UNIVERSITY of RWANDA

ACEIoT

Website: www.aceiot.ur.ac.rw
Mail: aceiot@ur.ac.rw

College of Science and Technology

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

Designing Smart System for Smallholder Farmers to Monitor Environmental Conditions for potato crop using IoT and Machine Learning

A dissertation submitted in partial fulfilment of the requirements for the award of masters of science degree in internet of things: wireless intelligent sensor network

Submitted By

Fancy KIPTOO (REF.NO: 221030783)

December, 2023

UNIVERSITY of RWANDA

ACEIoT

Website: www.aceiot.ur.ac.rw
Mail: aceiot@ur.ac.rw

College of Science and Technology

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

Designing Smart System for Smallholder Farmers to Monitor Environmental Conditions for potato crop using IoT and Machine Learning

A dissertation submitted in partial fulfilment of the requirements for the award of masters of science degree in internet of things: wireless intelligent sensor network

Submitted By:

Name: Fancy KIPTOO (Ref. No: 221030783)

Supervised by:
Dr. James RWIGEMA
Dr. Evariste TWAHIRWA

December, 2023

DECLARATION

I, FANCY Kiptoo, declare that this work is completely my own and has never been presented for any degree before. With the exception of sections where proper credit and acknowledgment are provided, this thesis is based on research that I conducted.

Name: Fancy Kiptoo

Signature:

Date: 4 December, 2023

BONAFIDE CERTIFICATE

This is to certify that this research project entitled “*Designing a Smart Potato System for Smallholder Farmers to Monitor Environmental Conditions based on IoT and Machine Learning”* is a record of the original work done by Fancy Kiptoo, Ref No: 221030783 MSc. IoT-WISNET Student at the University of Rwanda / College of Science and Technology / African Center of Excellence in Internet of Things, the Academic year 2022/2023.

This work has been submitted under the supervision of Dr. James RWIGEMA and Dr. Evariste TWAHIRWA

Main Supervisor: Dr. James RWIGEMA	Co-Supervisor: Dr. Evariste TWAHIRWA
Signature:…………………	Signature:………. …………………..….
Date:……………………………	Date:……………………………….

The Head of Masters and Training

Dr. James RWIGEMA

Signature:………………………….

Date:………………………………

ACKNOWLEDGEMENT

I want to start by giving thanks to the Almighty God for giving me good health. I am grateful to Dr. James Rwigema and Dr. Evariste Twahirwa, who supervised my research and provided valuable feedback and guidance. Additionally, I would want to express my gratitude to all lectures that had an impact on my career advancement and personal growth during my studies.

Secondly, I would want to express my gratitude to the University of Rwanda, specifically the African Center of Excellence in Internet of Things (ACEIoT), for their invaluable help in facilitating my academic pursuits. My employer, Moi University for allowing me study leave to pursue my master's degree. To center administration, Prof. Damian Hanyurwimfura, the acting Director Center, Dr. James Rwigema, the Head of Masters Studies, and the entire Staff, thank you for your support

Also, I appreciate my friends, classmates and everyone who provided me with encouragement and technical support while I was working on my thesis.

Finally, I would want to express my sincere gratitude to my family, specifically my parents, siblings, and extended relatives, for their unwavering support, prayers, and consistent motivation during my journey. To my lovely husband you deserve a special thanks, I lack words to express my joy, thank you for the overwhelming support, granting me permission to be away from home as well as, taking good care of our children during my absence despite your busy work schedule.

ABSTRACT

Because of the rising urbanization and strong demand for farm products, the agriculture sector has expanded rapidly, particularly in Africa. Agriculture sector in Kenya is one of the main economic activities that provide employment roughly to two-thirds of the working population, contributing 33 percent of the country's GDP on average. Potato farming in Kenya comes as a second food crop after maize, and a source of income that helps to improve many livelihoods. However, smallholder potato farmers continue to face environmental challenges, which threaten the country's food security. In Kenya, most smallholder potato farmers use traditional methods (visual observation) to monitor the environmental parameters of potato crop, due to the high cost of monitoring tools available on the market. In addition, the available tools in the market such as rain gauge are limited to a specific use. Therefore, this study proposes the use of smart potato system to monitor environmental parameters which employ the use of IoT and ML technologies to address environmental challenges that smallholder potato farmers face which has huge negative effect on potato crop; high or low temperatures interferes with the growth of potato tubers and damage potato leaves, high humidity causes late blight, slow tuber development and high moisture leads to tuber rot, high or low soil pH results to interference of the nutrients absorption. This study developed a prototype system to monitor the environmental parameters. We deployed the prototype system in the potato field to monitor environmental parameters, and the data collection process was completed successfully. The study designed a web application for potato farmers to store environmental data collected from the field and a prediction system that utilizes machine learning (ML) algorithms to recommend a course of action when the environmental parameters under observation drop or rise above the ecological recommended threshold. This system will help farmers in better decision-making, improve efficiency, minimize resource wastage and lower production costs.

***Keywords**: Potato, Gross Domestic Product (GDP), Smallholder, ML, IoT*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACEIoT:	African Center of Excellence in Internet of Things
API:	Application Programming Interface
AT:	Advanced Technology
CSS:	Cascading Style Sheet
Colab:	Colaboratory
FAO:	Food Agricultural Organization
4G:	Fourth Generation Wireless
GSM:	Global System for Mobile Communication
GPIO:	General Purpose Input Output
GDP:	Gross Domestic Product
GPU:	General Processing Unit
GPRS:	General Packet Radio Service
HTML:	Hypertext Transfer Markup Language
HTTP:	Hyper Text Transfer Protocol
TPU:	Tensor Processing Unit
IDE:	Integrated Development Environment
IR:	Infrared
IoT:	Internet of Things
LCD:	Liquid Crystal Display
LTE:	Long Term Evolution
LED:	Light Emitting Diode
LoRa:	Long Range
LoRaWAN:	Long Range Wide Area Network
ML:	Machine Learning
NB-IoT:	Narrowband Internet of Things
PA:	Precision Agriculture
pH:	Potential Hydrogen
PHP:	Hypertext Preprocessor
PR:	Polynomial Regression

RF:	Random Forest
SDLC:	System Development Life Cycle
SSL:	Secure Socket Layer
SMS:	Short Message Service
SIM:	Subscriber Identity Module
SQL:	Structured Query Language
SVR:	Support Vector Regression
TCP/IP:	Transfer Control Protocol/ Internet Protocol
UML:	Unified Modeling Language
UABs:	Unmanned Aerial Base Station
UAV:	Unmanned Aerial Vehicle
UV:	Ultraviolet Radiation

CHAPTER ONE

1.1 Introduction

The agricultural sector holds paramount significance in a nation's economy, particularly in developing nations [1], [2]. The agricultural sector in Kenya plays a significant role in the country's gross domestic product (GDP), accounting for around 33 percent of its total output. Furthermore, it serves as a major source of employment for approximately 70 percent of the rural population in Kenya [3], [4]. Based on a report published by the United Nations, it is projected that the global population will reach approximately 8.3 billion individuals by the year 2030. Consequently, it becomes important to establish collaborative partnerships between the government and all relevant stakeholders within the agricultural industry. This collaborative approach is essential for effectively addressing the issue of food security and enhancing the overall well-being of the population [5].

The potato (*Solanum tuberosum*) production comes fourth after rice, wheat, and maize, and it is ranked third in the world after rice and wheat in terms of human consumption [6]. Potato crop is known to have originated from Southern Peru, and it's consumed by more than one billion people globally across South America, Asia, and Africa [6]. In African countries potato was introduced in late 17th century by missionaries who had come to Africa to spread the gospel while in Kenya, potato crop was introduced in 1880s by British farmers, comes second after maize, and it is regarded as one of the cash crop as well as stable food among families in Kenya [7]. It is grown in highlands parts of Rift Valley, Central and Eastern Provinces of Kenya [8].

In the global market there are two main types of Potatoes; fresh potatoes and processed potatoes. Apart from potatoes being regarded as human food consumed on day to day basis, it is also used for industrial purposes for making food ingredients, producing glues, adhesives, ethanol for alcohol, and feeds for animals among other benefits [9]. According to Food Agricultural Organization (FAO) statistics, more than 158 countries in the world are cultivating potatoes, the global potato production in 2021 was 376 million tons, with China producing 94 million tons, and India producing 54 million tons, respectively, while most of the African countries produced less than 3 million tons [10]. According to agriculture and development authority, potato yields dropped in the year 2022 by approximately 10 to 15 percent [11]. In developing countries, particularly in Sub-Saharan Africa, potato production is still low, yet it is considered as a source of income to improve the livelihoods of smallholder farmers through income generation and job creation, as well as being rich in vitamins [12].

Smallholder potato farmers face numerous challenges while cultivating potatoes, some of the problems they experience include visual monitoring of environmental parameters, poor soil management practices, infestation of pests and diseases on potato crop such as early blight and late blight, and limited availability of potato seeds. Most farmers in African countries, particularly in Kenya, are unable to access good quality seeds from certified potato seed companies, forcing farmers to use seeds from earlier harvests, which in most cases such seeds are infected with pathogens [13]. Furthermore, the main contributing factor to this problems potato farmer's face is related to unfavorable environmental conditions which keep on fluctuating from time to time due to effects of the climate change, making difficult for farmers to monitor closely since most of the farmers use traditional methods such as visual (observation) to monitor the environmental parameters, resulting in production of unhealthy or diseased potato; thus affecting the overall yield productivity [14].

Potato crop is highly vulnerable to pests, diseases, and changes in environmental conditions such as extreme temperature, humidity, soil moisture, and soil pH. Therefore, modern farming technologies such as precision agriculture, need to be adopted by farmers towards effective monitoring and controlling of environmental parameters such as high temperature which affects potato growth and tuber development due to the sensitivity of the temperature[15], [16]. Inadequate humidity encourages the spread of pests, diseases, tuber decay, and physiological stress during potato growth stage [17]. On the other hand, soil acidity, interferes with potato nutrient intake due to changes in chemical elements present in the soil.

Environmental conditions are important in the growth and development of potato crop. Hence, it is necessary that the environmental conditions fall within the range of set standards. In Kenya, the ecological requirements for potato cultivation exhibit variability based on factors such as potato crop kinds, soil type, and several stages of potato growth. These stages include tuber formation, germination, vegetative growth, tuber growth, tuber bulking, and maturity stage.

The ideal temperature range for potato tuber formation is typically between 15°C and 20°C. Additionally, the soil temperature should be maintained within the range of 15°C to 24°C. Adequate soil moisture levels, ranging from 400mm to 800mm, are also necessary for optimal potato growth. Furthermore, the soil pH should lie within the range of 5.5 to 7.0, and the potato crop requires a rainfall amount ranging from 600mm to 1000mm. The optimum temperature for potato during tuber formation ranges between 15°C to 20°C, soil temperature 15°C to 24°C, soil moisture 400mm-800mm with soil pH ranging from 5.5 to 7.0 and rainfall ranging from 600mm to 1000mm. The required temperature for potato during the vegetation and flowering stage is between 15°C and 25°C, soil temperature 15°C and 20°C, and soil pH is between 5.0 and 7.0 [18],[19],[20].

The internet of things (IoT) and machine learning (ML) technologies have become more important towards addressing day to day agricultural challenges that farmers experience while farming their crops. Farmers can remotely monitor their farms using IoT technologies to collect data, assess soil condition, and perform data analysis to obtain meaningful information to facilitate better decision-making [17], [18]. This research aims to develop a smart potato system using IoT and ML technologies to monitor environmental conditions for potato crop. This will enable smallholder farmers to monitor potato closely and take appropriate action to minimize the negative impacts of environmental conditions on potatoes. The system collects the sensor data in the field and sends it to a cloud server, where it can be accessed by the user using the web application (dashboard). Machine learning is used for analysis and to make recommendations to allow smallholder farmers to make informed decisions based on the system recommendation. For example, when temperature is high the system recommends the farmer to consider irrigating the crop.

1.2 Background and Motivation

The advancement of IoT technologies in agriculture has significantly boosted crop productivity and sustainability. However, smallholder farmers lack access to smart systems for monitoring potato crops, therefore, it becomes difficult to make informed decisions when it comes to monitoring environmental parameters for potato crops.

Existing literature emphasizes on how important it is to keep an eye on the environment parameters in a timely and accurate way in order to boost crops yields and growth. Moreover, despite the adoption of technologies such as precision agriculture in yield monitoring, soil selection and mapping, crop field irrigation, fertilization application, and pest management, a smart potato system for smallholder farmers that is cost effective, efficient, and user friendly is still required [21].

The motivation for this research results from the challenges that smallholder potato farmers face when it comes to monitoring and controlling environmental parameters for potato crop in the County of Elgeyo-Marakwet, one of the 47 Counties in Kenya. Potato farmers are unable to make better informed decisions because they don't have access to a low-cost smart system to monitor what is happening on their farm. By developing a smart potato system to monitor environmental parameters using IoT and Machine learning technologies will assist smallholder potato farmers to make informed decisions about irrigation, fertilization, and potato crop management. This improves efficiency, reduces resource waste, increase yield productivity, and contribute to food security as well as promoting the Sustainable Development Goal 2 (Zero Hunger) [22].

1.3 Problem Statement

The potato industry in Africa has experienced a drastic drop in production output[23]. The drop of the potato yield production has been attributed to changes in weather conditions[24]. Monitoring and controlling environmental parameters due to effects of climate change is required to promote yield productivity [25]. However, monitoring and controlling environmental parameters for potato crop still remains a major challenge in Kenya, among smallholder potato farmers, particularly those in rural areas are using traditional methods (visual monitoring) to monitor their potato crops. This is primarily due to the high cost of environmental monitoring tools available on the market. Some farmers prefer to use locally available tools and instruments in the market like rain gauge to measure the amount of rainfall, a thermometer to monitor temperature level, and some use pH testing kits to measure soil pH on the farm. Furthermore, when it comes to monitoring these environmental parameters, potato farmers are unable to make timely and informed decisions regarding the overall management of potato crop.

Farmers also, rely on the knowledge from experts such as agricultural extension officers; where farmers normally participate in trainings, seminars, or field days organized by the agricultural department at the county level; farmers are then, provided with guidance on best practices on monitoring environmental parameters and advised on ways to identify the early signs of crop diseases visually, without any use of technology [26]. These methods are more costly, time consuming, inefficient, and unreliable. As a result, there is need to develop a smart potato system for smallholder farmers to monitor environmental parameters, by incorporating modern farm technologies such precision agriculture, to allow smallholder farmers to monitor environmental conditions for potato crops, and promote environmental management practices, yield productivity, efficiency and better decision making.

Research Questions

This study sought to answer the following questions on environmental monitoring parameters for potato crop

1) What are the main challenges facing smallholder potato farmers?
2) What is the most effective approach to designing and deploy a user-friendly web application for farmers to monitor environmental factors that impact potato crops?
3) How can a smart system based on IoT and ML technologies be designed and develop to monitor environmental parameters for potato crops?

1.4 Study Objectives

1.4.1 General Objective

The general objective of this research is to provide a cost-effective solution to smallholder potato farmers to monitor environmental parameters such as air temperature, humidity, soil temperature, soil moisture, and soil pH using IoT and ML technologies.

1.4.2 Specific Objectives

Specific Objectives of study are:

1) To address challenges smallholder potato farmers face in monitoring environmental parameters.

2) To design and deploy a user-friendly web application for farmers to monitor environmental parameters

3) To design and develop a smart system based on IoT and ML technologies that smallholder farmers can use to monitor environmental parameters affecting potato crop

1.5 Hypothesis

Developing a smart potato system by incorporating IoT and ML technologies to monitor environmental parameters for potato crop will significantly improve yield productivity, increase efficiency, cost effectiveness, and resource utilization among smallholder potato farmers.

1.6 Study Scope

Monitoring environmental parameters for the potato crop is a wide field with so many parameters to monitor. This study will be only focusing on environmental parameters like air temperature, humidity, soil temperature, soil moisture, and soil pH for potato crop among smallholder potato farmers in Chepkorio ward, Elgeyo-Marakwet County in Kenya. We chose these environmental parameters after extensive research based on the related topics on scientific literature research published in articles, which indicated that these environmental parameters have a direct negative impact on potato growth, as well as extensive consultation with agricultural experts like agronomists along with the interactions with smallholder potato farmers, who identified these parameters as a significant risk and hindrance to potato growth and productivity. Other environmental parameters were not put into consideration on this study. The study integrates IoT and Machine learning technologies; IoT technology was used to collect sensor data and machine learning is employed for data analysis.

1.7 Significance of the Study

The proposed solution for smallholder potato farmers to monitor environmental parameters for potato crop will be of much beneficial to agriculture sector. This is because environmental conditions have a negative impact on the farm crops if they are not monitored. The developed system will help stakeholders such as the government to make appropriate plans to address food security in the country. Incorporating modern technologies in environmental monitoring will allow smallholder potato farmers to make informed and timely decisions about irrigation, potato crop management, and the fertilization application. As a result, yield productivity will increase and food security is ensured. Furthermore, the designed system for monitoring environmental parameters for potato crop will help smallholder farmers practice smart agriculture, allowing them to benefit economically from high yield productivity of potatoes and thus improve their livelihoods.

1.8 Organization of the Study

The study is organized into the following six sections. Chapter one introduces the study's introduction, background, as well as the motivation for the study; the problem statement explains in detail the challenges that smallholder farmers face; objectives of the study discusses what the study looks towards addressing, the hypothesis touches on the significance of the proposed system; the study scope touches more on the parameters the study focused on and what the study is limited to explore, significance of the study discuss on the impacts the system contributes. Finally, the conclusion discusses the results and findings of the system. The second chapter describes previous studies on monitoring environmental parameters for potato crops conducted by other researchers. It starts with a review of the existing literature and identifies the gaps and how to fill them. The third chapter of this study addresses the research technique and procedures employed. It discusses the data gathering methods and tools that were utilized throughout the study, as well as the Internet of Things (IoT) devices that were employed in the overall implementation of the project. The fourth chapter explains more about system analysis and design of the system prototype, as well as the system models to employ in the study.

