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College of Science and Technology

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

# Title: IoT-Based Quality Monitoring System for Cassava Value Chain

***A dissertation submitted in partial fulfillment of the requirements for the award of Masters of sciences degree in Internet of Things: Wireless Intelligent Sensor Network***

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**December, 2022**

## Declaration

I, Gabriel Karerangabo, Master ‘student from African Center of Excellence in internet of things, at University of Rwanda declares that this research thesis is my own original work and it has never been presented before anywhere in the world.

Gabriel Karerangabo
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Signed: ………………………….
Date: ……/……/……

**Bonafide Certificate**

This is to certify that this submitted Research Thesis work report is arecord of the original work done by Gabriel Karerangabo (**Ref. Number: 221000043**), MSc. IoT-WISeNet Student at the University of Rwanda / College of Science and Technology / African Center of Excellence in Internet of Things, the Academic year 2021/2022.

This work has been submitted under the supervision of Dr.Omar Gatera and Dr.Emmy Mugisha

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## Acknowledgments

My special thanks be to the Almighty God and my family for their incredible support during the entire studies and research period. I am expressing my full gratitude to all of the people for their time, effort and the tremendous support they offered me till the completion of this research.

I thank my supervisors, Dr. Omar Gatera and Dr. Emmy Mugisha, for their ongoing support, supervision, timely advice, and inspirational guidance that helped this project come to a successful conclusion.

I would like to thank my family again from the bottom of my heart. My wife for her encouragement, and the entire management team at the ACEIoT for their invaluable advice and unending help. I appreciate all of the professors and my dear classmates who patiently provided every kind of assistance needed to complete this research.

Although it would be hard to list everyone who helped me here, their support is appreciated and will continue to be .Your prayers have been heard, and I cannot express how grateful I am.

Thank you and may God bless you All!

## Abstract

Internet of Things refers to the overall network of linked devices as well as the technology that enables communication between connected devices and the cloud as well as within each individual device. It is flexible and is the best technology to adopt to enhance agricultural production and reduce poverty and hunger while protecting the environment. Cassava is an agricultural product that Sab-Saharan Africa's people consume much, especially in Rwanda. It provides consumable products such as roots and leaves. Roots provide cassava flour once prepared industrially and can be kept in stores before being distributed to consumers. However, some conditions like Ph, moisture, temperature, and humidity may degrade the quality of the cassava flour in the stores, and consuming highly contaminated flour should harm the life of the consumers. The Current solutions are a manual-based system where industries, after receiving and processing cassava from farmers, store the product in an environment from which it will be taken for sale. The changes in environmental conditions are not controlled, which causes the flour and other cassava-derived products to lose their quality, and sometimes consumers are exposed to harmful products. This study aims to implement an IoT-Based prototype to monitor the quality of the cassava value chain and provide massive and high-quality products without any loss and ensure environmental protection. The system comprises 4 ports where sensors such as PH, Temperature and Humidity, $CO_2$, $NH_3$, NPK, and Moisture content are plugged to measure any parameter. The results are displayed on the device's LCD and sent to the cloud for storage, analysis, and visualization and the owner of the cassava products via mobile phone. Since cassava constitutes a crucial food cultivated, sold, and consumed across Africa, particularly in Rwanda, some environmental conditions may occur and degrade the product by exposing it to harming consumers and waste some quantities in the environment; During testing, the results were that, during farming, the set of the values(Humidity, ph, temperature, NPK) detected by the system is called "data." The decision is made as follows: data<=100% and data>=67%; the soil is good for cassava. Whenever data is not in the above mentioned range, then the view on LCD is soil is bad for cassava. During processing, the set of the values(Humidity, ph, temperature, color, and smell) detected by the system are called **"**iss**."** The decision is made as the following: iss<=100% and iss>=70%, the cassava flour quality is high. When iss<=79% and iss>=50%, the cassava flour quality is Medium, and Finally, when iss<50, the quality of cassava flour is low, and the harmful environmental gases display. The decision made at the processing level is the same at the market level. During transportation, the high or low temperature is detected, the sound is played, and the message is sent to the truck driver's phone to take action. The implemented system significantly impacts the community by increasing the income and safety of the environment, health and safety of the people, and decreasing waste, which is also the solution to climate change.



