. 41-50
- D. More than 50

2. What is your gender?

- A. Male
- B. Female

3. What is your level of education?

- A. Intermediate
- B. A2
- C. A1
- D. A0
- E. Masters

4. Which of the following work experience do you have in wetland irrigation?

- A. Less than 1 year
- B. 1-5 years
- C. More than 5 years

Section II: Questions related to my objective.

1. What is the water source used in the farm?

- A. Borehole
- B. River/ Dam
- C. Others

2. How many days in a week do you spend for irrigation of the plants during Season Time?

- D. One day
- E. Two days
- F. Three days
- G. More

3. Does your organization provide end users or farmers with advice regarding irrigation, drainage, fertilization management?

- A. Yes
- B. No

4. If **Yes**, what type of pump is used for the system?

- A. Submersible multistage centrifugal motor pump set
- B. Submersible pump with surface mounted motor
- C. Reciprocating positive displacement pump

5. If **yes**, which model does your organization uses for water needs estimation?

- A. Blaney-Cridle
- B. Hargreaves
- C. Penman-Monteith
- D. Others

6. What are the specific communication channels utilized for farmers? Answer by YES or NO

Communication channel	YES	NO
Phone calls		
Written notices		
Emails		
In-person visits		

7. What are soil moisture monitoring tools farmers used to determine soil moisture content for plants?

Answer by YES or NO

Monitoring tools	YES	NO
Tensiometers		
Gypsum blocks		
Time Domain Reflectometry		
Remote sensing platforms		
Other		

8. If you have some soil moisture tools, what are the factors affecting soil moisture faced while testing?

- A. Texture
- B. Structure

- C. Organic matter content
- D. Density
- E. Salinity
- F. Depth
- G. Not sure

9. In your opinion, how does automating irrigation system can improve productivity for the farmers?

- A. Positively
- B. Negatively
- C. No impact
- D. Not sure

10. What are the challenges faced by automating irrigation systems? Answer by YES or NO

Challenges	YES	NO
Lack of farmers training		
Lack of guidance and rules regarding water distribution		
Lack of strategy regarding water management		
We do not have water shortages in our area		
Inefficient water management at end user level		
Desertification		
Insufficient size of central irrigation system		
High cost of system maintenance needs		
Soil erosion		
Excessive need labor to run the system		

APPENDIX II: CODE IN ARDUINO IDE

```
#include <Servo.h>

#include <ESP8266WebServer.h>

#include <ESP8266HTTPClient.h>

#include <ESP8266WiFi.h>

//const char* host = "192.168.1.74";

const char* host = "irrigation.softechsupply.com";

WiFiClient client;

const char* ssid = "JC";

const char* password = "112345678";

ESP8266WebServer server(80); //--> Server on port 80

int readsuccess;

byte readcard[4];

char str[32] = "";

String StrUID;

int httpCode;

String UIDresultSend, postData;

String response1,response2,response3,payload;

const int servoPin = D6;

Servo servo;

int angle = 0; // servo position in degrees

int ledPin = D7;// water pump

#define AOUT_PIN A0 // Arduino pin that connects to AOUT pin of moisture sensor

void setup() {

  Serial.begin(9600);

  servo.attach(servoPin);
```

```

pinMode(ledPin, OUTPUT);
digitalWrite(ledPin, HIGH);
WiFi.begin(ssid, password); //--> Connect to your WiFi router
Serial.println("");
Serial.print("Connecting");
while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
}
Serial.println("");
Serial.print("Successfully connected to : ");
Serial.println(ssid);
Serial.print("IP address: ");
Serial.println(WiFi.localIP());
}
String getValue(String data, char separator, int index)
{
    int found = 0;
    int strIndex[] = {0, -1};
    int maxIndex = data.length()-1;
    for(int i=0; i<=maxIndex && found<=index; i++){
        if(data.charAt(i)==separator || i==maxIndex){
            found++;
            strIndex[0] = strIndex[1]+1;
            strIndex[1] = (i == maxIndex) ? i+1 : i;
        }
    }
}

```

```

return found>index ? data.substring(strIndex[0], strIndex[1]) : "";
}

void dataFunction(int x){
    HTTPClient http; //Declare object of class HTTPClient
// String url = "http://192.168.1.74/elic_data/getdata.php";
    String url = "http://irrigation.softechsupply.com/getdata.php";

    url += "?UIDresult=" + String(x);
    Serial.println(url);
    http.begin(client,url.c_str());
// delay(5000);

    httpCode = http.GET();
// delay(2000);

    payload = http.getString();
// delay(3000);
while(httpCode<10){
    Serial.print("trying.... ");
    http.begin(client,url.c_str());
    httpCode = http.GET();
    payload = http.getString();
}

    Serial.print("ID: ");
    Serial.println(UIDresultSend);
    Serial.print("Code: ");

    Serial.println(httpCode); //Print HTTP return code

    Serial.print("Response: ");

```

```

Serial.println(payload); //Print request response payload

response1 = getValue(payload,'#',0);
response2 = getValue(payload,'#',1);
response3 = getValue(payload,'#',2);

http.end(); //Close connection
if(payload!=""){
  if(response1=="Not registered"){
    }
  }
}

void loop() {

int value = analogRead(AOUT_PIN); // read the analog value from sensor
Serial.print("Moisture: ");
Serial.println(value);
dataFunction(value);
if(value>800){
  Serial.println("Water is low, system is pumping!");
  digitalWrite(ledPin, LOW);
  // scan from 0 to 180 degrees
  for(angle = 45; angle < 180; angle++) {
    servo.write(angle);
    delay(10);
  }
  // now scan back from 180 to 0 degrees
  for(angle = 180; angle > 45; angle--) {

```

```
servo.write(angle);  
delay(10);  
}  
// delay(2000);  
}else if(value<100){  
digitalWrite(ledPin, HIGH);  
Serial.println("Soil Moisture is not connected well!");  
}else{  
digitalWrite(ledPin, HIGH);  
}  
delay(500);  
}
```