Chapter five focuses on results and analysis of the machine learning algorithms used in the study, along with discussing on the findings of the study as well as explanations on the graphs used. Finally, the last chapter summarizes the conclusion and future work recommendations.

1.9 Conclusion

This study has clearly introduced the background of the potato crop in Africa, as well as the contribution of the agriculture sector to increasing the country's GDP and improving citizens' livelihoods. The study has clearly highlighted the motivation towards this work, with the main focus being on monitoring environmental parameters for potato crop. This is in consistent with the goal of this research project, which is to monitor environmental parameters in order to address challenges that smallholder potato farmers face when cultivating their potato crop, as well as to develop a solution that smallholder potato farmers can use to monitor environmental parameters towards increasing yield productivity. Adopting IoT and ML technologies in monitoring environmental parameters for potato crop has a positive impact on the agriculture sector. Smallholder potato farmers can make informed decisions on agricultural farm practices such as irrigation, fertilization, and crop management resulting to efficiency, resource management, yield productivity and food security.

CHAPTER TWO

2.0 Literature Review

2.1 Introduction

This chapter examines the literature on previous research conducted by different scholars on the use of IoT and machine learning technologies in monitoring environmental parameters for farm crops. This review of literature starts by discussing the agricultural technologies that has evolved over the past years, review on the studies that have been proposed towards monitoring of environmental parameters using IoT technologies and ML models.

The world is currently experiencing the effects of climate change, which are becoming more unpredictable day by day due to the rising temperature levels, putting the agriculture sector at risk and countries on the path to addressing food security. To address these challenges, the use of IoT technologies in agriculture is important towards addressing environmental conditions and yield productivity.

2.2 Evolution of Agricultural Technologies

The agriculture sector has undergone significant transformation over the years, from the earlier experience realized during the existence of agricultural periods (Agriculture1.0 to Agriculture 4.0). Agriculture 1.0 was the first agricultural era. This was the traditional agriculture period, where farmers relied on manpower and the use of animals such as bulls and donkeys to push shovels to help farmers cultivate the land. This method is time-consuming, inefficient, and yields low results[27],[28]. Agriculture 2.0 was introduced in the nineteenth century, during the industrial evolution period, when machines were introduced but farmers had to operate them manually. Also during this period the introduction of agricultural chemicals came into use, where farmers used to apply on their crops to mitigate the spread of disease [29]. Agricultural productivity increased in comparison to the first era, but excessive chemical use contributed to an unfriendly environment, among other effects. Agriculture 3.0 emerged around the twentieth century, bringing about a drastic change in the agriculture sector due to the introduction of computers and robot techniques, which enabled agricultural machines to be intelligent and perform work without human intervention [30]. This benefited the agriculture sector by saving time, lowering labor costs, and increasing crop productivity. Farmers are currently utilizing Agriculture 4.0, which has been realized as a result of new precision agriculture technologies such as IoT, ML, and UAVs[31].

2.2.1 UAVs and Remote Sensing Application in Agriculture

The application of remote sensing in agriculture sector has rapidly expanded over the past years, with the combination of different technologies in agriculture; it is possible nowadays to promote growth of health crops and boost yield production. With the deployment of satellite-based systems to collect environmental parameters from the farm; farmers are in a better position to monitor environmental conditions, soil nutrients levels, yield, water level status for crops, and perform the assessment of the crop, land cover and degradation mapping, early identification of weeds, pests and diseases [24]. Furthermore, the applications of Unmanned Aerial Vehicles (UAVs) in agriculture are increasing rapidly. Drones are mounted with different sensors, for both underground or above ground sensors to collect different data parameters from the field. Drones, for example, are mounted with high resolution multispectral cameras to capture images of plant weeds, pests, and pathogens on farms [25].

2.2.2 Internet of Things (IoT) and Machine Learning (ML) in Agriculture

The use of IoT technologies such as sensors makes it much easier for farmers to collect data on environmental conditions, which aids farmers in decision making. Furthermore, incorporating ML for recommendation purposes enables quick response to actions that must be addressed immediately in order to prevent and minimize crop damage caused by climatic changes. IoT in agriculture is divided into several domains, including irrigation management, monitoring of agricultural machines, and agricultural monitoring such as soil condition monitoring, environmental monitoring such as temperature, humidity, air pressure and wind direction fertilization monitoring, disease and pest monitoring through use of IoT sensors [32]

2.3 Related Works

The use of IoT and ML technologies in agriculture applications has attracted the interest of many researchers in the field of IoT to conduct research that contributes towards providing a solution to agricultural problems that farmers face while cultivating their crops.

In [33] the authors proposed an intelligent system for agriculture with the integration on IoT and ML technologies to monitor agricultural field. The study managed to collect environmental conditions such as soil moisture, soil temperature, atmospheric temperature and humidity from the farm. The study explained the importance to have a clear understanding about soil type, since each type of soil has different qualities for crop productivity. Sensor nodes were deployed at various locations on the farm field to monitor environmental parameters, and ML (naïve bayes) algorithm was used to predict crop yield, which achieved accuracy of 76.47 percent. Sensor data was stored in the cloud using the ThingSpeak IoT platform for visualization and analysis. Furthermore, when the threshold data value did not meet the expected set limits, users were notified via email to take appropriate action.

Gómez, D et al. [34] proposed a solution that predicts potato yield using ML techniques such as linear regressor, support vector regression, as well as random forest. The data from European satellite were collected to predict potato yield for a period of three years between 2016-2018. The study highlighted that high spatial image data as well as temporal satellite imagery significantly improved potato yield. In addition, the study noted that better crop modeling tools were needed to address the challenges caused by extreme weather conditions, which cause outbreaks of diseases and pests, resulting in food insecurity. The authors also pointed out that information loss can occur while monitoring crops using passive remote sensing, due to environmental factors such as cloud covers making difficult to get larger data sets. However, the study did not provide any alternative solution to address information loss challenge mentioned in the study. Therefore, there is need to incorporate IoT technologies to address the environmental challenges resulting for weather changes.

Similarly, Kuradusenge, M. et al. [35] used ML models such as polynomial regression, support vector regressor, and random forest (PR, SVR, RF) to predict the upcoming harvests based on crop yields and weather historical data for Musanze district in Rwanda.

From there study random forest performed well as compared to polynomial regression, and support vector regressor. The focus was mainly on two crops; Irish potatoes and maize, and the predictors used were rainfall and temperature data obtained from Rwanda's meteorological office to determine the optimal crop yield. However, the study acknowledged the model prediction results were good, and even the results could be much better if other environmental parameters such as soil moisture, air humidity are taken into account.

The authors in [36] proposed a low cost smart IoT system that uses multi-sensors to monitor environmental parameters such as water level, soil moisture, temperature, humidity, and rain. The network communication was based on LoRa technology, and the system users were able to monitor and control their farms either manually or automatic using a mobile application. However, because there are a number of sensors distributed across the farm, a huge amount of data was generated from the sensors, Therefore, using IoT blynx platform for visualization and storage will be limited thus alternative cloud storage is essential to accommodate large data generated from different sensors from the farm. Also, if the system's internet connection is lost, IoT blynx will be inaccessible, posing a challenge during data transmission.

In [37] the authors of the paper designed a low cost system platform for monitoring of environmental parameters such as; temperature, humidity, solar radiation and rain level, soil moisture, and air pressure. This study used both underground and above ground sensors. The system sends data to a ground gateway at every one-hour intervals using LoRa protocol and 4G cellular communication technology, to facilitate communication between the ground gateway server and cloud, before transmitting data to the cloud for storage and analysis every twelve hour. However, one of the limitations of the system is power consumption, therefore consideration for drone power optimization is critical to sustain the flight time for the drone to cover large area on the farm.

Gaia et al.[38] Proposed a system that uses IoT and LoRaWAN to monitor indoor and outdoor environmental parameters such as; air temperature, humidity and soil temperature for the green house and vineyard field, the study focused on vegetables and grapes crops. Air temperature sensor, humidity sensor, and soil temperature sensor was used to collect the data at the interval of ten (10) minutes and transmitted after every thirty (30) minutes. After the deployment of four sensor nodes for a period of 81 days three of the nodes had packet transmission success rates without packet loss of over 80%, while one of the nodes achieved 70 percent and the possibility of low results rate were attributed to the location in which the node was installed in the greenhouse. Moreover, this study used LoRaWAN technology for transmitting data to cloud, rechargeable lipo batteries by use of a solar panel were used to allow sustainability of the system for some months, and web based application to provide user insights. However, one of the study's limitations is the loss of some sensor data during transmission, which occurs during rainy days due to battery discharge.

The authors of [39] proposed a UAVs system for monitoring potato crops that uses narrow band IoT (NB-IoT) to communicate with unmanned aerial base station (UABS). Underground soil parameters were collected using NB-IoT system. The study collected data from underground sensors using a quadcopter UAV with a flight time of at least 45 minutes with the goal of increasing sensor power by minimizing data transmission time. Sensors were inserted into the ground at different depth levels starting from 0cm, 25cm, 50 cm and 75cm respectively to monitor dry and wet soil conditions.

Doshi J. et al. [40] proposed a farm monitoring solution for farmers. The temperature, humidity, soil moisture, Infrared (IR), and Ultraviolet Radiation (UV) indexes were used in the study, and the system collected the data and sent it to the Blynx IoT cloud every 18 minutes. The system then goes to sleep mode before waking up to take another reading. Farmers can receive alerts via visual LED alerts, sound from buzzers, and mobile phone notifications. IoT system for monitoring plants has been presented in [41], which uses GSM technology for communication. The researchers managed to deploy temperature sensor, soil moisture sensor and light sensor to monitor environmental parameters for crops and notify the farmers through SMS.

Authors in [42] developed a system that farmers can use to monitor environmental parameters such as temperature, humidity and soil moisture from any location, with a focus on the wheat crop. Bluetooth and ZigBee technology were used to send fetched sensor data, the results were then analyzed based on temperature, humidity and moisture to allow farmers to act appropriately.

IoT monitoring system for early plant disease prediction based on environmental and soil conditions collected using farm installed wireless sensor networks was presented in [43]. The main focus crops were potato and tomato, and five disease control models based on artificial intelligence were developed. The study highlighted some of the system's capabilities, such as the ability to communicate a warning message to users prior to disease outbreaks and the reduction of chemical use on crops.

Singh, R. et al. [44] emphasized the importance of continuously monitoring the physical environmental conditions of the crop due to changing climatic conditions. The marigold plant was the focus of the study, and the environmental variables considered were humidity, temperature, soil moisture, soil temperature, and light intensity. Sensor data were collected in the field, and send to the ThingSpeak platform for storage and data visualization. Moreover, logic regression, linear SVC, and gradient boost classifier were used to predict the best crop suitable for growth depending on the environmental parameters. Gradient boost classifier achieved higher accuracy of 83% compared to other two models. However, due to the huge data generated from the sensor, it is evident that ThingSpeak is not suitable to handle large data since it is limited in terms of the data to be sent to the cloud and API requests, compromising reliability or real time access of data in cloud.

2.4 Summary

From the review of the literature done on monitoring environmental parameters for potato crops as well as other related crops, the study identify the following gaps, which the study seek to contribute; most of the solutions use unmanned aerial vehicles, which uses both underground and above sensors to collect data from the farm. While UAVs are an excellent tool for monitoring large farms, the high cost involved makes them unsuitable for smallholder farmers. Also, some of the aforementioned solutions mostly provide limited storage of data which makes it challenging to access historical data which is essential for making decisions**.** As a result, this research aims to contribute towards the development of a of a low-cost system prototype for smallholder potato farmers to monitor environmental conditions by incorporating other environmental parameters not previously studied, such as soil pH to determine acidity or alkalinity in the soil, which has a negative impact on soil nutrients if not monitored thus, affecting the potato crop. Furthermore, to develop a user-friendly web application for farmers to help them track historical data based on environmental parameters monitored on the farm and finally, identify machine learning algorithm with high accuracy to analyze environmental parameters and live data from sensors, and provide a recommendation to farmers in order to gain a clear understanding of environmental parameters.

CHAPTER THREE

3.0 Methodology

This chapter focuses on the following areas; the study area, sampling techniques used in the study, data collection, data analysis, and ethical considerations.

3.1 Study Area

This study was conducted in Chepkorio Ward, Elgeyo-Marakwet County, and is among the 47 Counties in Kenya, with four constituencies namely: Marakwet East, Marakwet West, Keiyo North, and Keiyo South, with its largest town in Iten. The county boarders West Pokot towards the North, Baringo to East, Uasin-Gishu to Southwest and West, and Trans Nzoia to the Northwest. The county is well known for tourism attraction sites like Rimoi National Reserve, which is home to wild animals, Lake Kamnorok, high altitude training camp, Torok waterfall, which is 200m high, 20m deep Cheploch Gorge which cross the highway, hills and view-point which gives a clear view of Rift Valley and Tugen hills.

The county's economic activity is primarily mixed small scale farming and cattle rearing both for dairy and beef production [45]. The county of Elgeyo-Marakwet is known for its potato crop, which comes as the second crop after maize. The county grows potatoes on about 23,000 hectares per year, yielding between 250,000 tons and 340,000 tons of potatoes annually [46]. Potato crop is majorly grown by Smallholder farmers in the county. The study area was considered based the study scope, the nature of the data to be collected, the availability of data, and the amount of time available to collect data. Based on the aforementioned factors; this study area was chosen because the majority of the farmers in the area grow potatoes. Furthermore, the soil in the area is loamy and sandy, which is well drained, aerated, and rich in organic matter, making it suitable for growing potatoes.

Map of the study area

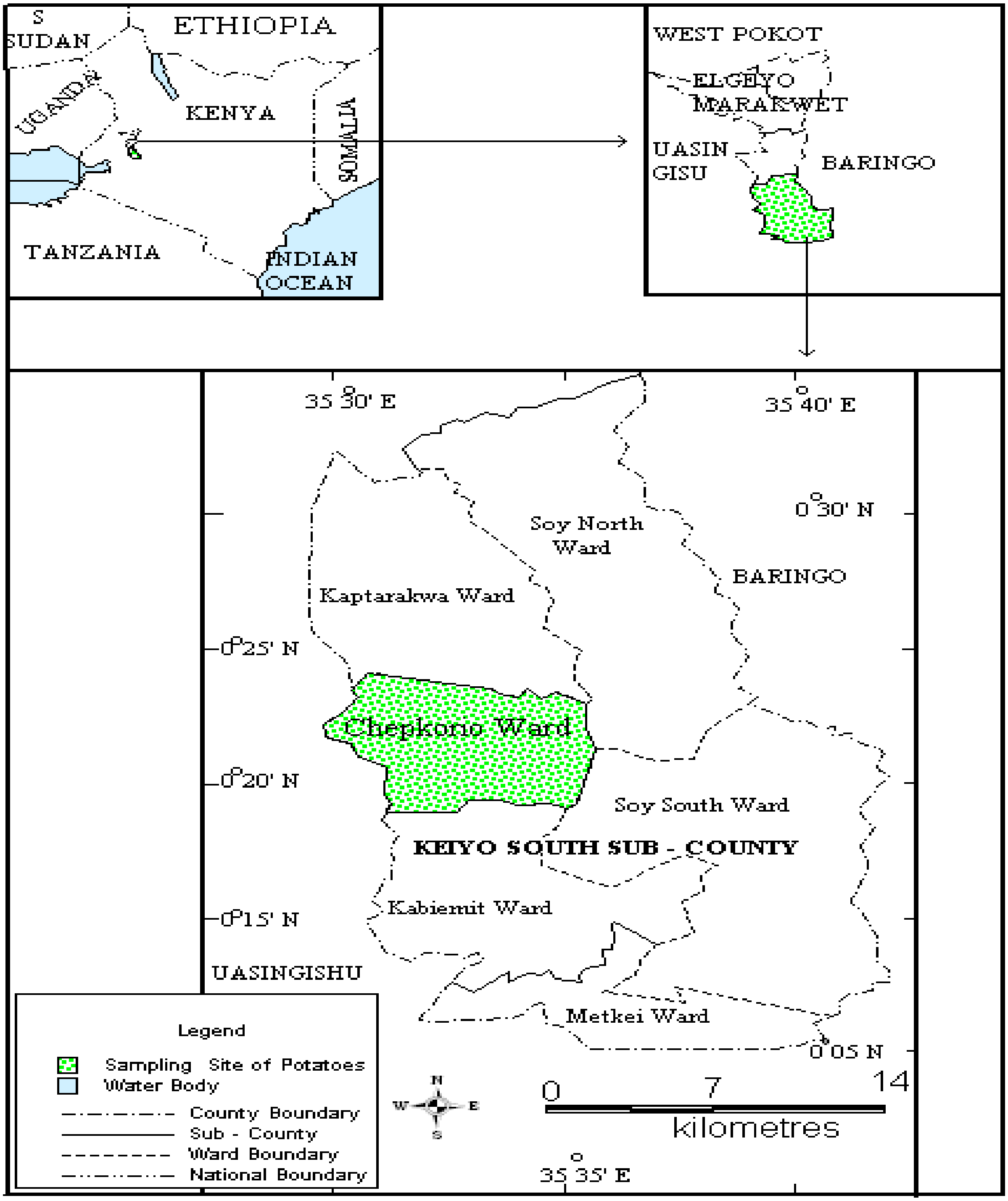


Figure 3. 1 Map of Keiyo South Sub-County showing Chepkorio Ward as study area.

3.2 Sampling Techniques

The study used a point sampling approach to determine specific location to deploy sensors to monitor environmental parameters. This technique was considered because it provides a systematic approach which is primarily suitable for agriculture applications and the field of environmental science. Furthermore, the study was focusing on monitoring environmental parameters for potato crop, which primarily provides information on spatial variations. The field was divided into smaller zones based on factors such as soil type and crop performance in the past. In addition, point sampling provides a clear insights and a fair representation of the entire farm area, it is also cost effective because the collection of environmental parameters is done on a predetermined sampling points[45], [46].