***Keywords:*** IoT, Quality monitoring, Cassava, Value Chain, High Quality Cassava Flour(HQCF)

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## Acronyms and Abbreviations

ACEIoT : African Center of Excellence in Internet of Things
IT :Information Technology
PAQI : Panafrican Quality Infrastructure
GSM :Global System for Mobile Communication
GPRS :General Packet Radio Services
SDGs : Sustainable Development Goals
IoT: Internet of Things
WISeNet: Wireless Intelligent Sensor Network
NPK: Nitrogen,Phosphorus,Potassium
NH3: Ammonia/Nitrogen, Hydrogen
CO2: carbon dioxide
CO: Carbon monoxide
LCD: Liquid Crystal Display
PH: Hydrogen Potential
HA: Hardware Architecture
HQCF: High Quality Cassava Flour
ICT: Information Communication Technology
CCPs: Critical Control Points
N2O: Nitrogen Dioxide
UN: United Nations
SMS: Short Messaging Service
DHT: Temperature and Humidity
I/O: Input/Output
PWM: Pulse Width Modulation
USB: Universal Serial Bus
ICSP: In-Circuit Serial Programming
SIMCOM: Simultaneous Communication
LPG: Liquefied Petroleum Gas
IDE: Integrated Development Environment
QMSCVC: Quality Monitoring System for Cassava Value Chain
HACCPs: Hazardous Critical Control Points

# CHAPTER I: GENERAL INTRODUCTION

## 1.1. Overview and Background

Internet of Things connects physical objects/things embedded with sensors, software, and other technologies to connect and communicate with other devices via the internet (Patel et al., 2016). Before the Internet of Things, Operations were performed using IT systems when applied and manually, which was time-consuming and will not provide a highly accurate product as the Internet of Things can do. This technology is an emerging and powerful technology that is changing life of people worldwide by making smart objects that respond to complex processes in a real-time basis. Internet of Things is used in Agriculture, wearable devices development for healthcare and other sectors, traffic monitoring fleet management, Smart Home, hospitality, smart grid and energy-saving and water supply(Bandyopadhyay&Sen, 2011).

The focus of the author in this research is in Agriculture, especially in the cassava value chain. This agricultural product is grown by most African countries and some countries worldwide such as Asia, and the USA, and constitutes a staple food in the countries that mostly grow this plant. In Africa, especially in Rwanda, cassava constitutes a staple food and grows in most of the regions in the country by farmers. In Rwanda, Cassava was given a value due to the implementation of the Cassava plant in Kinazi, which processes fresh cassava to the final products(*Kinazi Fine Cassava Flour Rwanda 1 Kg*, 2022).

Statistics have shown that over 700,000 Rwandan Families grow cassava and produce over 1.7 million tonnes per year. As the most consumed product in Rwanda, Cassava products such as roots, cassava flour presents many challenges, such as degradation in quality, which can cause diseases to consumers and loss to the vendors and processing industries.

IoT-Based Quality monitoring system for cassava value chain (QMSCVC) is a system that will monitor the quality of the cassava along its value chain during the production and in the supply chain to increase productivity for cassava farmers,cassava flour producers and vendors, health and safety to consumers, reduce waste and environmental protection. Using this system will provide safe and affordable cassava products at an affordable cost and help processing industries and vendors gain trust in the side of the consumers.