3.3 Data Collection

In this study we used quantitative and qualitative approach. This is because the study was dealing with the numeric data obtained from sensors deployed in the field to monitor environmental conditions in the potato farm. As well as the use of questionnaires for farmers, to help us understand the challenges the smallholder farmers face while monitoring environmental parameters for potato crop, also face to face interviews with the agronomists were conducted to get clear information on potato crop. Secondly, the design was preferred because data can be visualized using tables and graphs, thus providing a clear understanding on the interpretation of our data for better-informed decision-making. Collection of primary data were done using DHT 11 temperature/humidity sensor, and type 485 soil comprehensive sensor (soil integrated sensor) incorporating soil temperature sensor, soil moisture sensor, and soil pH sensor were deployed in the potato field to collect the environmental parameters, from the specified sampling points for a period of two weeks. The sensor was able to collect environmental parameters at an interval of one minute, and data were transmitted to the cloud platform. Sensor was placed on one zone for one day, before moving sensors to a different zone point; this decision was arrived after having a wide consultation with the experts in the domain (agronomist). Data were then transmitted to cloud platform for storage and analysis.

The following were steps followed during data collection:

In order to gather environmental parameters from the potato farm, this research used DHT 11 temperature/humidity sensor, soil integrated sensor (measuring soil moisture, soil temperature, and soil pH). Data pre-processing was done on the data after it was collected to get rid of outliers and missing values. This is significant because it addresses the missing values and guarantees data consistency. Splitting of data into train and test was done at 0.8 and 0.2 respectively as indicated on figure 3.3; after starting with the sixth percent (60%) has we increased the training gradually to have a better

Performance on our ML model. training was performed for the purpose of prediction, and finally we evaluated our model accuracy using cross validation.

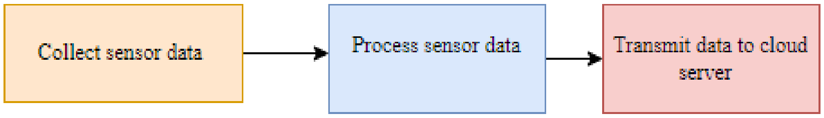


Figure 3. 2: Shows the main steps follow during data collection

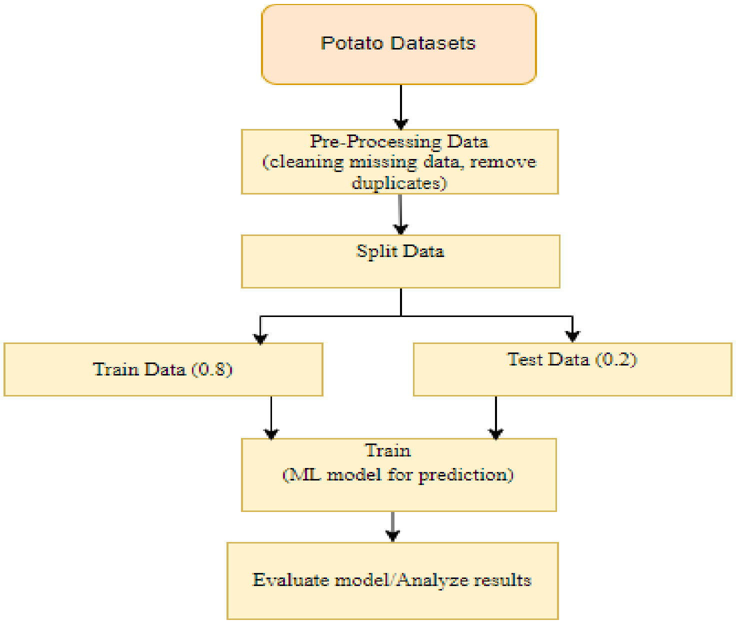


Figure 3. 3: Showing steps follow to analyze ML model

3.4 Data Analysis

The study used Google Collabaratory, also known as Colab. Cloud-based Jupyter notebook is a free application from Google, which provides users with a Jupyter environment for coding and running Python code. Furthermore, it provides the user with access to General Processing Units (GPUs) and Tensor Processing Units (TPUs) which is a virtual memory space [47]. The environmental parameters collected from the field using sensors were sent to a cloud platform for storage. The data was retrieved from cloud storage, converted to a useful format (excel.csv), and then cleaned to remove any missing values. The datasets were uploaded to Google Colab in order to train machine learning models. We set up the necessary Python libraries and frameworks on our Jupyter environment in order to run the machine learning model. A variety of ML algorithms were used to train datasets before selecting the best model for our system based on model accuracy and performance.

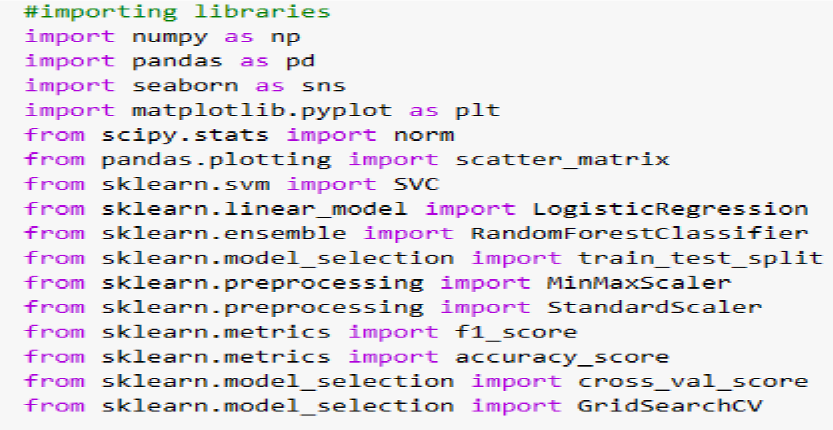
3.5 Machine Learning Model

Among the subfields of artificial intelligence is machine learning [48]. ML tackles the world's complicated problems by using statistical models and algorithms like supervised, unsupervised and reinforcement learning. Supervised learning majorly focuses on the labelled data and works well with regression (predict continuous values), and classification (classification handles labels, categorical data). Unsupervised learning handles unlabeled data which are used to train the model while reinforcement learning allows the interaction with the environment for decision making [49]. In our study we used machine learning to analyze the data collected from the sensors, with the focus on supervised learning algorithm; because we were working on labelled data and also we needed to employ the use classification and regression.

The following procedures were taken into account when training ML model.

Step 1: Open Google Colab in your web browser and select TP4 GPU as the runtime type.

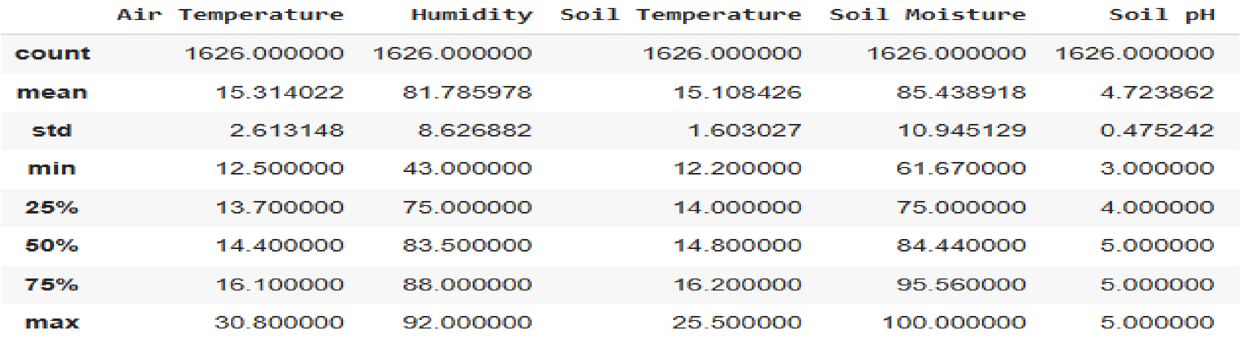
Step 2: Import the necessary libraries, such as metrics, accuracy score, standard scaler, matplot lib, pandas, numpy, seaborn etc. as shown in the 3.4



```
#importing libraries
import numpy as np
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
from scipy.stats import norm
from pandas.plotting import scatter_matrix
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import MinMaxScaler
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import f1_score
from sklearn.metrics import accuracy_score
from sklearn.model_selection import cross_val_score
from sklearn.model_selection import GridSearchCV
```

Figure 3. 4: Importing Libraries

Step 3: Gather and process data: In this step, we import the dataset file into Google Colab, then we perform statistical measures like count, mean, standard deviation, min, max, and percentage of our datasets as indicated below. We also verify for missing values and duplicates.



	Air Temperature	Humidity	Soil Temperature	Soil Moisture	Soil pH
count	1626.000000	1626.000000	1626.000000	1626.000000	1626.000000
mean	15.314022	81.785978	15.108426	85.438918	4.723862
std	2.613148	8.626882	1.603027	10.945129	0.475242
min	12.500000	43.000000	12.200000	61.670000	3.000000
25%	13.700000	75.000000	14.000000	75.000000	4.000000
50%	14.400000	83.500000	14.800000	84.440000	5.000000
75%	16.100000	88.000000	16.200000	95.560000	5.000000
max	30.800000	92.000000	25.500000	100.000000	5.000000

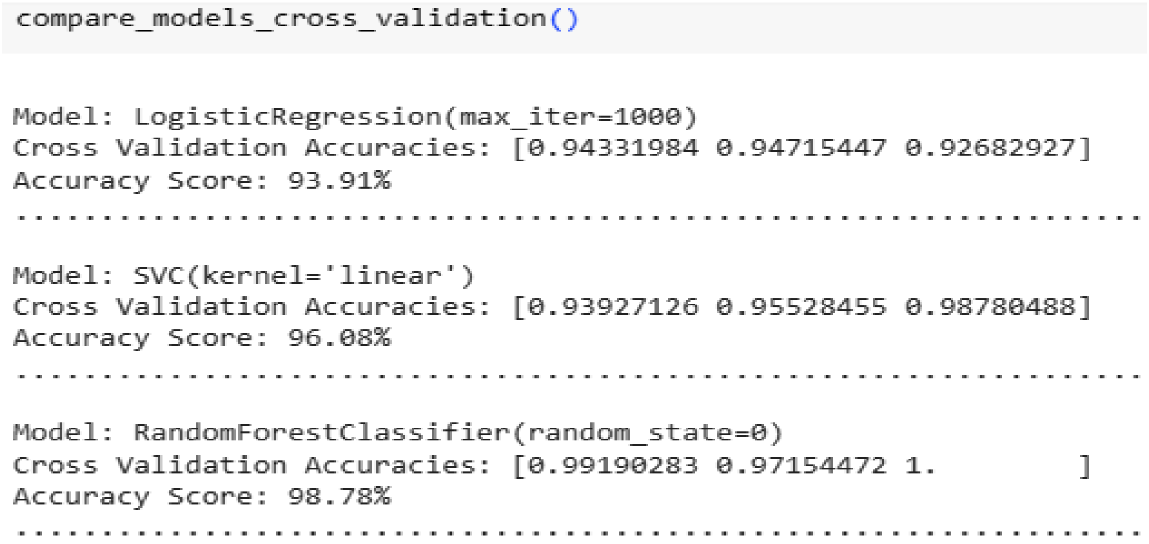
Figure 3. 5: Statistical measures of datasets

Step 4: Divide the data into two groups training and testing: Out of the 1626 datasets, 80% of the data was used for training and 20% for testing

Step 5: Data Standardization: This improves the ML model to fit well. Both the min max and standard scaler were applied.

Step 6: Model Training: Prior to selecting the top-performing model, the study employed the following machine learning models. We used support vector classifier, random forests, and logistic regression to train our model.

After training and testing our model, random forest performed well on the trained data with the accuracy of 98%, SVC 96%, and Logistic regression 93%



```
compare_models_cross_validation()
```

```
Model: LogisticRegression(max_iter=1000)
Cross Validation Accuracies: [0.94331984 0.94715447 0.92682927]
Accuracy Score: 93.91%
..................................................................

Model: SVC(kernel='linear')
Cross Validation Accuracies: [0.93927126 0.95528455 0.98780488]
Accuracy Score: 96.08%
..................................................................

Model: RandomForestClassifier(random_state=0)
Cross Validation Accuracies: [0.99190283 0.97154472 1.        ]
Accuracy Score: 98.78%
..................................................................
```

Figure 3. 6: cross validation

3.6 Data Presentation

Tables and bar charts were used to represent the data. Since, we were dealing with sensor data which was collecting numerical values, the use of tables was important in making comparison of different environmental parameters collected in the potato field. Bar charts makes simple for users to interpret and visualize data in order to gain a clear understanding of data patterns[50].

3.7 Ethical Consideration

This study was carried out following the code of conduct governing academic studies and research established and adopted by the University of Rwanda (UR) and all allowed principles for the research methodology validation. Therefore, this study was conducted protected by the university regulations for the dissertation writing. This ensures that the participant's rights, such as privacy are not infringed upon in any way.

CHAPTER FOUR

4.0 System Analysis and Design

4.1 Introduction

This chapter elaborates on system architecture design, hardware components, software applications, system development approach used, and system models

4.2 System Design and Architecture

The system design and architecture are critical stages in the system's development. It describes the system's architectural structure, components to be used, system functionality, and system interfaces. To have a clear picture of the system functionality, functional requirements such as data processing and user interaction are paramount during system design. Moreover, non-function requirements are also necessary, with the main focus on the system's performance and technical requirements [51]. This study is divided into the following sections: sensing units, processing units, communication modules, cloud storage, and an analysis section where we deploy our ML model. The figure below shows the system architectural design of our system; in the sensing unit we have sensors collecting environmental conditions in the potato field, microcontroller Arduino UNO does processing and data is send to cloud storage via GSM/GPRS module. Finally, system users use a dashboard for data visualization and decision-making.

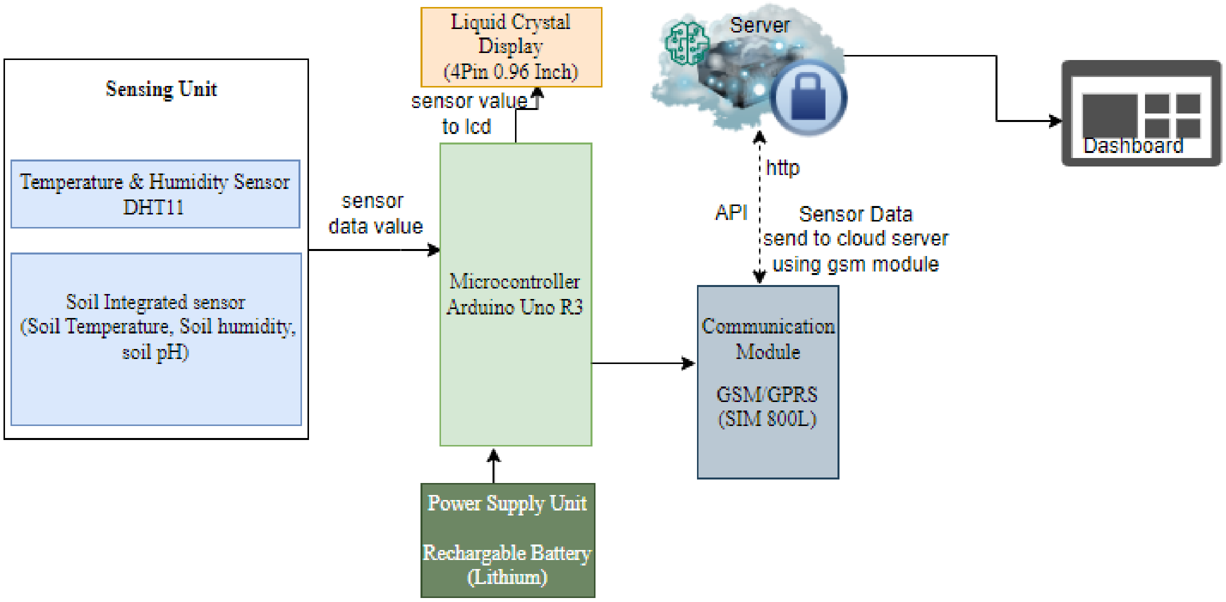


Figure 4. 1: System protype design

4.2.1 System layered Architecture

The layered architecture of our system comprises four layers; namely perception layer, network layer, processing and application layer.

Perception layer: is also known as physical layer, it comprises the hardware components such as sensors, and microcontrollers. Sensors normally interact with the physical environment to measure environmental conditions. In this study we used a number of sensors to monitor environmental conditions for potato crop; some of the sensors used were air temperature sensor, humidity sensor, soil integrated sensor (soil temperature, soil humidity, soil pH sensor). Data from the sensors were collected and sent to the microcontroller for processing.

The network layer: was used to facilitate information exchange between the connected devices in the network. GSM/GPRS which is a communication module was used to send data to cloud for storage as well as sending SMS to farmers.

Processing layer: was used to store, process and predict the environmental conditions to provide insights relating to the sensor data collected on the farm

Application Layer: This is responsible for providing user accessibility as well as allowing data visualization through the use of dynamic web applications. The figure below shows the system layered architecture

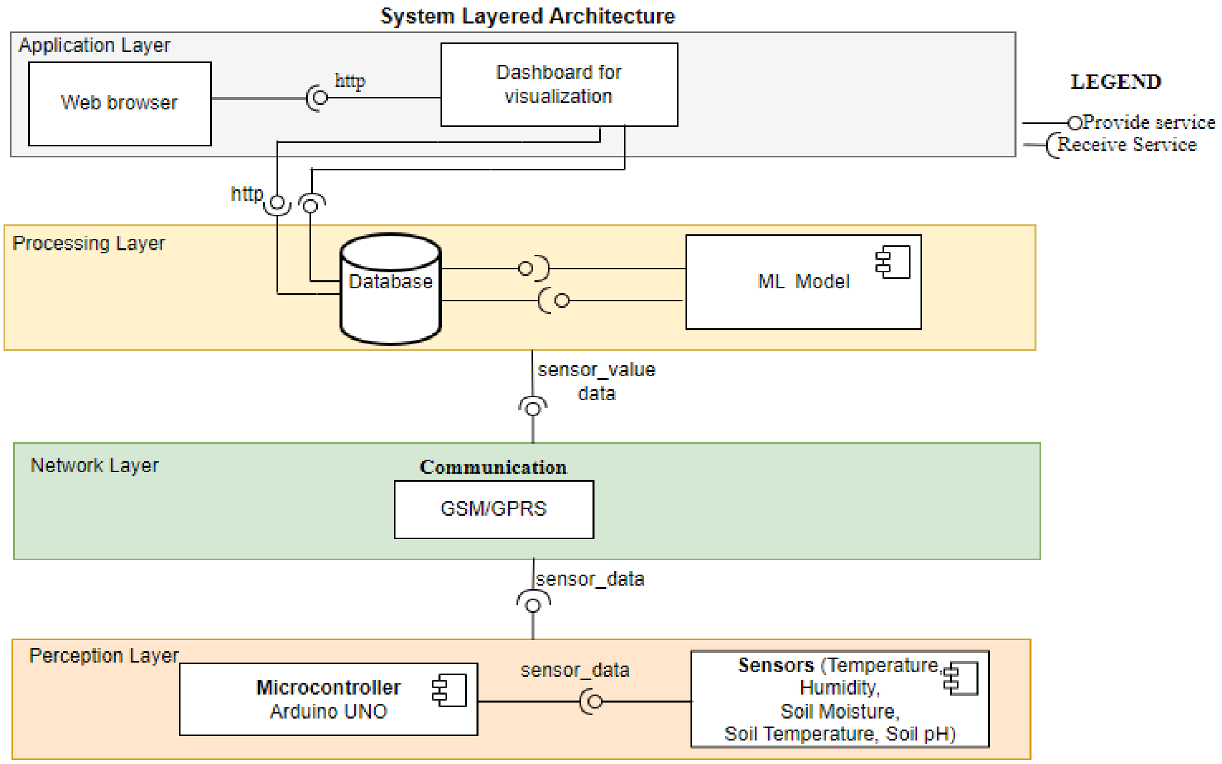


Figure 4. 2: Shows system layered architecture

4.3 System Design Approach

There are several software methodologies that can be used during system development, this methodology include the system development life cycle (SDLC), such as waterfall model, agile, and spiral [52]. The waterfall model was the first to be introduced, and it follows a step by step approach in which each phase should be completed first before moving on to the next phase. The agile model focuses on software applications that require rapid system deployment; it begins with system planning and progresses to system design, development, testing, and deployment[53]. The agile model was used in this study because it allows for continuous improvement of the system, which helps to address problems that may arise during system development. Also allows the user to perform testing and make any necessary changes while the deployment process is in progress.

For example, the system prototype can be deployed in the potato farm to monitor environmental parameters and if any issue arises that requires improvement in the system, there is the possibility of adjusting the system to address the problem arising. Furthermore, the agile methodology encourages user interaction, with the system developer interacting with system users like farmers and other stakeholders; it ensures the successful deployment of a system that meets user needs.

Agile models support a number of frameworks, including scrum, kanban, crystal, lean, and extreme programming. We chose the scrum agile framework because it allows the user to plan for system requirements, providing a clear picture of the task to be completed, building, testing, and reviewing, all of which are critical for a system to function properly [54].

4.4 Flow Charts

4.4.1 Data collection, processing and transmission flow chart

The process of data collection follows the following sequence as shown in Figure 4.2

Step 1: System initialization – This involves checking that all necessary components, including the sensors, an Arduino UNO, a GSM module, and a liquid crystal display, are connected and functioning properly as well as software libraries required.

Step 2: Gathering the environmental parameters such as; air temperature, humidity, soil temperature, soil moisture and pH of the soil

Step 3: send the sensor data to the microcontroller for processing

Step 4: After processing the data transmit to the cloud using GPRS Module

Step 5: Examine the data to give a clear understanding of the monitored environmental parameters through visualization.

Step 6: continue back to step 2 to step 5 to ensure smooth process of data collection, processing and transmission

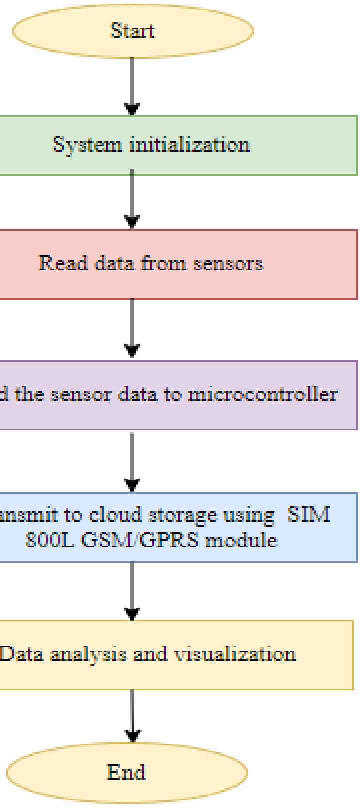


Figure 4. 3: Flowchart for Data Collection, Processing and Transmission

The process flow of checking the environmental parameters is depicted in Figure 4.3 below. Initial system setup is done first, then environmental parameter collection and transmission to a cloud server. The system checks to see if the recommended range of environmental parameters has been met; if so, the output recommendation is displayed; otherwise, if the recommended range has not been met, the system will recommend the farmer by suggesting an action to be taken.

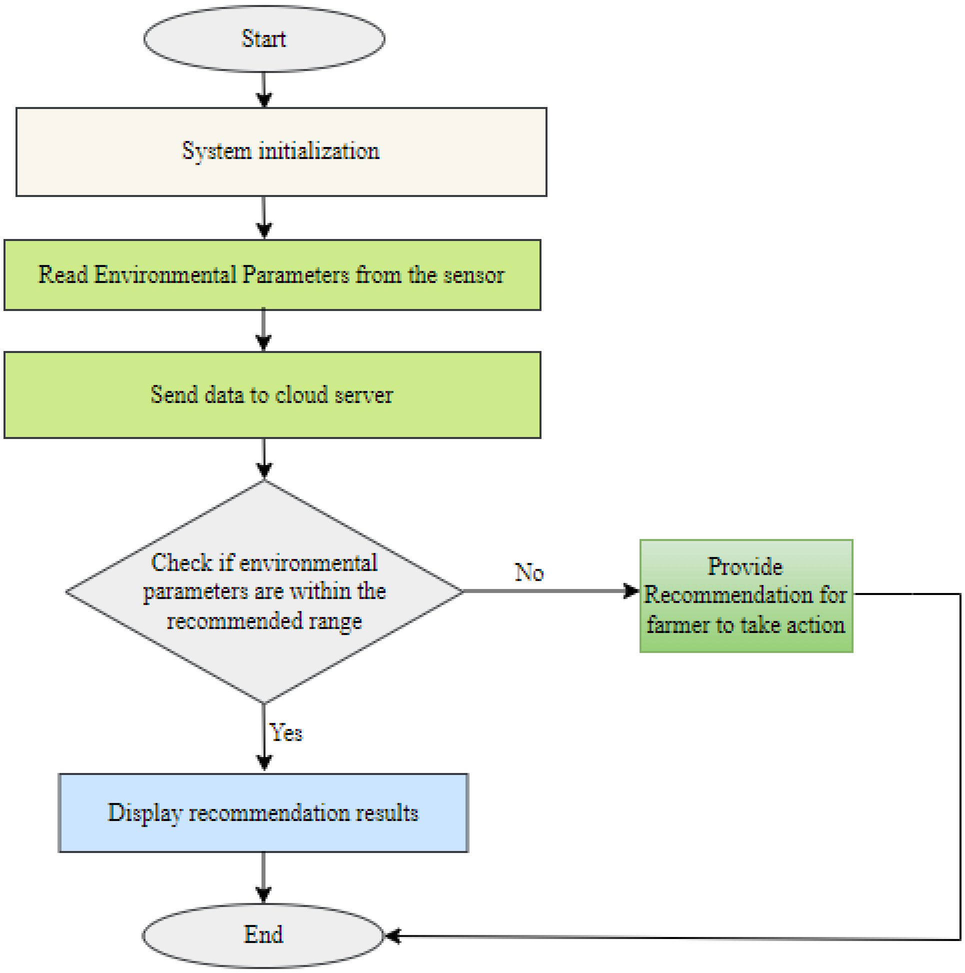


Figure 4. 4: Flowchart for Checking Environmental Parameters

4.5 System Models

System modeling refers to the method by which system developers and designers use during system design to facilitate quicker and simpler system design as well as system conceptualization using models. We created the architecture and flowcharts for our system prototype using the unified modeling language (UML). This was necessary because using UML tool during system design; enables system developers and designers to communicate clearly the system functionality as well as system goals through a visual representation which results into better understanding of the entire system. Moreover, using UML speeds up the design process and helps in creating the system diagrams that can be used easily to communicate complex systems concept [55].

4.5.1 Use Case Diagram

The use case diagram illustrates a sequence of interaction between the users and the external entities of the system [56]. This study used use case diagram to show the interaction between the actors and the external entities, in this case the admin and the farmer were the main actors interacting with the system, indicating each role users has to execute in the system. To illustrate the relationships with external entities we employed use of tools such as association arrow to illustrate the relationship between the admin and the system as well as farmer interaction with the system. The extend arrow was used to represents optional use case behavior, while include arrow represented the relationship where the use case has to depend on another use case to function well.as shown in figure 6 below.

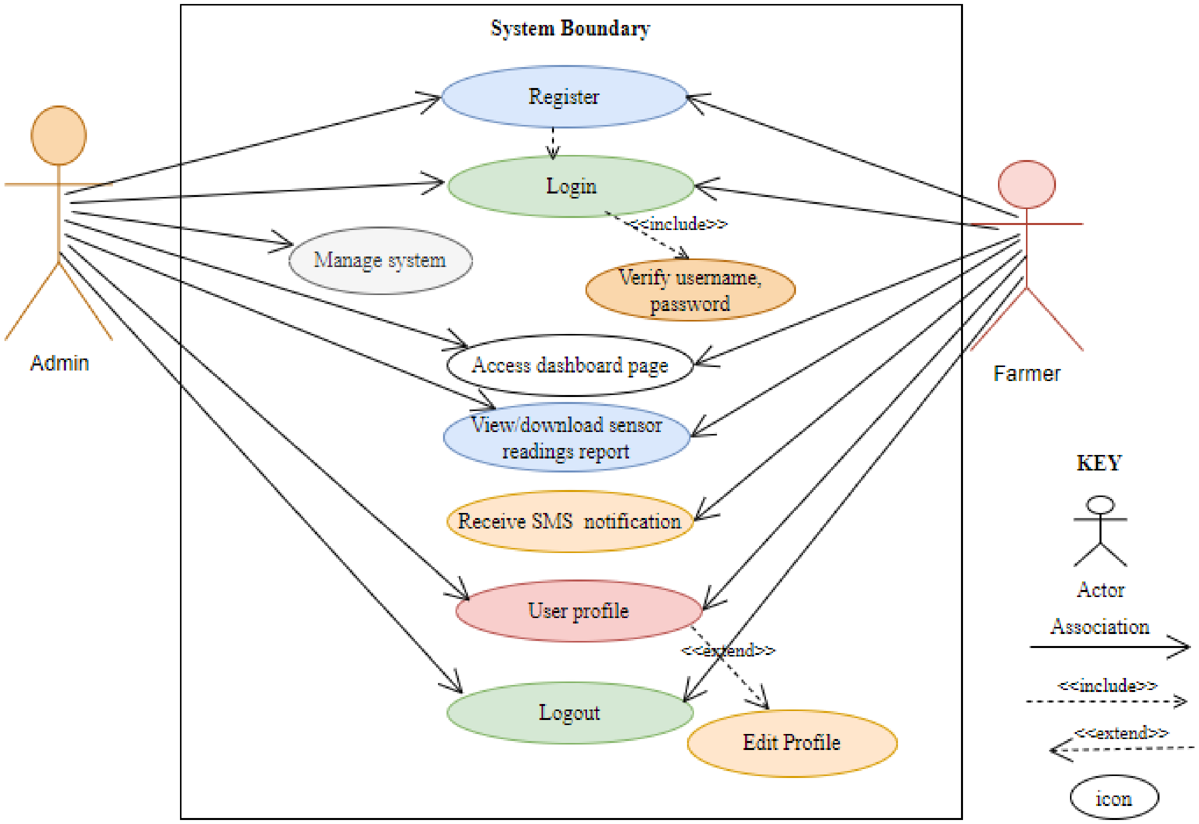


Figure 4. 5: Use case diagram represinting (Admin and farmer as the main actors)

4.6 System Design Requirements

This section is divided into two sections: hardware and software used during the system prototype design. Temperature and humidity sensor, soil integrated sensor measuring (temperature, soil humidity, and soil pH), microcontroller (Arduino Uno R3), a GSM/GPRS module (SIM 800L), a liquid display crystal, a breadboard, jumper wires and a battery are some of hardware components the study used. Software requirements describe the programming languages used in the design of a web application, and software tools used in the system prototype's design. User and system requirements, technical specifications for the devices, performance, system compatibility, power consumption, cost, communication protocol, and support documentation that serve as a reference during system troubleshooting were put into consideration before starting the development of the system prototype.

4.6.0 Hardware Components

4.6.1 Sensors

4.6.1.1. Temperature and Humidity Sensor (DHT11)

This sensor is used to measure the temperature and humidity. It has the capability to measure the temperature ranging from 0^0 to 50^0c as well as humidity from 20% to 90%. Uses a power voltage ranges from 3.5v to 5.5v, with the accuracy of ±1°C and ±1%, and has three pins for power, data and ground. DHT 11 is mostly used for application related to environmental monitoring, climate control as well as weather station monitoring.

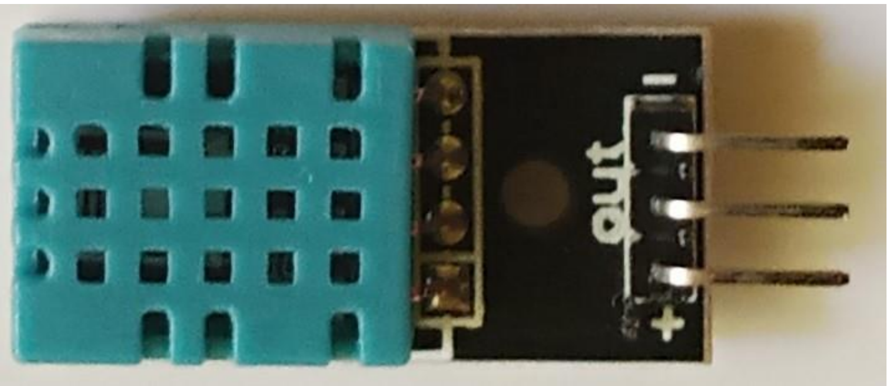


Figure 4. 6: DHT11 Temperature and Humidity Sensor

4.6.1.2 Soil Integrated Sensor

The soil integrated sensor measures three parameters; soil temperature, soil Moisture, and soil pH, and is set up using its register address. It measures soil temperature between -40 and 80^{o}C, soil moisture between 0 and 100%, and soil pH between 3 and 9. It uses an RS485 module to output the signal, which has a baud rate of 2400bps, 4800bps, and 9600bps. Additionally, it is highly accurate when calibrated correctly, responds quickly to parameter measurements, is corrosion-resistant, and is waterproof [57].

Figure 4. 7: Type 485 Soil Comprehensive Sensor (Soil Integrated sensor/Soil moisture,

4.6.2 Microcontroller

The Arduino UNO is a microcontroller which is portable; its board is designed using ATmega328P processor. The board has a total of 20 input and output pins, 6 analog pin inputs for supporting analog sensors as well as General Purpose Input Output pins (GPIO), and 14 digital pins, a USB connector for connection to computer and acts also as a power source, a reset button, a power jack. Arduino board is programmable using Integrated Development Environment (IDE), Arduino Uno uses external power source as well as power from USB connector, supports 3V and 5V, making it suitable for low power devices [58].

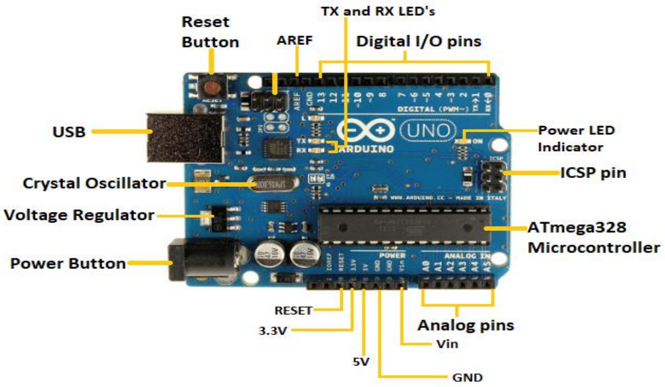


Figure 4. 8: Arduino UNO (https://www.javatpoint.com/arduino-uno)

4.6.3 GSM/GPRS Module

In this study, we used the SIM 800L GSM/GPRS module, which supports voice and short text messaging, data transfer, as well as sending and receiving phone calls in addition to text messages. A GSM modem works similarly to a mobile phone and uses a SIM card (micro SIM card). To communicate, one has to uses a serial-based AT command, which enables one to check the signal strength, SIM card connection, and network connection. The 900MHz and 1800MHz frequency bands are used by SIM 800L, operates with a voltage range of 3.4 to 4.4 volts, and has an antenna connector. Furthermore, with inbuilt GPRS internet connectivity is possible making it suitable for data transfer using two protocols that is hypertext transfer protocol (HTTP) and transfer control protocol (TCP/IP). Applications for the SIM800L include vehicle tracking, security access control systems, and remote control systems [59].