### 1. 2. Motivation

Most African countries use cassava as an alimentation because it grows in their soils. It consists of the most important staple crops that grow in Rwanda. Ingabo Syndicate said that over 700,000 Rwandan families grow cassava and produce over 1.7 million tonnes of cassava per year(*In Rwanda, Public-Private Partnerships Benefit Small-Scale Cassava Farmers*, 2021). This crop is rich in nutritional profile and is adaptable to various by-products. Looking at the cassava value chain, the author found that many different products such as bread, donuts, chinchin, cakes, biscuits, and mandazi are derived from cassava and are primarily consumed in Rwanda. Considering the stipulated reasons, cassava is becoming an essential crop that is available and used to make quality and nutritional food in Rwanda and across Africa. However, the cassava value chain faces challenges due to its chemical and environmental changes in the way it is harvested, transported, and stored which can contribute to the unhealthy food provision to the consumers, loss to the industries and cassava sellers and farmers, and also to the environmental pollution that contributes to the climate change. Due to COVID-19 pandemic, the economy of Rwanda has recessed and severely impacted Rwandan Households as thousands faced unemployment, revenue losses and increased consumption prices that pushed the population into poverty. The rate of inflation is high and a significant number of people are not able to cover their needs and face food insecurity. Increasing cassava productions exempted from any kind of loss is the only way to reduce poverty as cassava grows in many regions in Rwanda. The author was motivated to raise the economy of farmers while alleviating poverty while implementing one of the UN Sustainable Development Goals ”zero hunger” , cassava processing industries, small businesses that sell cassava products and protect against environmental pollution and climate change by implementing an IoT-based System to monitor the quality of cassava value chain products.

### 1.3. Problem Statement

Cassava is the crop that is mainly cultivated and consumed by most Rwandans as statistics showed that over 700,000 Rwandan family farms grow cassava and harvest over 1.7 million tons per year, according to Ingabo Syndicate. This crop has a high nutritional profile and can be converted into a range of by-products. Looking at the cassava value chain, cassava is used to make various items, including bread, donuts, chinchin, cakes, biscuits, and mandazi, which are predominantly consumed in Rwanda. Cassava is becoming a very significant crop that is available and used to make quality and nutritious food in Rwanda and across Africa for the reasons stated. However, the cassava value chain faces challenges due to chemical and environmental changes such as NPK, $CO_2$, Moisture, Temperature, PH, Humidity, and $NH_3$ in the way it is cultivated, harvested, transported, and stored, which can contribute to the provision of unhealthy food to consumers, loss to industries, cassava sellers and farmers, and environmental pollution that contributes to climate change. The fact that Cassava industries cannot control all of these factors, sometimes they provide risky products unwillingly to the consumers, which can affect their health. Also, it is the source of loss they always face because they throw away the flour and other risky products that they find degraded and that the consumers can easily detect. To keep their trust, they decide not to use it and these challenges reduce the productivity of the sellers. Additionally COVID-19 pandemic has become a source of recession in the economy where there is an observation of a high rate of inflation in Rwanda:"Declared World Bank in the report sorted out on 8th February,2021". Having a Solution that can remove all of the above-mentioned issues and increase productivity would be a crucial contribution to the Rwandan society. Therefore, the real quality monitoring system based on IoT would be one of the solutions to handle the existing problems in cassava value chain. This study proposes a new device that will monitor the quality of cassava in real time so as to maintain the cassava quality, to increase the production and to reduce losses throughout the cassava value chain.

### 1.4. Objectives of the study

This study is organized into two objectives: General objective and specific objectives.

#### 1.4.1.General objective of the study

To implement an IoT-Based solution to monitor the quality of the cassava value chain, especially during farming, transportation, and at the market level to produce and provide massive and high-quality cassava products without any kind of loss and ensure environmental protection.

#### 1.4.2. Specific objectives

i. To assess the existing solution to identify the existing search gaps.
ii. To develop a prototype to detect soil quality suitable for cassava, cassava flour quality based on NPK, temperature, humidity, ph, color measurements and control greenhouse gases such as CO2, CO, NH3,N2O that may harm the environment.

iii. To incorporate notification mechanism into the developed prototype to notify cassava products processing and storing industries, corporations and SMEs that sell cassava products about the parameters measured and alert them in case of risky products and the next action to take. The data are stored in the cloud and visualized data are displayed on the dashboard for real-time readiness.

## 1.5. Research questions

i. What method should be applied to assess the existing solution and to identify the existing search gap?

ii. What are strategies to apply in developing a prototype to detect soil quality suitable for cassava, cassava flour quality based on NPK, temperature, humidity, ph, color measurements and control greenhouse gases such as $CO_2$, CO, $NH_3$, $N_2O$ that may harm the environment?

iii. In which way the developed prototype notifies cassava products processing and storing industries, corporations and SMEs that sell and supply cassava products about the measured parameters and action to take and how the decision will be made?