4.6.4 Breadboard

Solderless plastic breadboard was used to facilitate the electric connection using the jumper wires. The board is made up of columns and rows, the horizontal rows consist of the rows rails which have plus sign (positive) used for power connection and minus sign (negative) for the ground. The horizontal rows on the breadboard allows one to use the positive row to connect other positive components as long as the devices supports the same voltage, but the negative row on the same breadboard can be connected to any components that needs to be supplied with negative voltage. Apart from positive and negative rows on breadboard is numbered using letters and numbers such as letter a to e and f to g are all connected, therefore communication is possible across that entire column [60].

4.6.5 Rechargeable Battery

We powered our prototype using Li-ion battery which is rechargeable. The battery makes use of high quality Li-ion cells which has high energy of density. Due to its low self-discharge, it can last for 5 days before having to be recharged [61].

4.6.6 Liquid Crystal Display (LCD)

The environmental parameters reading values from our sensors were displayed on an LCD 16*2. The LCD has two rows, each of which can display up to 16 characters. Both alphabetical and numeric characters are supported. Power consumption varies between 4.7V and 5.3V, and it works well with both 4Bit and 8Bit display modes, as well as with either a blue or green backlight. LCD has16 pins, with each pin serving a unique purpose. Pin 1 is used to connect to ground, pin2 for powering, pin 3 for controlling the display on the screen, pin 4 for command mode, pin5 supports read and write operations, pin 6 for executing process such as read and write, pin 7-14 are data pins, and pin 15 is a positive pin that supports 5V, finally pin 16 which is a negative pin is connected to ground [62].

4.6.7 Data Storage

There are different types of cloud storage available that users can use to store their data. This include private cloud, public cloud, and hybrid cloud, when it comes to deciding which one to use depends on the user's specific needs [63]. In our study we choose a private server provided by cloud service provider hostingar and accessible is via Application Programming Interface (API). The sensor data collected in the field was stored on a cloud server. Storing data on a private cloud server was considered because of the services it offers; such as data security, unlimited storage, and easy system accessibility from any location provided the user has access to internet.

4.7 Software Application Requirements

4.7.0 Integrated Development Environment (IDE)

In this study, we used Arduino open source software to write C++ programming code that allowed us to interact with our sensors, lcd, and gsm/gprs module. The code was uploaded after programming to the microcontroller Arduino UNO to allow for compilation and testing before deploying sensors in the field to collect environmental parameters.

4.7.1 Server Side Applications

Hypertext Preprocessor (PHP), Structured Query Language (SQL), and JavaScript were used to write the code for the server-side application for the system, which is also known as back-end development. PHP was used to design the server side of the web application. PHP was chosen because it is free open source software that works well with HTML, making it ideal for our web application design. Moreover, it is easy to use and compatible with a number of operating systems. We used MySQL database because it is efficient in terms of data accessibility and provides a database with functionalities that allow for easy management and interaction with the data stored on the database.

4.7.2 Front-end Development

Front-end design is also known client-side application. Here, the user normally interacts with a website using an application that runs on different device, such as a computer or a smart phone. On the client's side, we used HTML to support website display in web browsers, JavaScript to make the website interactive, and cascading style sheets (CSS) to make the website look more appealing. We designed the website layout using various elements such as color, images, and different font sizes. A login user interface, user registration, tables, forms, and a user profile were created[64].

The table below shows the flow of communication from the client-side (front end) to server-side (backend); the client first sends a request to webserver, to request for the service or application then the web server will sent a request to web application which has access to files from the database. Web application will response back to the web server relating to the request made, and finally the client side receives the response from web server which is achieved using http protocol.

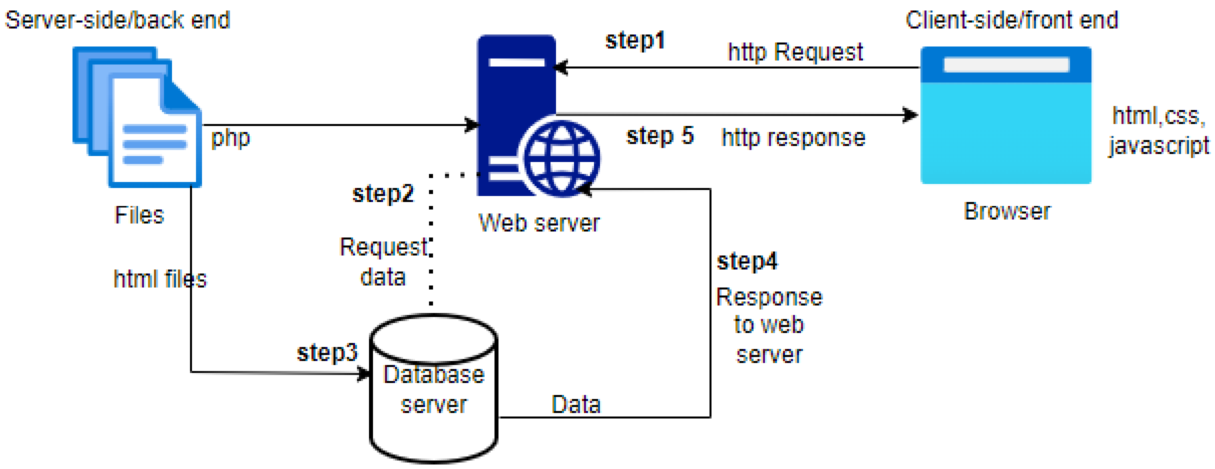


Figure 4. 9: Showing communication between client-side and server-side

4.8 System Security

This research focused on two security mechanisms; authentication and authorization, which were implemented on the web application, where the user needs to sign in first with the username and password, if the account is already created in order to be identified as the real user of the system. This was necessary to prevent unauthorized persons from using the system [65].

CHAPTER FIVE

5.0 Results and Analysis

5.1 Introduction

This chapter presents the results of our study we conducted to design a prototype system that uses IoT and ML technologies to monitor environmental parameters for potato crops. It starts with the prototype implementation, overview of the data we collected during research, presentation of results and analysis using machine learning algorithm.

5.2 System Prototype

This research resulted into development of system prototype for monitoring environmental parameters for potato crop. As shown in figure 5.1, this was made possible by incorporating both the software and hardware into the system prototype design. The hardware devices used include DHT 11 temperature and humidity sensor, soil integrated sensor which measures soil temperature, soil humidity and soil pH, LCD display, breadboard, jumper wires, Arduino Uno and SIM800L GSM/GPRS Module for communication and sending data to cloud storage. Arduino integrated development environment (IDE) software was used to write the codes for the microcontroller Arduino Uno and to program our sensors to function well.

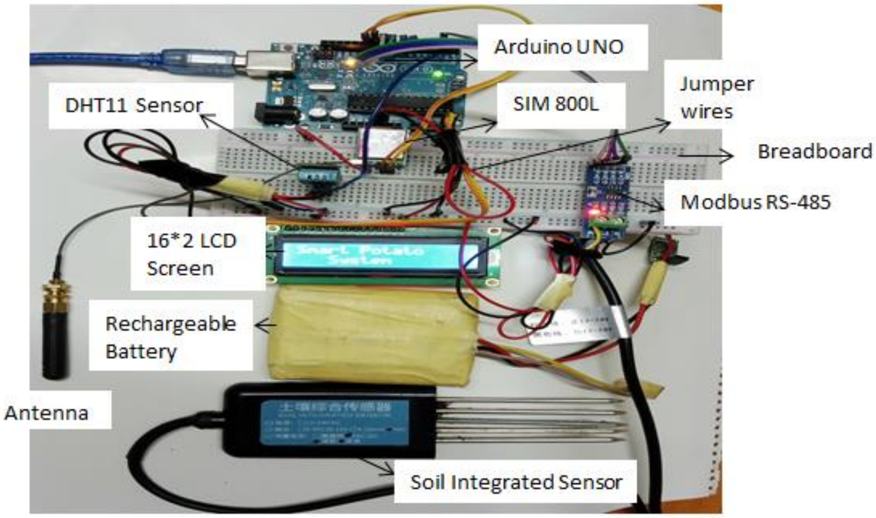


Figure 4. 10: System Prototype Hardware Connection

5.2.1 System Initialization

System initialization is the first step that takes place when our system is powered on. This checks the system functionality and the hardware connection of the system is working well. After system initialization process is completed, the title of our project is first displayed on the LCD screen as shown in figure 5.3, then followed by the environmental parameter being monitored (air temperature, air humidity, soil temperature, soil moisture and soil pH) as shown in figure 5.4. Data is uploaded to cloud server using SIM 800L GSM/GPRS module. GSM/GPRS connection is established to facilitate communication with the Arduino UNO using AT commands set which are accessible using serial connection, for successful GSM/GPRS network connection to the cloud server and establishment of communication using http protocol the system response with 'ok' message when the following commands are executed successfully.

Step 1: AT+SAPBR=1, 1: This command is the one that start GPRS process

Step 2: AT+SAPBR=2, 1: This command checks the status of GPRS and incase of any issues Then we use to diagnose the problem

Step 3: AT+HTTPINIT: This command helps to start HTTP services

Step 4: AT+HTTPPARA=CID, 1: We used this command to assign the carrier and it is always assigned number 1

Step 5: AT+HTTPPARA=URL," + url: Allows the request of the URL

Step 6: AT+HTTPPARA=CONTENT, application/x-www-form-urlencoded: Defines contents the to be sent to the

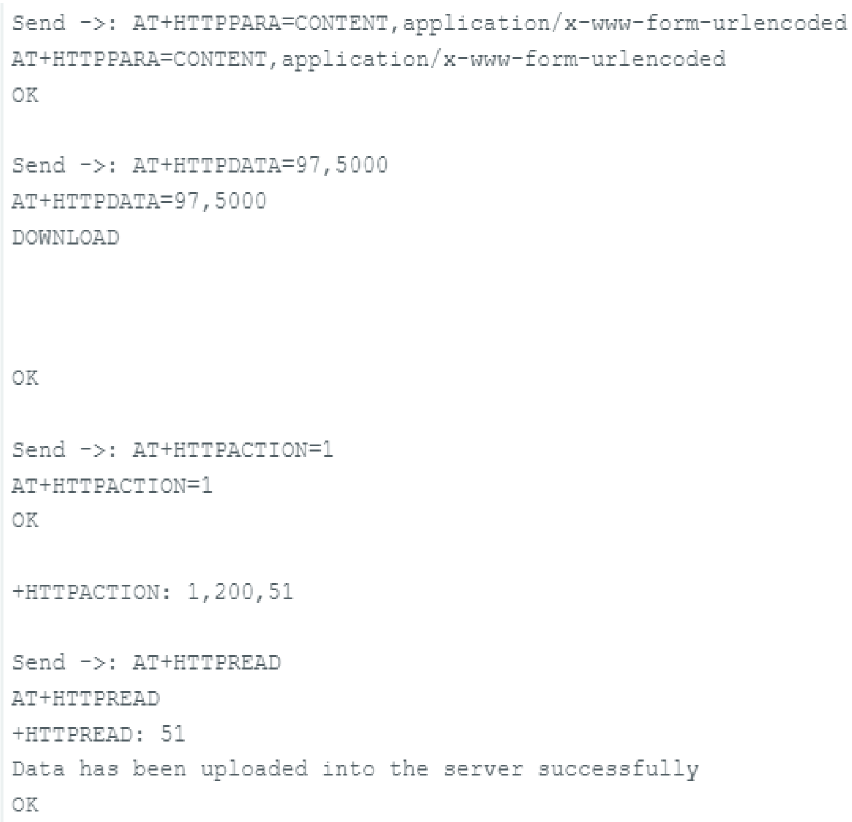
Step 7: AT+HTTPDATA: Define the data to be sent to server in size (mainly in bytes)

Step 8: AT+HTTPACTION=1: Defines the method of data transfer which is always in POST Method

Step 9: AT+HTTPREAD: process the response for successful data transmission to server

Step 10: AT+HTTPTERM: used to terminate the http request running

Step 11: AT+SAPBR=0, 1: Terminate the gprs carrier after data is send to server, before the process starts again from step 1.When the above instructions are properly executed, the acknowledgement message for successfully data upload to the cloud is displayed, as shown below



```
Send ->: AT+HTTPPARA=CONTENT,application/x-www-form-urlencoded
AT+HTTPPARA=CONTENT,application/x-www-form-urlencoded
OK

Send ->: AT+HTTPDATA=97,5000
AT+HTTPDATA=97,5000
DOWNLOAD



OK

Send ->: AT+HTTPACTION=1
AT+HTTPACTION=1
OK

+HTTPACTION: 1,200,51

Send ->: AT+HTTPREAD
AT+HTTPREAD
+HTTPREAD: 51
Data has been uploaded into the server successfully
OK
```

5.2.2 Potato Farm

The field of study for this research was a potato farm, as indicated in figure 5.1, where a sensor was deployed to gather environmental data, figure 5.2. The farm size covered half a hectare in total. In order to obtain additional insights and improve our ability to comprehend various environmental variations at a given point in time, we divided the farm into twelve zone points.

Figure 5. 1: potato farm

5.2.3 Sensor Deployment in the field

We deployed the sensor firmly on the ground field as shown in figure 5.2 to monitor environmental parameters for a period of two weeks, the sensor was deployed on different zone points of the farm to have a fair representation of the entire farm to collect environmental variables and data were sent to cloud web server for storage after every one minute.

Figure 5. 2: Sensor Deployment

5.2.4 System Prototype Results

Following prototype system testing, the prototype system output results were shown on a serial monitor and LCD screen, as displayed below.

```
Smart Potato
   System
```

Figure 5. 3: System Project Title

When the system is powered on after successful initialization, the project name title is displayed as shown in figure 5.3 above, followed by the following environmental parameters in figure 5.4 which were successfully collected from the farm using our system prototype.

Figure 5. 4: Air Temperature, Air Humidity, Soil Temperature, Soil Moisture, Soil pH Output Results

5.3 Cloud Storage

This study chose a cloud server for data storage, analysis, and visualization, provided by a web service provider. Cloud service providers offer dependable services, security, and scalability that enable increased storage capacity and guarantee data availability for stakeholders for future use in making decisions. The following graph displays sensor data that was collected from the potato field indicating the sensor value, date and time.

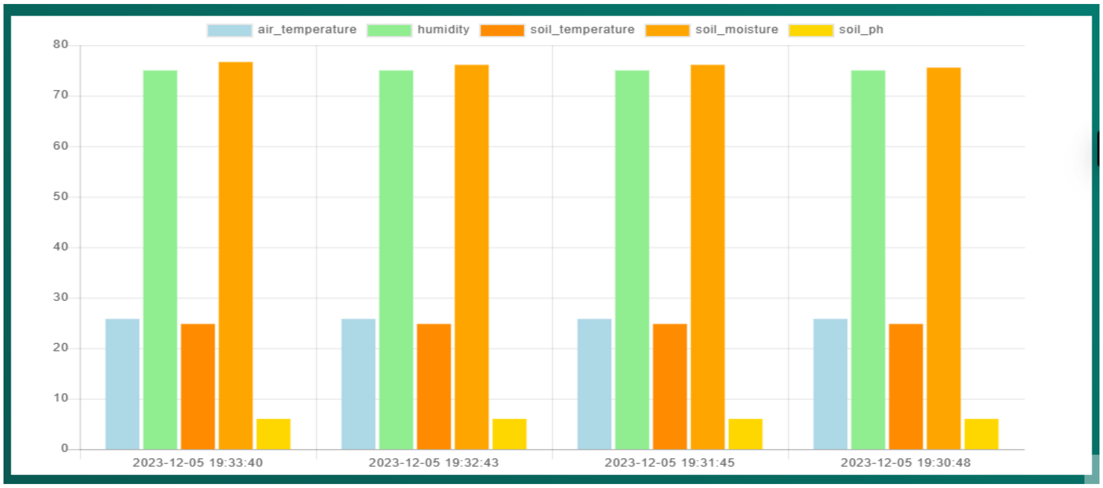
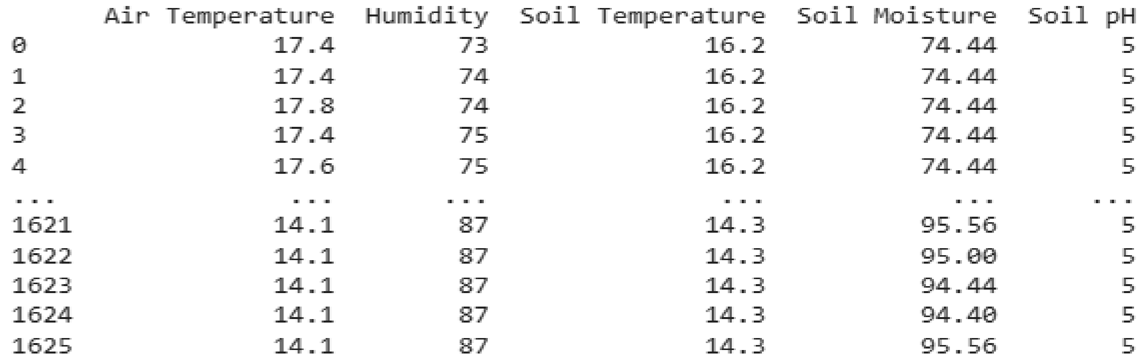


Figure 5. 5: Sensor Readings

5.4 Datasets

We obtained 4001 datasets for the potato crop from the farm in total; however, following data preprocessing to eliminate duplicates and missing values, we were left with the 1625 datasets, as seen in figure 5.8, next we separate our datasets into two groups: test datasets and training datasets. Additionally, 80% of the total dataset, were used for training, 20% of the total dataset, were used for testing.



```
      Air Temperature  Humidity  Soil Temperature  Soil Moisture  Soil pH
0                17.4        73              16.2          74.44        5
1                17.4        74              16.2          74.44        5
2                17.8        74              16.2          74.44        5
3                17.4        75              16.2          74.44        5
4                17.6        75              16.2          74.44        5
...               ...       ...               ...            ...      ...
1621             14.1        87              14.3          95.56        5
1622             14.1        87              14.3          95.00        5
1623             14.1        87              14.3          94.44        5
1624             14.1        87              14.3          94.40        5
1625             14.1        87              14.3          95.56        5
```

Table 5. 1: Sensor Data

5.5 Model Prediction Results

In this thesis, using the environmental parameters gathered from the sensors, we built a recommendation system to suggest a course of action for the farmer to follow when the environmental parameters under observation drop or rise above the recommended threshold [19], [20].Our initial action involved the determination of the optimal range for the environmental parameters. The anticipated environmental variables comprised; air temperature ranging from 15 to 25 degrees Celsius, humidity levels between 65% and 75%, soil moisture levels ranging from 60% to 80%, soil temperature ranging from 15 to 20 degrees Celsius, and soil pH levels within the range of 5 to 6.9. The following environmental parameters provide further elaboration on the model's predictions.

Air Temperature Prediction

The air temperature prediction capabilities of the system are as follows: Air temperature is predicted High when air temperature is greater or equal to 26 degree celsius, Low prediction when air temperature is less or equal to 14 degree celsius and Normal prediction when air temperature range is within the optimal range 15 to 25 degree celsius

Humidity Prediction

The prediction for humidity can be High, Low, or Normal. Humidity predictions between 65% and 75% are expected to fall within the normal range; those above 76% are considered high and those below 65% are considered low.

Soil Temperature Prediction

Potato crop prefers soil temperature between 15 to 20 degrees celsius, which is considered to be within the range. Soil temperature below 15 degrees celsius and above 20 degrees celsius is unfavorable for potato crops

Soil Moisture Prediction

The usual range for prediction outcomes is observed when the soil moisture prediction falls within the range of 60% to 80%. Outside the stated range, parameters will be either Low or High, which is not suitable for potato crop. As a result, farmers will be prompted to take immediate action based on the prediction results.

Soil pH Prediction

When soil pH falls outside the recommended range of 5-6.9 pH levels, the system predicts either High or Low results. Understanding the level of acidity or alkalinity in the soil is critical for farmers.

5.6 Analysis of Environmental Parameters

This study analyzed the five environmental variables (humidity, air temperature, soil moisture, soil temperature and soil pH) data collected from the farm. In order to plot the environmental parameters for easy visualization and interpretation, we used the matplot library, which was imported using Google Colab. As explained below:

I) Humidity

In order to promote healthy crops, potato crops typically do well in moderate humidity levels. Normally, potatoes require a humidity of between 65 and 75 percent. The humidity values of the sensor, as seen in the figure 5.8, ranged from 65% to 90%, which was influenced by the changing weather. Additionally, as illustrated in figure 5.9, we can see that, the rise in temperature above 25 degree celsius caused the humidity to drop below 50% at one point.

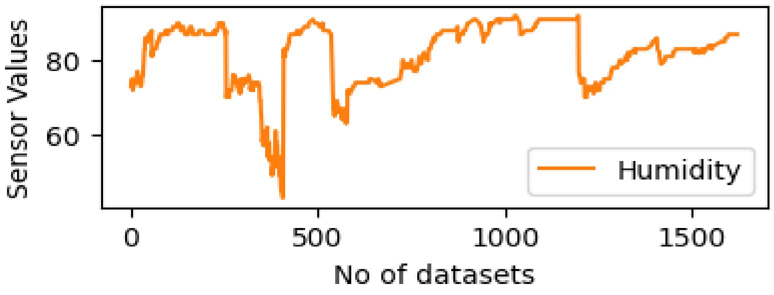


Figure 5. 6: Humidity

II) Air Temperature

From the figure below, we can conclude that the majority of the sensor values for air temperature were within the recommended range of 15-25 degrees Celsius, which is favorable for potato crop. The figure also shows that the air temperature readings were primarily between 15 and 25 degrees Celsius, with a few readings falling below 14 degrees and above 25 degrees.

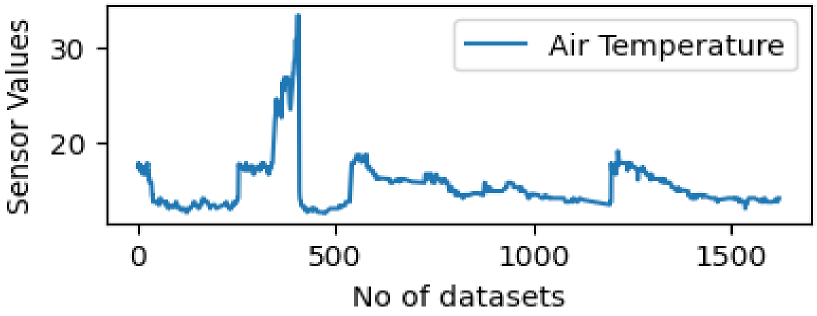


Figure 5. 7: Air Temperature

III) Soil Temperature

When soil temperature is high or low it interferes with the growth of potato which thus results to low crop productivity. From the figure below, Most values of the soil temperature were within the range of 15-20 degrees Celsius, with the exception of few values falling outside the range of 15 and 20 degrees Celsius. In relation to the sensor values collected, the air temperature values in figure5.9 and the soil temperature values were closely comparable. This leads us to the conclusion that the soil temperature conditions were fairly favorable for potato crop

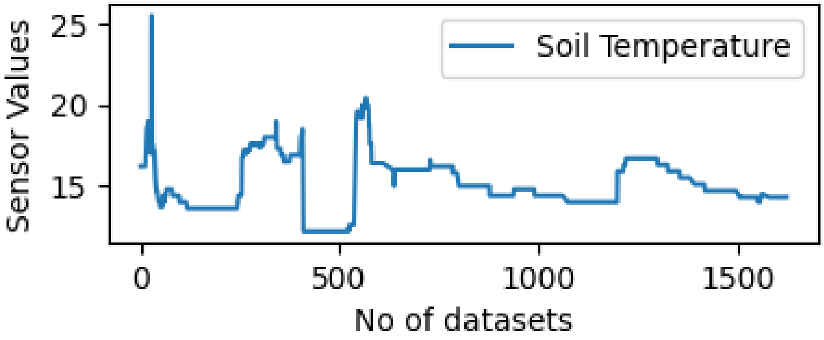


Figure 5. 8: Soil Temperature

IV) Soil Moisture

Potato crop prefer moderate range of soil moisture, which is in the range of 60-80 percent. Therefore, tuber rot and the spread of diseases occur when soil moisture levels are high. Figure 5.11 clearly shows the rise in soil moisture above 80% percent, this resulted from the weather fluctuations which were experienced during the data collection period. The weather generally, during the data collection period was primarily cloudy and rainy. It is evident from the figure below how environmental factors can have adverse effects on the growth of potato crops. Therefore, even a slight change in the environment could negatively impact the potato crop if it is not closely monitored.

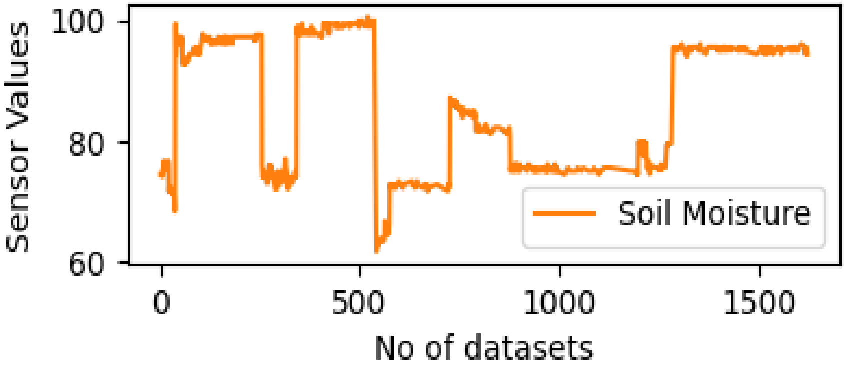


Figure 5. 9: Soil Moisture

V) Soil pH

For potato crops, soil pH should be between 5 and 6.9. The figure below indicates most soil pH values were within the ideal range, with the exception of a small number of sensor readings where the pH value was ranging below 5. This indicates that the soil was deficient in certain nutrients, necessitating the application of sulphur to farms.

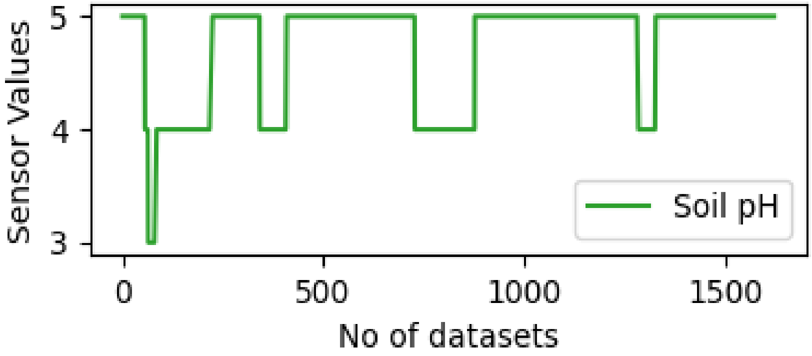


Figure 5. 10: Soil pH

The line graph below provides a clear illustration of the environmental parameters plotted. It is clear from the sensor data collected in the field that the soil pH, air temperature, and soil temperature were mostly within the recommended range (15–25 degrees Celsius for the air temperature, 15-20 degrees Celsius for the soil, and 5–6.9 soil pH), respectively. However, the humidity and soil moisture were slightly above the ecological recommended standard for potato crop, 65-75 and 60-80 degree Celsius respectively due to weather fluctuations experienced.

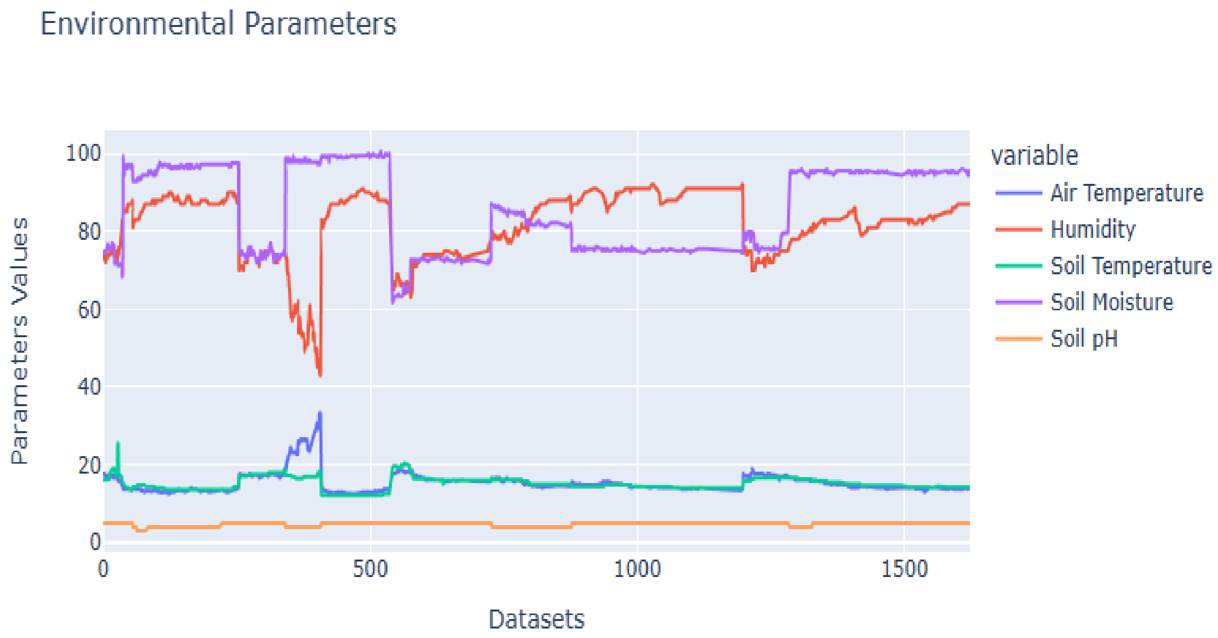
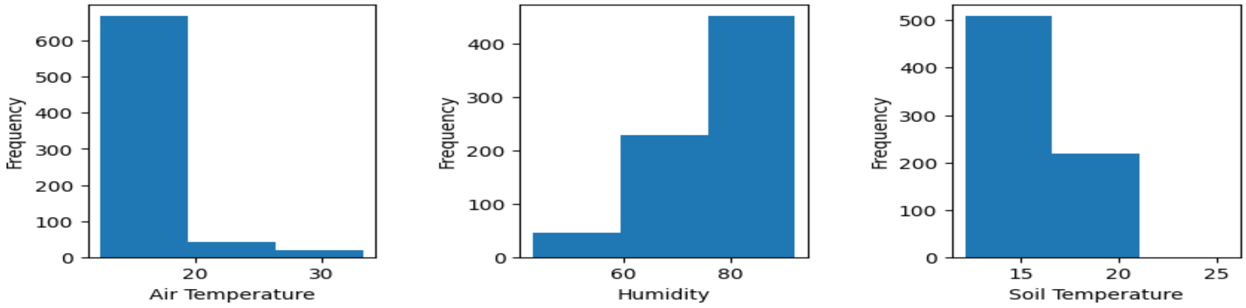


Figure 5. 11: Representation of Environmental parameter values vs datasets frequency

5.7 Overview Distribution of Environmental Variables

In this study, a histogram was employed to visually illustrate the distribution frequency of the environmental parameter datasets collected from the potato farm. The sensor reading values are displayed on the x-axis, while y-axis represents the distribution frequency of our environmental variables data. The air temperature, humidity, soil temperature, and soil pH exhibited a normal distribution, with the exception of a few cases where the parameter values were seen to vary from the expected range. Soil moisture exhibited high variability at some point due to change in weather conditions. Looking at environmental parameters represented using histograms below is a clear indication that most of the environmental parameters collected were found to be within the range.



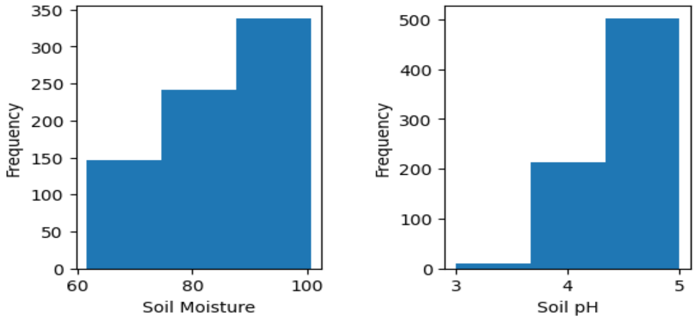


Figure 5. 12: Overview Distribution of Environmental Variables

5.8 Findings from the smallholder farmers relating to potato crop

In this study we administered questionnaires to farmers. Out of 80 respondents, 60 (75%) were female while 20 respondents representing (25%) were male. Majority of the respondent's age group was ranging from 35-45 representing 62.5% of the total sample size, in addition from the study most farmers own a farm land between 0.125-5acres and 90% of the respondents cultivate potato crop while 10% cultivate other crop; as shown below

Demographic Characteristics		**Respondents**	**Percentage**
Age	18-35	25	31.25%
	35-45	40	50%
	45 Above	15	18.75%
Gender	Male	20	25%
	Female	60	75%
Farm size (acres)	between 0.125-5(acres)	55	68.75%
	Between 5-10(acres)	20	25%
	Above 10 (acres)	5	6.25%
Potato farmer	Yes	70	87.5%
	No	10	12.5%

Table 5. 2: Respondents Demographic Information

5.8.1 Respondents on challenges smallholder potato farmers face while cultivating potato

During our study it came out strongly that monitoring environmental conditions affecting potato crop is the main challenge that most farmers encounter, 65% of the respondents agree that environmental parameters thus affect potato, while 25% believe pests and diseases are the challenge farmers face, and 10% pointed on lack of access to certified seeds, as indicated in figure 5:13

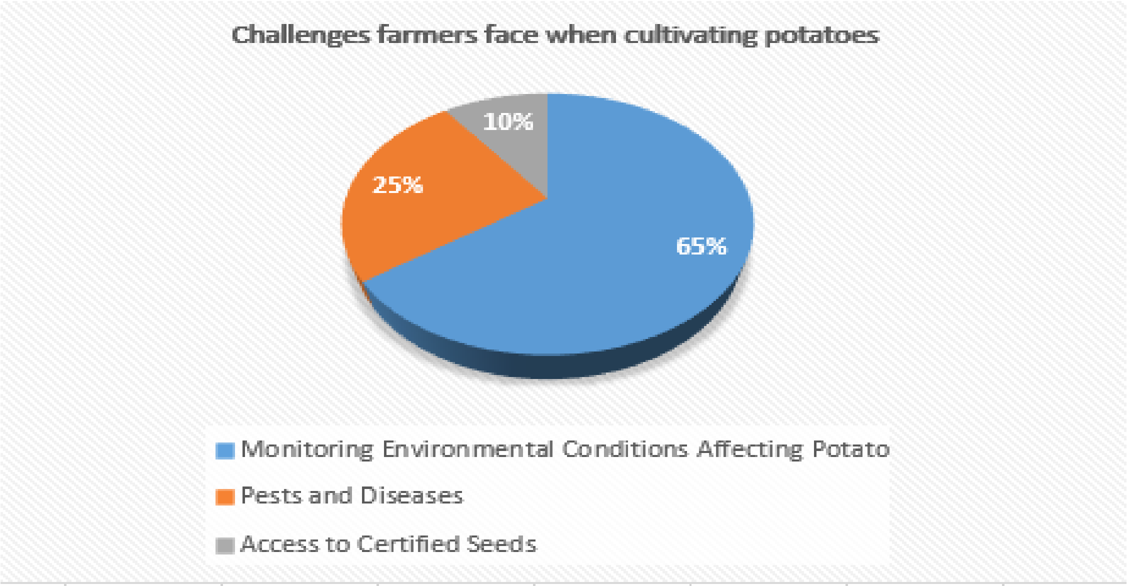


Figure 5. 13: Respondents on challenges farmers face when cultivating potatoes

5.8.2 Respondents awareness on ecological recommended requirements for environmental Parameters for potato crop

The study sought to know the respondent's awareness on the set recommended ecological standard of potato crop; like air temperature, humidity, soil temperature, soil moisture and soil pH. Out of the total 80 respondents; 96.25% are unaware of the set standard of ecological requirements for the potato crop. Moreover, 3.75% of the respondents are aware of the set standard requirements of the potato crops, since they had a background in general agriculture as indicated in figure 5:14

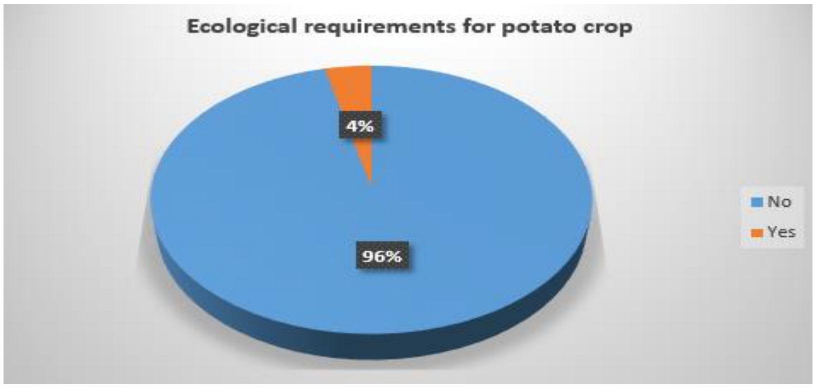


Figure 5. 14: Ecological requirements for potato crop

5.8.3 Respondents on methods used to monitor the environmental conditions for potato crop

The study found out smallholder farmers use different methods to monitor their potato crop, including visual inspection of the farm crop, the use of IoT technologies, and locally available instruments. 75 respondents (93.75%) monitor their farms visually, whereas 2 respondents (2.5%) employ IoT technology. Furthermore, the survey discovered that 3 (3.75%) use locally available tools. This research suggests that farmers require a smart potato system to help them monitor the environmental variables affecting their potato production.