## 1.6. Hypotheses

The hypotheses of this study describe the integration of IoT system to monitor the quality of cassava along its value chain. The necessity of this system is at high level because it boosts the economy of cassava farmers by using technology and protects the environment from cassava waste that generates atmosphere gases.

## 1.7. Scope

The developed device will be used in Rwanda by the cassava processing industries and cassava flour storekeepers responsible for knowing the quality of cassava products in stock to know which flour to sell first to the consumers and what is next to sell. This study emphasizes on using IoT to monitor the quality of cassava along its value chain to ensure mass productivity, healthy products provision to the consumers, raising the economy of the country and protect the environment. Data are collected by sensors and visualized to the dashboards. The duration period of the study is from 2020-2022. The geographical area of the study is Rwanda, although the system should be used in other countries of Africa and worldwide due to its necessity.

## 1.8. Significance of the study

This study contributes to alleviate poverty in Rwanda by increasing productivity in the country, providing healthy products and protect environment. Given that cassava farmers are unaware of cassava fertile land, the sensors show them the best land to grow cassava which relates to cassava mass productions.

Also, cassava products stores, the parameters such as temperature, humidity, cassava flour ph and color are taken to ensure the quality of the products that are delivered to end consumers. It means that the end consumers consume the healthy products. Because the quality of the products is ensured on a real-time basis, using the technology reduce loss and waste to the environment and then, climate change protection.

This study not only benefits the cassava farmers, processing industries but also benefits the country because if the people's living conditions are improved, the country's economy steps forward. Note that the study doesn't reduce the inflation going on a high level in Rwanda, but it increases the resilience of Rwandans because they have products to sell and buy any item they need.

African Center of Excellence in Internet of Things and University of Rwanda are judged benefiting the country because they form innovative students who are not useless but are to contribute or give back to the community, hence receive additional students in the domain.

### 1.9. Organization of the Study

The document is organized as follow:

Chapter 1 introduces the idea of the project, chapter 2 presents a review of related literature, chapter 3 outlines the methodology used in the study, chapter 4 consists of System Design, chapter 5 presents the System Analysis and Results and performance evaluation, chapter 6 Comprises the conclusions and recommendations.

### 1.10. Conclusion

The control of cassava quality in cassava value chain while harvesting mass cassava is a focus since its products are consumed worldwide, Rwanda particularly.  With the evolution of technology, the development of an an IoT-Based Quality Monitoring system to detect the quality of cassava products to ensure safety of the consumers, to measure soil quality for cassava plantation and climate change protection from the reduction of greenhouse gases emitted during cassava processing industrial operations.  Therefore, zero poverty and zero hunger is possible by mass production of cassava and consuming high quality cassava while protecting environment and putting the country's agricultural technology to the next level of development.

## CHAPTER II: LITERATURE REVIEW

### 2.1. Introduction

This chapter consists of the presentation of previous works done on cassava farming, cassava products transportation, and storing conditions to increase cassava production. It discusses the challenges cassava farmers and processing industries and Small scale businesses selling cassava products are facing, existing solutions, existing open prototypes, and their limitations. Previous work has shown some laboratory experimentations and traditional practices to use in order to increase root yields of cassava and produce high-quality cassava flour favorable for the health of consumers. However, limitations are discussed in the chapter.

### 2.2. Related Literature

**PAQI** (Pan African Quality Infrastructure) simply discussed the function and impact of quality infrastructure in the cassava value chain in their final report, which was titled "Gap Analysis and Needs Assessment Study on the Function and Impact of quality Infrastructure in the Cassava Value Chain in African Countries." In order to enable purchasers to ensure the quality and amount of stores available, location and pricing, and facilitation of cassava purchase, they advised using an ICT-enabled raw material information tracking system for local stock determination. PAQI concluded that ICT-enabled technology must be used for raw cassava raw material information tracking in order to determine local stocks in order to give buyers confidence in the quality and quantity of stores available, location and price, and ease of cassava purchase. This recommendation followed an assessment of the needs to produce high-quality cassava products internationally. An Internet of Things (IoT)-enabled system that would monitor all environmental conditions in relation to the cassava value chain and enable high-quality, inexpensive, and mass cassava production while safeguarding the environment is not mentioned here. They also haven't yet put into practice the ICT-enabled raw material information tracking system they mentioned.

**GlobalG.A.P. (2020)**, in the published book entitled:*" Hazard Analysis and Critical Control Point,"* mentioned that in agricultural products, there are Critical Control Points to be respected and if they are not well followed and controlled, they can be a hazard to the life of the products consumers. GlobalGAP clearly showed the critical control points(CCPs) as the steps included in the process of critical preventing, reducing, or eliminating hazards to Human health. They said that monitoring is very important for this task. There is a need to set essential limits for it, and additionally the risk control should be at Low level, Medium, and High Levels. According to this literature, they discussed about the required need and provided some tips to follow but there is no clear picture of how they will be done and a lack of Technology to control those CCPs and other factors so as to provide mass production of cassava and a high quality products to consumers by ensuring good health and environmental protection. IoT-Based solution comes to help cassava farmers produce mass cassava, high quality and controlled food from cassava products; enhance vendors economy by reducing waste while ensuring environmental protection.

Nigeria, (2006), in their publication on action plan for the development of the Nigerian cassava sector", they have mentioned many points. Still, they were only focused on small-scale farmers, cassava processing industries, and challenges they are facing and set measures to improve in all of the sectors. They said that cassava is a product that needs serious consideration because it contains some points that may harm the consumers. According to the Literature, the change in temperature, humidity, moisture, ph, NPK and other factors harm the life of people who consume the products if there are at a high risk and the environment Establishing a strategy of studying all of these factors and find a lasting solution is needed. They said that researchers are needed to study such factors. All of the set actions that have been studied were focusing on the cassava products contents such as starch, flour, ethanol, and animal feed. The successful and competitive market in Nigeria will be enabled by the behavior of the organizations in charge. In their proposed solution, they is a lack of technology that is capable to real-time monitor the above parameters, process them and provide high quality and affordable cassava products without any loss.

**Costa, C., & Delgado, C. (2019),** in their publication on the cassava value chain in Mozambique, they mentioned all of the ways to proceed to improve cassava production. They mentioned that Cassava seed is vulnerable to diseases and pests that hamper mass production. There is a need a using variety that resists on diseases and pests. This solution remains manual and traditional solution as they have not set any technical strategy to find lasting solution. They did not also mention strategies to be applied to produce and supply high quality products of cassava to fight against hunger and poverty. The use of IoT technology is the best way that the researcher is proposing to provide real-timely data and monitor the quality remotely.

**NanamTayDziedzoav,AdebayoBusulaAbas, Wisdom K.A, MawuliSablah(2017)**, in their book entitled:" High Quality Cassava Flour Production Quality Management Manual, have mentioned many points to study during cassava value chain. They additionally added that there is a need to set up a cassava processing plant and quality management of the products, which involve identifying hazard points, chemical points, physical points and biological points. Also to improve production, there is a need to control the diseases and pests that may hamper the production. The process they undertake is that in case of temperature, as they are inside the store, they can note if the room is hot or cold, and in case it is hot, they open the windows and doors. In case of humidity, they close windows and doors and light the lamps. There is no involvement of technology. However, this manual process is not effective because they cannot protect the cassava products a hundred percent.

**World Bank Group. (2016),** In their report:"Climate Change action plan," they have mentioned the source of climate change factors and mentioned industries, plants wastes, and humidity and the Sun. In plant waste, they said that CO2 emission and other gases such as NH3,CO, N2O can be emitted from cassava waste and other sources during processing time, and are the enablers of greenhouse gases that make the changes in temperature that we are constantly confronted with. To find a solution to this matter results in reducing cassava's waste and real-time control of the gases in industrial production in the environment. So an IoT system that may help them to control all of the parameters and make decision even in the remote environment placement would be a better solution.

**A.Taiwo(2006)** discussed in the book"Utilization Potentials of cassava in Nigeria:The domestic and Industrial Products" the mechanisms to be applied to take cassava products to the next level to increase food security and poverty reduction. He mentioned that quality control is a focus because it helps maintaining a good quality for cassava products, improve market for small-scale enterprises. To control the quality, only hygienic measures are discussed along the study. However, there is no technology that was proposed or implemented to control this quality while improving productivity and protecting environment. Washing dishes and other Hygienic measures are not sufficient to fully control the quality of cassava products. IoT technology is effective solution to apply.