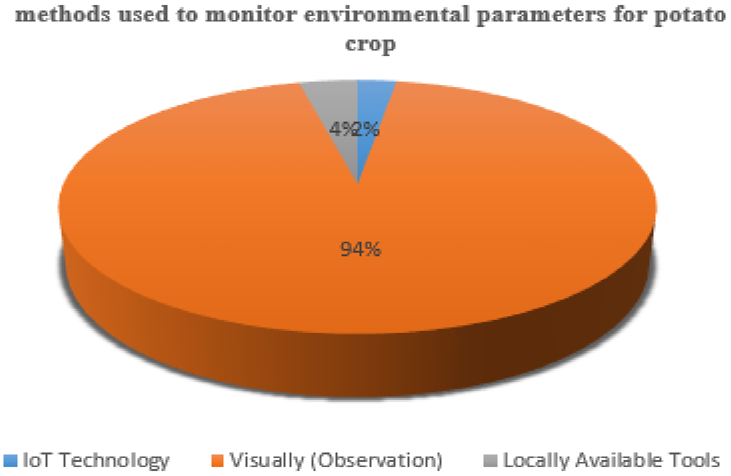


Figure 5. 15: Respondents on methods farmers use to monitor environmental conditions of potato crop

5.8.4 Respondents on the user requirements to be incorporated in the design of IoT system Prototype

The study sought to identify user requirements to be incorporated into system development depending on how the user prefers to visualize data like use of pie, bar or line chart, how frequent the user would like to receive recommendations, and whether or not the farmers own a smart phone. The table below clearly shows the user requirements that were incorporated in the system development.

User Requirements	**Respondents**	**Percentage**
User Access to smart Phone		
Yes	70	87.5%
No	10	12.5%
Data Visualization		
Pie	20	25%
Bar	50	62.5%
Line	10	12.5%
Notifications timeline		
After every 3 hours	10	12.5%
Daily	55	68.75%
Weekly	12	15%
Monthly	3	3.75%

Table 5. 3: Respondents on user requirements for the system

5.9 The Web Application

We developed the web application system for users to keep an eye on the environmental parameters. Figure 5.16 shows the authentication page where the user has to provide right username and password to have access to the system, if the system user key in wrong username or password the system will display an error message automatically showing “invalid username or password, prompting the user to try again”. The new user has to click on create the account by providing the following details as shown in figure 5.17

Figure 5. 16: authentication page

Figure 5. 17: User Registration page

5.10 System Dashboard

As shown in figure 5.17, the system dashboard consists of tables, average sensor readings, a form, a user profile, and a calendar. Sensor readings are contained in tables, and users can access data by printing, downloading, or copying it in PDF, Excel, or CSV format.

The system can also generate recommendations based on the environmental parameters gathered from the sensors and calculate the average of the sensor readings. The user can also update personal information by accessing the profile.

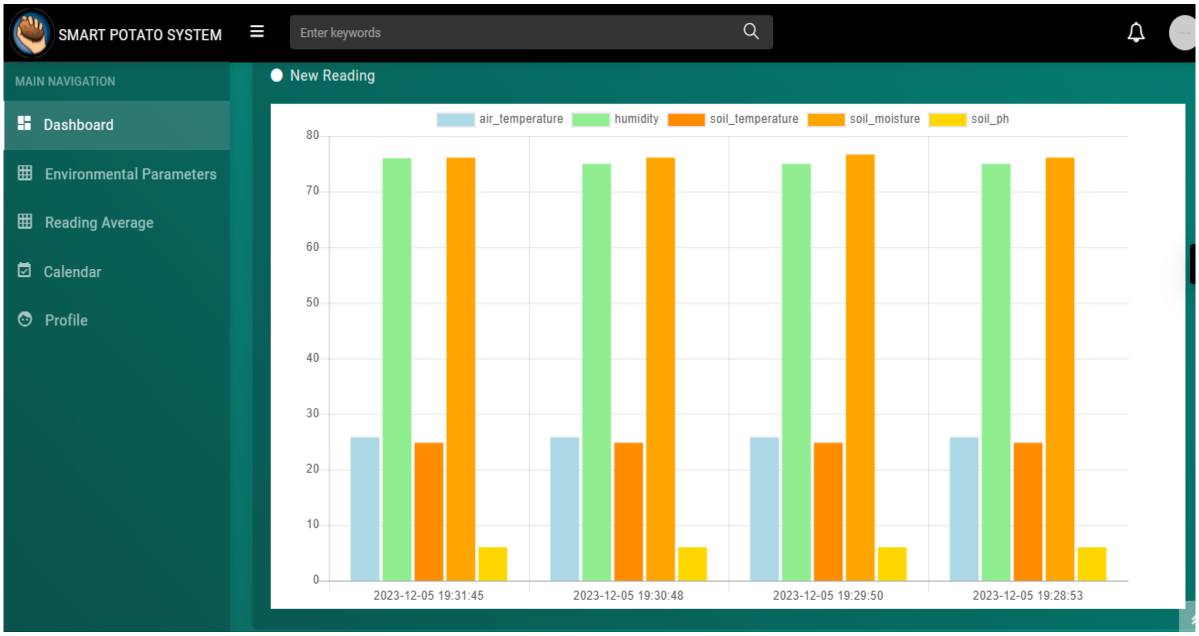


Figure 5. 18: System Dashboard

5.11 Average Sensor Readings

The average sensor readings for the environmental parameters gathered from various zone points on the potato farm are displayed in Figure 5.18. On a daily basis, we calculated the mean averages of the sensor readings for the collected environmental variables. The recorded data indicates that over a period of ten days, the average values of various environmental parameters were as follows; air temperature was between 15 and 19 degrees Celsius, humidity was between 71% and 90%, soil temperature was between 15 and 16 degrees Celsius, and soil pH was between 4-5, soil moisture readings ranged from 75% to 95%. It is evident from the sensor readings that we collected over a period of ten days that there were strong correlations between the sensor readings we collected from various farm zone points, particularly the air temperature and soil temperature.

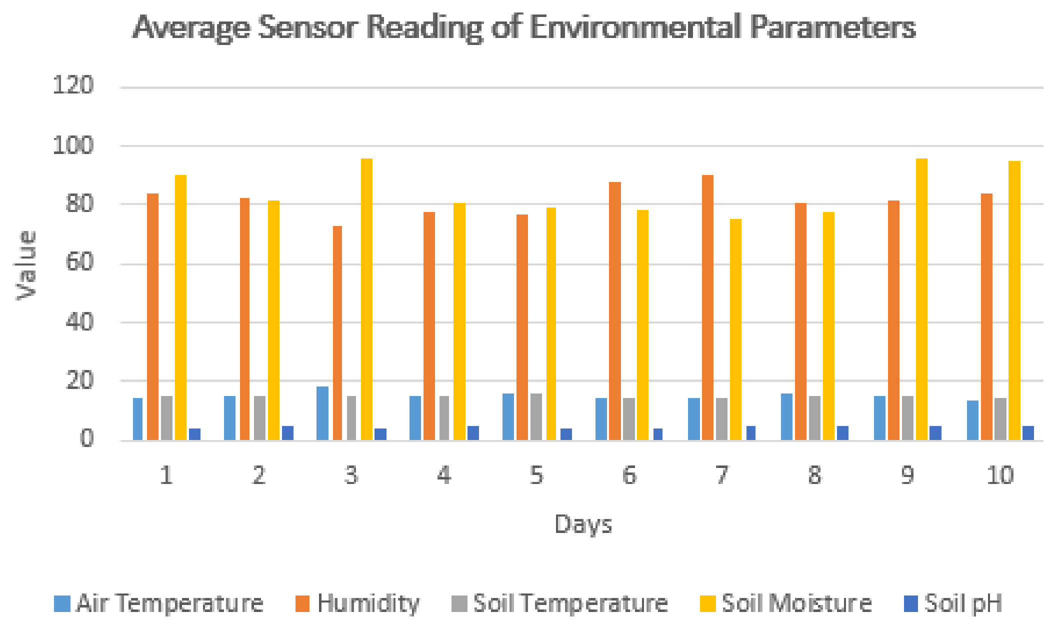
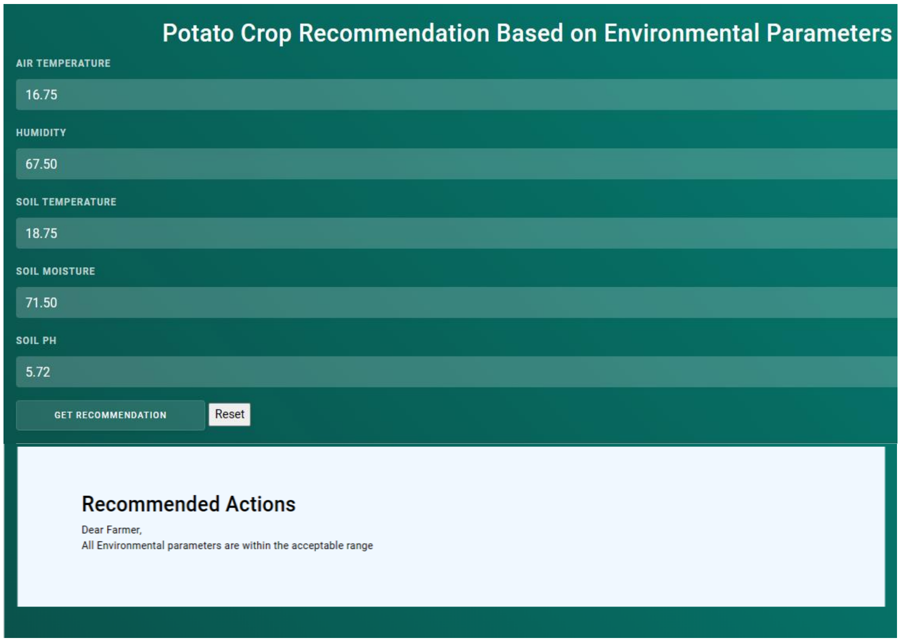


Figure 5. 19: Average Sensor Readings

5.12 System Recommendation

Based on the environmental data acquired by our sensors, a recommendation system was designed. When the environmental parameters under observation fall below or rise above the suggested threshold, it recommends a course of action for the farmer to follow. The figure below displays an example of our system's recommendation based on the average readings of the environmental parameters we collected using the sensors. In the figure shown below all the five environmental parameters monitored were within the optimal recommended range as stated in [19], [20].



Potato Crop Recommendation Based on Environmental Parameters

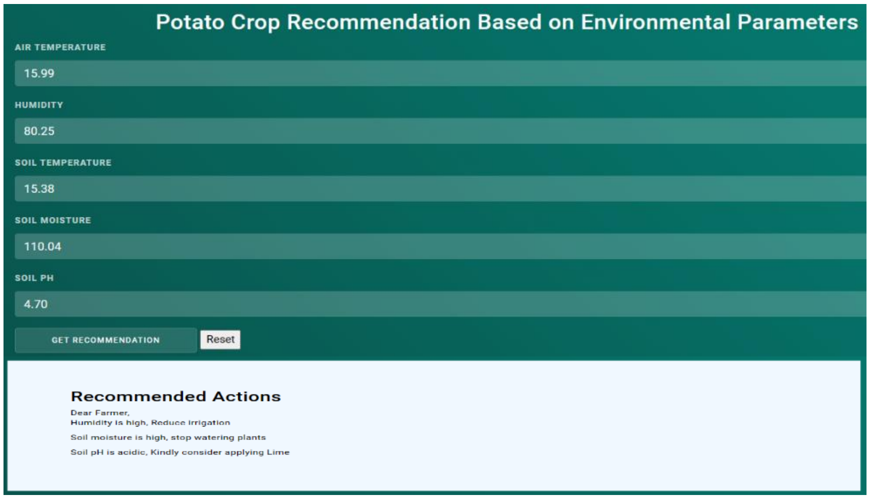
AIR TEMPERATURE: 16.75
HUMIDITY: 67.50
SOIL TEMPERATURE: 18.75
SOIL MOISTURE: 71.50
SOIL PH: 5.72

Recommended Actions

Dear Farmer,
All Environmental parameters are within the acceptable range

Figure 5. 20: System Recommendation (within the range)

The figure 5.21 displays system recommendation when environmental parameters are outside the recommended range. The system recommends the farmer to take the action, for example in the figure below the system predicted humidity, soil moisture and soil pH has high, this is because upon the system checking the environmental parameters the values were outside the recommended set standard range, which is humidity 65-75, soil moisture 60-80% and soil pH 5-6.9



Potato Crop Recommendation Based on Environmental Parameters

AIR TEMPERATURE: 15.99
HUMIDITY: 80.25
SOIL TEMPERATURE: 15.38
SOIL MOISTURE: 110.04
SOIL PH: 4.70

Recommended Actions

Dear Farmer,
Humidity is high, Reduce irrigation
Soil moisture is high, stop watering plants
Soil pH is acidic, Kindly consider applying Lime

Figure 5. 21: System Recommendation (outside the recommended range)

CHAPTER SIX

6.0 CONCLUSION, RECOMMENDATION AND FUTURE WORK

6.1 CONCLUSION

In conclusion, this work has clearly highlighted environmental parameters has the main challenge smallholder potato farmers face. Our research has demonstrated that it is feasible to include IoT and ML technologies into the design of the smart potato system for smallholder farmers to monitor environmental conditions. Our findings clearly shows this system prototype design is a promising technology that enables smallholder potato farmers to gain more insights in monitoring environmental conditions like air temperature, humidity, soil moisture, soil temperature and pH levels in their potato field. The system's ability to gather sensor data from the agricultural field and advise the farmer on the best course of action for their potato crop is a clear indication that our system is possible to address challenges smallholder potato farmers face towards addressing environmental conditions which are unpredictable.

The study area, Chepkorio Sub-County, Elgeyo Marakwet County in Kenya, one of the counties that grows potatoes, provided datasets of environmental parameters that we used to train our model using supervised machine learning algorithms; Random Forest, Support Vector Machine, and Logistic Regression algorithms. After applying cross-validation to validate the results, we tested our model and found that the random forest algorithm produced results with a higher accuracy of 99%. In addition, a predictive system model was developed to give the farmers recommendations based on sensor data. The remarkable outcomes seen in the trained model and system prediction demonstrated that machine learning models and IoT technologies could be integrated to address even more global issues.

This solution will help smallholder potato farmers to make more informed decisions more quickly, and it will also assist stakeholders including the government in creating plans that are appropriate for addressing the country's food security

6.2 RECOMMENDATION

This research has proved that is possible to monitor and control environmental parameters to help the country to address food insecurity issue. Therefore, we propose implementation of IoT system in real world to monitor environmental conditions for potato crop.

We were unable to send our solution to government labs for validation due to time and resource constraints. Nevertheless, since this is ongoing work, we intend to partner with the ministry of agriculture to ensure that our solution is subjected to testing and approved for use.

To achieve higher accuracy on model training, there is need to have large number of datasets. A minimum period of four months is required for field data collection and extensive data analysis in order to achieve a more accurate interpretation of environmental parameters affecting potato crop.

Furthermore, to partner with the national government and county governments in creating awareness to farmers on the importance of using technology in agriculture, and mostly providing technology to farmers, especially smallholder farmers.