**J.Muhita(2022)** In the book assessing the Manual Management of the quality for Production of High Quality Cassava Flour", mentioned the presentation of hazardous critical control points to observe inorder to maintain the quality of cassava flour. However, the gap is the lack of the sustainable solution instead of recommending other researchers to control the hazardous critical control points. There is no Internet of Things technology involved in this study.

**Panni T.Johnson(2008)** presented, in the study entitled: "Development of an appropriate Quality assurance System for two cassava-based convenience foods in Ghana", challenges cassava industries face in ensuring safety and quality of their products. Besides the Hazardous critical control points, environmental conditions inadequate for cassava products harm the quality of cassava. The study shows that measures like constructing the team to study on HACCPs, monitoring procedures, creative corrections and other measures to ensure safety and quality of cassava products during the industrial processing. There is no inclusion of technology that would be used to real-timely collect data to determine and control the quality of the product without any human Intervention.

All of the solutions provide is manual. They did not say using an Internet of Things technology or other computerized technology that should be or currently be used to enhance the productivity, improve consumer's safety and protect the environment by observing climate change actions. They did not mention where they store the information. But we understand that to those who use computer, store the information in the files that may be lost and may interrupt the future data provision. They control manually the elements that may be hazardous, and sometimes they cannot control all of them in full. The experimentations they do in Laboratories take time and are more costly.

## 2.3. Research Contribution

This research focuses on the implementation of an IoT-Based Quality monitoring system for cassava along its value chain to support cassava farmers, processing industries, small-scale businesses that sell cassava, and end consumers to produce mass and healthy cassava products, provide high-quality cassava products and protect the environment while reducing the cassava waste that actually results in $CO_2$ atmosphere gases emission. The UN has implemented sustainable goals(SDGs) for sustaining global health and Wealth across the World.
Among them, are zero hunger figures. Due to covid-19 and other conditions, the inflation rate of consumer products is high in Rwanda and is affordable by a limited number of citizens. Some Citizens have found themselves in a high level of poverty where they cannot afford money for basic needs and this may affect the nutrition and schooling of their kids and relative. The research benefits them in the way that they have to produce more cassava products, consume them and sell them in the processing industries and small-scale businesses to get money for other food to equilibrate the diet and also to get money for the school of their kids. With this solution, life becomes Normal.

To the environment, the production of $CO_2$ in the environment is a source of climate change always observed in the planet. The United Nations is mandate to create a green planet exempted of the changes that most of times take lives of the World citizens. Studies have shown that cassava waste generates 60%(Cassava waste generation $CO_2$ gas emission). The solution provides high quality cassava products and as the hazardous environmental conditions are measured real timely and the decision is taken the time of finding hazardous parameters, there is no longer waste and the environmental protection is assured.

# CHAPTER III: RESEARCH METHODOLOGY

## 3.1. Introduction

An IoT prototype has been developed. The prototype (device) is made of a combination of ph, moisture content, color, Temperature, humidity and NPK, CO2, NH3, N2O sensors. It has three power sources. One is the battery, the second one is electricity and the last one is energy harvesting using solar energy. It comprises 3 ports for the sensors so that the user will use the device according to the parameters to measure.

The data collected by the plugin sensors are sent to the Microcontroller(Arduino Uno Board) which processes them. It may happen that the sensed data show that the cassava product is at risk, then, a real-time decision is made. The information and decision display on the LCD of the device and are also sent to the dashboard and the owner of the cassava products via mobile phone using GSM/GPRS module and the cloud as well. From the cloud, the data is visualized on thedashboard.

### 3.2. Prototype Testbed

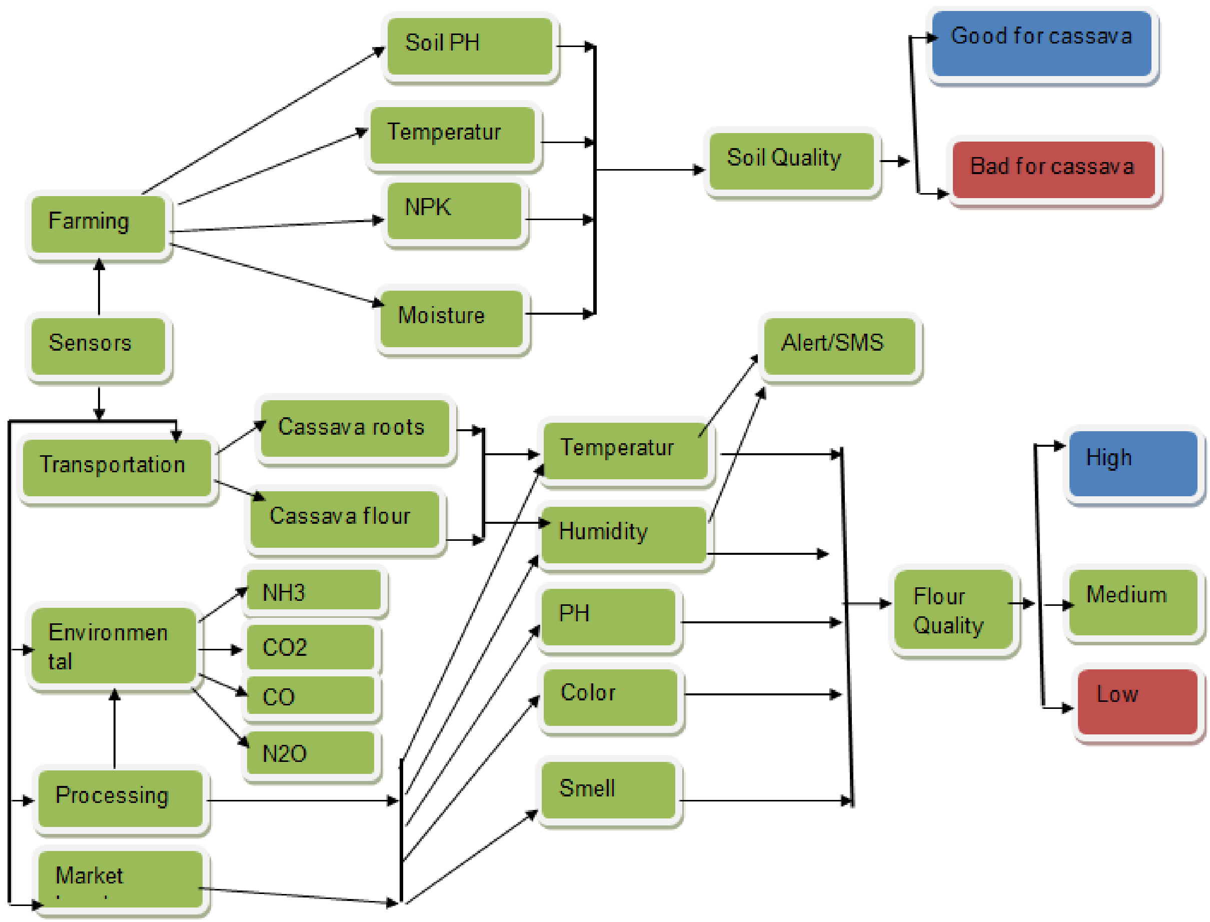



Figure 1: Prototype Test bed

IoT-based Quality monitoring system for cassava along its value chain's test bed is explained below:

Basically, Sensors are the main components that collect data from farming to determine the quality of the soil to the end consumer.

#### a. Farming

At farming level, sensors like soil ph, temperature, NPK and Soil moisture collect data about the state of the soil and after processing they provide results that the soil is good or bad for cassava.

#### b. Transportation

During transportation, cassava value chain face challenges such as temperature and humidity inside trucks transporting cassava roots or cassava flour that may go high or low and may harm the products. Sensors like temperature and humidity are used here. Inside the truck, if the temperature is high, the sound will be played automatically and the message is dropped into the phone of the driver to show him the state of temperature inside the truck and will open the fun to cool down the system. Whenever the temperature is low, the response is the same. It is the same process with the humidity changes.