6.3 FUTURE WORK

The goal is to expand our solution by incorporating additional environmental factors such as; rainfall, nitrogen, phosphorus, and potassium (NPK). To monitor the potato crop during both the rainy and dry seasons in order to compare the environmental factors between the two seasons.

In addition to have a comprehensive understanding of how environmental factors affect the various stages of potato crop growth, we intend to continuously monitor the environmental parameters from tuber formation to tuber development stage. This monitoring will span a minimum duration of four months before the potatoes are harvested.

To monitor environmental conditions for different farm crops; not only potato crop would be much beneficial to farmers to address the environmental challenges for the government to make better decisions to address food security in the country. Finally, to extend our work to predict potato diseases as well as build a predictive model to predict yield production based on historic data.

REFERENCES

[1] P. Banda, “Agriculture: The Backbone of the African Economy,” *Int. J. Adv. Res. Soc. Sci. Environ. Stud. Technol.*, vol. 7, no. 1, pp. 62–74, 2022, doi: 10.48028/iiprds/ijarssest.v7.i1.06.

[2] F. and C. Ministry of Agriculture, Livestock, “Agricultural Sector Transformation & Growth Strategy,” 2022. [Online]. Available: https://kilimo.go.ke/wp-content/uploads/2022/03/ASTGS-Long-version.pdf, Accessed on 12, November 2023.

[3] Fao-in-kenya, “Fao-in-kenya/kenya-at-a-glance.” [Online]. Available: https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/.

[4] Central Bank, “Monetary Policy Committee Agricultural Sector Survey.” [Online]. Available: https://www.centralbank.go.ke/2022/07/29/mpc-agriculture-survey-july-2022/ Accessed on 12, November 2023.

[5] U. N.-D. of E. and S. Affairs, “Population 2030: Demographic challenges and opportunities for sustainable development planning,” 2015. [Online]. Available: www.unpopulation.org.

[6] International Potato Center, “Potato Facts & Figures.” [Online]. Available: https://cipotato.org/potato/potato-facts-and-figures/Accessed on 12, November 2023.

[7] Food and Agricultural Organization, “African Potato Production-2007,” 2007. [Online]. Available: https://www.fao.org/3/i0500e/i0500e03c.pdf/Accessed on 12, November2023.

[8] potato pro, “Potato & Products: Industry.” https://www.potatopro.com/kenya/potato-statistics (accessed Apr. 14, 2023).

[9] “Potato market size & share analysis - growth trends & forecasts (2023 - 2028).” [Online]. Available: https://www.mordorintelligence.com/industry-reports/potato-market.

[10] FAO, “Global potato statistics.” [Online]. Available: https://www.potatonewstoday.com/2023/01/21/global-potato-statistics-latest-fao-data-

published/ (Accessed on 11 April 2023).

[11] Teagasc, “Potato yields declined in 2022 by 15 per cent.” [Online]. Available: https://www.teagasc.ie/ (Accessed on 11 April 2023).

[12] AGRA, “Alliance for a Green Revolution in Africa,” 2017. [Online]. Available: https://agra.org/wp-content/uploads/2017/09/Final-AASR-2017-Aug-28.pdf.

[13] L. Ahmad, U., & Sharma, “A review of best management practices for potato crop using precision agricultural technologies. Smart Agricultural Technology, 100220.,” 2023.

[14] S. (2023). Adekanmbi, T., Wang, X., Basheer, S., Nawaz, R. A., Pang, T., Hu, Y., & Liu, “Assessing Future Climate Change Impacts on Potato Yields—A Case Study for Prince Edward Island, Canada. Foods, 12(6), 1176.”

[15] I. Momčilović, “Effects of heat stress on potato productivity and nutritive quality,” *Hrana i Ishr.*, vol. 60, no. 2, pp. 43–48, 2019, doi: 10.5937/hraish1902043m.

[16] National Potato Council of Kenya 2020, *Climate Resilient Potato Production Handbook*. .

[17] M. K. Jatav, V. K. Dua, P. M. Govindakrishnan, and R. P. Sharma, “Impact of climate change on potato production in India,” *Sustain. Potato Prod. Impact Clim. Chang.*, no. February 2020, pp. 87–104, 2016, doi: 10.4018/978-1-5225-1715-3.ch004.

[18] Apni, “Potato Production in Kenya.” https://www.apni.net/wp-content/uploads/2021/08/Kenya-Potato-Guide-0821-.pdf (Accessed on 11 April 2023).

[19] Kephis, *Seed Potato Production and Certification Guidelines*. .

[20] npck.org, “Potato production handbook.” [Online]. Available: https://npck.org/Books/PotatoProductionHandbook2019(002).pdf Accessed on 28 October 2023.

[21] R. Akhter and S. A. Sofi, “Precision agriculture using IoT data analytics and machine learning,” *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 34, no. 8, pp. 5602–5618, 2022, doi: 10.1016/j.jksuci.2021.05.013.

[22] United Nations, “Sustainable Development Goals.” https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (Accessed on 29 May, 2023).

[23] J. Witte, “Growing potatoes: Production and consumption in East Africa,” Wageningen University The Netherlands.

[24] W. Kaguongo, G. Maingi, I. Barker, N. Nganga, and J. Guenthner, “The Value of Seed Potatoes from Four Systems in Kenya,” *Am. J. Potato Res.*, vol. 91, no. 1, pp. 109–118, 2014, doi: 10.1007/s12230-013-9342-z.

[25] R. J. T. et. al. . Rael Jepkemei Taiy et.al., “Climate Change Challenges and Knowledge Gaps in Smallholder Potato Production: The Case of Mauche Ward in Nakuru County, Kenya,” *Int. J. Agric. Sci. Res.*, vol. 7, no. 4, pp. 719–730, 2017, doi: 10.24247/ijasraug201795.

[26] npck.org, “Elgeyo Marakwet to scale up potato seeds production.” [Online]. Available: https://npck.org/elgeyo-marakwet-to-scale-up-potato-seeds-production/.

[27] Z. Zhai, J. F. Martínez, V. Beltran, and N. L. Martínez, “Decision support systems for agriculture 4.0: Survey and challenges,” *Comput. Electron. Agric.*, vol. 170, p. 105256, 2020.

[28] E. Symeonaki, K. G. Arvanitis, D. Piromalis, D. Tseles, and A. T. Balafoutis, “Ontology-Based IoT Middleware Approach for Smart Livestock Farming toward Agriculture 4.0: A Case Study for Controlling Thermal Environment in a Pig Facility,” *Agronomy*, vol. 12, no. 3, 2022, doi: 10.3390/agronomy12030750.

[29] A. G.- D Paculík, “Innovative Development in Agriculture 4.0 and the Use of Smart Technologies,” 2022.

[30] I. Kovács and I. Husti, “The role of digitalization in the agricultural 4.0 – how to connect the industry 4.0 to agriculture?,” *Hungarian Agric. Eng.*, vol. 7410, no. 33, pp. 38–42, 2018, doi: 10.17676/hae.2018.33.38.

[31] M. Javaid, A. Haleem, R. P. Singh, and R. Suman, “Enhancing smart farming through the applications of Agriculture 4.0 technologies,” *Int. J. Intell. Networks*, vol. 3, no. July, pp. 150–164, 2022, doi: 10.1016/j.ijin.2022.09.004.

[32] M. W. . Maduranga and R. Abeysekera, “Machine Learning Applications in Iot Based Agriculture and Smart Farming: a Review,” *Int. J. Eng. Appl. Sci. Technol.*, vol. 04, no. 12, pp. 24–27, 2020, doi: 10.33564/ijeast.2020.v04i12.004.

[33] K. N. Bhanu, H. J. Jasmine, and H. S. Mahadevaswamy, “Machine learning Implementation in IoT based Intelligent System for Agriculture,” *2020 Int. Conf. Emerg. Technol. INCET 2020*, pp. 1–5, 2020, doi: 10.1109/INCET49848.2020.9153978.

[34] D. Gómez, P. Salvador, J. Sanz, and J. L. Casanova, “Techniques and Sentinel 2 Data,” *Remote Sens.*, vol. 11, no. 1745, 2019.

[35] M. Kuradusenge *et al.*, “Crop Yield Prediction Using Machine Learning Models: Case of Irish Potato and Maize,” *Agric.*, vol. 13, no. 1, 2023, doi: 10.3390/agriculture13010225.

[36] T. A. Khoa, M. M. Man, T. Y. Nguyen, V. D. Nguyen, and N. H. Nam, “Smart agriculture using IoT multi-sensors: A novel watering management system,” *J. Sens. Actuator Networks*, vol. 8, no. 3, 2019, doi: 10.3390/jsan8030045.

[37] F. A. Almalki, B. O. Soufiene, S. H. Alsamhi, and H. Sakli, “A low-cost platform for environmental smart farming monitoring system based on iot and uavs,” *Sustain.*, vol. 13, no. 11, 2021, doi: 10.3390/su13115908.

[38] G. Codeluppi, A. Cilfone, L. Davoli, and G. Ferrari, “LoraFarM: A LoRaWAN-based smart farming modular IoT architecture,” *Sensors (Switzerland)*, vol. 20, no. 7, 2020, doi: 10.3390/s20072028.

[39] G. Castellanos, M. Deruyck, L. Martens, and W. Joseph, “System assessment of WUSN using NB-IoT UAV-aided networks in potato crops,” *IEEE Access*, vol. 8, pp. 56823–56836, 2020, doi: 10.1109/access.2020.2982086.

[40] J. Doshi, T. Patel, and S. K. Bharti, “Smart Fanning using IoT, a solution for optimally

monitoring fanning conditions," *Procedia Comput. Sci.*, vol. 160, pp. 746–751, 2019, doi: 10.1016/j.procs.2019.11.016.

[41] A. Pravin, T. Prem Jacob, and P. Asha, "Enhancement of plant monitoring using IoT," *Int. J. Eng. Technol.*, vol. 7, no. 3.27 Special Issue 27, pp. 53–55, 2018, doi: 10.14419/ijet.v7i3.27.17653.

[42] R. K. Jha, S. Kumar, K. Joshi, and R. Pandey, "Field monitoring using IoT in agriculture," *2017 Int. Conf. Intell. Comput. Instrum. Control Technol. ICICICT 2017*, vol. 2018-Janua, pp. 1417–1420, 2018, doi: 10.1109/ICICICT1.2017.8342777.

[43] A. Khattab, S. E. D. Habib, H. Ismail, S. Zayan, Y. Fahmy, and M. M. Khairy, "An IoT-based cognitive monitoring system for early plant disease forecast," *Comput. Electron. Agric.*, vol. 166, no. June, p. 105028, 2019, doi: 10.1016/j.compag.2019.105028.

[44] R. Singh, S. Srivastava, and R. Mishra, "Increasing the Yield in Crop Production," *IEEE Internatinal J. Electr. Electron. Eng.*, pp. 301–305, 2020.

[45] NC State Extension, "Soil Sampling Strategies for Site-Specific Field Management." [Online]. Available: https://content.ces.ncsu.edu/soil-sampling-strategies-for-site-specific-field-management.

[46] J. P. Anzola, V. García-Díaz, and A. C. Jiḿenez, "WSN analysis in grid topology for potato crops for IoT," *ACM Int. Conf. Proceeding Ser.*, vol. Part F1296, 2017, doi: 10.1145/3092090.3092104.

[47] E. (2019) Bisong, E., & Bisong, "Google colaboratory. Building machine learning and deep learning models on google cloud platform: a comprehensive guide for beginners, 59-64.," 2019.

[48] D. (2019). Mehrotra, *Basics of artificial intelligence & machine learning. Notion Press.* 2019.

[49] P. Kotsiantis, S. B., Zaharakis, I., & Pintelas, *Supervised machine learning: A review of classification techniques. Emerging artificial intelligence applications in computer*

engineering, 160(1),. 2007.

[50] D. J. Slone, “Visualizing qualitative information,” *Qual. Rep.*, vol. 14, no. 3, pp. 489–497, 2009, doi: 10.46743/2160-3715/2009.1407.

[51] B. Paech, A. H. Dutoit, D. Kerkow, and A. von Knethen, “Functional requirements, non-functional requirements, and architecture should not be separated--A position paper,” *8th Int. Work. Requir. Eng. Found. Softw. Qual.*, pp. 102–107, 2002.

[52] I. K. Kirpitsas and T. P. Pachidis, “Evolution towards Hybrid Software Development Methods and Information Systems Audit Challenges,” *Software*, vol. 1, no. 3, pp. 316–363, 2022, doi: 10.3390/software1030015.

[53] R. Wallen, “Software Development Life Cycle Models,” *Tutorials point simple easy Learn.*, vol. 6, no. 1, pp. 168–172, 2005, [Online]. Available: http://codebetter.com/raymondlewallen/2005/07/13/software-development-life-cycle-models/.

[54] Y. Leau, W. K. Loo, W. Y. Tham, and S. F. Tan, “Software Development Life Cycle AGILE vs Traditional Approaches,” vol. 37, no. Icint, pp. 162–167, 2012.

[55] D. Jäger, A. Schleicher, and B. Westfechtel, “Using UML for software process modeling,” *ACM SIGSOFT Softw. Eng. Notes*, vol. 24, no. 6, pp. 91–108, 1999, doi: 10.1145/318774.318788.

[56] H. Gomma, *Software modeling and design: UML, use cases, patterns, and software architectures*. Cambridge University Press, 2011, 2011.

[57] scribd.com, “Soil-Integrated-Sensor.” https://www.scribd.com/ (accessed Aug. 07, 2023).

[58] Arduino, “Arduino UNO,” 2023. https://www.google.com/arduino-uno (accessed Aug. 26, 2023).

[59] last minute engineers, “SIM 800L GSM Module.” https://lastminuteengineers.com (accessed Oct. 31, 2023).

[60] Watelectronics, “BreadBoard.” https://www.watelectronics.com/breadboard-construction-types-working/ Accessed on 15,July 2023 (accessed Jul. 15, 2023).

[61] Amazon, “Lithium Rechargable Batteries.” https://www.amazon.com/lithium-rechargeable-batteries/s?k=lithium+rechargeable+batteries /Accessed on 12, November 2023 (accessed Nov. 12, 2023).

[62] Elprocus.com, “LCD 16×2 Pin.” https://www.elprocus.com/lcd-16x2-pin (accessed Oct. 30, 2023).

[63] A. Liu and T. Yu, “Overview of Cloud Storage And Architecture,” *Int. J. Sci. Technol. Res.*, pp. 3–5, 2018.

[64] T. Fadhilah Iskandar, M. Lubis, T. Fabrianti Kusumasari, and A. Ridho Lubis, “Comparison between client-side and server-side rendering in the web development,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 801, no. 1, 2020, doi: 10.1088/1757-899X/801/1/012136.

[65] R. Oppliger, *SSL and TLS: Theory and Practice*. Artech house, 2023.

APPENDICES

Appendix 1: Questionnaire

Introduction

My name is Fancy Kiptoo, A Master's Student at the African Center of Excellence in Internet of Things- University of Rwanda. I am conducting a study with the focus to design IoT system prototype for monitoring environmental conditions for potato crop. In order to achieve the objectives of this study, a questionnaire has been developed to collect data from you as the identified respondent of the study. I am kindly requesting for your assistance to spare some time to fill this questionnaire and to be honestly as possible by ticking or filling in the spaces provided. Your responses will remain confidential and shall **ONLY** be used to achieve the objectives of this study. The findings of the study and the recommendations arrived will be of benefit to smallholder potato farmers and the government, to make informed decisions.

Thank you.

Instructions: This questionnaire has been structured into three sections, **Section A, B and C**. Kindly fill the questionnaire and provide the required information to the best of your knowledge. The information provided will remain confidential and will only be used for the purpose of this research.

Section A: Demographic Information

Kindly tick ☑ the answer which is appropriate for you, and leave blank any question that does not apply.

1. Respondent's age (Years)
   a) Between 18-35 ☐
   b) Between 35-45 ☐
   c) Above 45 ☐

2. Respondents Sex
   a) Male ☐
   b) Female ☐
   c) Others ☐
3. Do you grow potatoes? a)Yes ☐ b) No ☐
4. If NO, kindly specify the type of crop you grow in your farm? ....
5. What is the total area size of your farm (in acres)?
   a) Between 0.125-5(acres) ☐
   b) Between 5-10 (acres) ☐
   c) Above 10 (acres) ☐
6. What are the main challenges you face while cultivating potato?
   a) Monitoring environmental conditions
   b) Access to certified quality seeds
   c) Pests and diseases
7. Do you know the recommended optimal environmental conditions for potato crop?
   a) Yes ☐ b) No ☐

   If yes, specify the optimal environmental conditions for potato crop
   a) Air Temperature
   b) Humidity
   c) Soil Ph

d) Soil Temperature

e) Soil Humidity

Section B: This section focuses on the user requirements that need to be incorporated in the design of IoT system Prototype.

1. How do you monitor the environmental conditions for potato crop?

   a) Physical (Visually)

   b) Using IoT Technology

   c) Using Locally available tools

   d) Others (Specify)

2. Do you own a smart phone?

   a) Yes ☐ b) No ☐

3. How would you like to visualize your data using chart

   a) Pie ☐ b) Bar ☐ c)Line ☐

4. How frequent would you like to receive a notification?

   a) After 3hours

   b) Daily

   c) Weekly

   d) Monthly

Section C: This section entails the Interview guide questions with agronomist

a) What are the standard recommended optimal environmental parameters (Temperature, Humidity, Soil Temperature, Soil Humidity, Soil pH) for potato crop?

b) Which kind of soil (relating to study area) is favorable for potato crop?

c) Most research shows that unfavorable environmental conditions are the major challenge affecting potato farmers. In your own opinion, what are the main causes of this, and how best can the problem be addressed?

d) How best do you think smallholder potato farmers can be assisted to address the problem?

e) How frequent do you organize trainings to educate farmers on challenges they face?

f) Do smallholder farmers use any technology to monitor their farm? If No, would you recommend farmers to use IoT technology and why?