### c. Processing

The processing level consists of two phases:

- **Phase1:** Cassava flour quality Determination where parameters like temperature, humidity or moisture, PH, color and smell are measured. The combination of the parameters' values determines the quality of the cassava flour. The results will display in the LCD that cassava flour is of high quality, medium quality or low quality.

- **Phase 2: Environmental protection.**

At processing level the general some of the gases such as $CO_2$, CO, $NH_3$, $N_2O$ are generated and emitted in the atmosphere. These are the greenhouse gases that result in climate change the planet earth is always confronted with. The device is intelligent enough to detect these gases at industrial processing and alert if they are at the level of polluting the environment.

All of these parameters are well controlled and result in producing high quality cassava flour (HQCF) while protecting the environment.

### d. Market

This is where the final product is put into stores and ready to be supplied and consumed. Customers for consume cassava flour, vendors, small-scale business owners who sell cassava flour come to the main store and buy the High quality flour. Without any doubt, they store the flour into stores with different environmental conditions according to the regions where they stay. The device is there to control the parameters that may result to harming of the product and alert whenever the harmful conditions are to occur. If the cassava flour own does not take any action, the flour may go from high quality to medium and finally to low quality.

The customers who purchase the cassava flour products have to see into the LCD of the device the following indications:

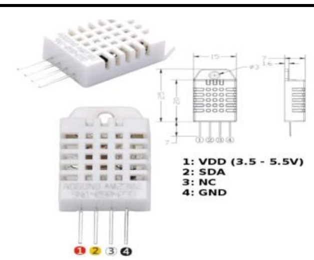
- High quality cassava flour/ Ifu ninzima
- Medium quality cassava flour/Ifu ni nzima
- Low quality cassava flour/ Ifu si nzima

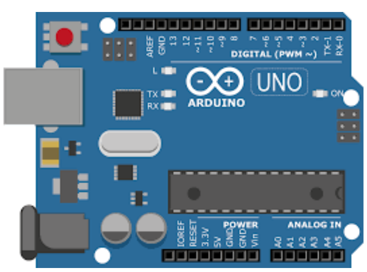
### 3.2. Tools

The system consists of Hardware and Software. The Hardware used is Arduino Uno and sensors: Temperature, NPK, PH, Moisture content and colour. It has also LCD for display, Buzzer for Risky product notification and GSM/GPRS for Data transmission to the cloud and to the Edge devices.

#### 3.2.1. Hardware

**Table 1: Hardware components**

| **Hardware** | **Description** | **View** |
|---|---|---|
| **Ph Sensor** | A pH sensor consists of one of the essential tools for measuring water. This sensor can detect the quantity of alkalinity and acidity in water and other liquids(Sensorex, 2019). It will be used in the solution to measure how alkaline and acid is the water that is in the flour. This sensor is used in this system because it is able to measure the ph of the solution and notify if it exceeds 9.37 the normal ph of the cassava flour. If the ph exceeds 9.37, it is harmful to the body as it can cause anomalies such as metabolic alkalosis that can result in vomiting and nausea of the people. |  |
| **Temperature and Humidity Sensor(DHT22)** | The temperature and humidity sensor is a device used to measure the Temperature and Humidity of Liquids, air temperature, and or the temperature of solid matter. In this scope, the DHT22 sensor will be used to measure the humidity and the temperature contained in the cassava flour. |  |

| | | |
|---|---|---|
| **Color Sensor(TCS3200 color sensor)** | A color sensor is used to detect the color of an object. A color sensor is a sort of "photoelectric sensor" that produces light through a transmitter, and The light reflected from the detecting item is then received via a receiver. |  |
| **Moisture Sensor** | A moisture sensor is used to measure the moisture content of any object such as soil, flour, etc. In this context, the moisture sensor will be measuring the moisture content of the cassava flour. |  |
| **Arduino Uno** | The Arduino Uno is a board used based on the ATmega328P. (datasheet) microcontroller (datasheet). It contains 14 digital I/O pins (six of which are PWM outputs), 6 analog inputs, a quartz crystal with a frequency of 16 MHz, a USB connection, a power jack, an ICSP header, and a reset button (Arduino - ArduinoBoardUno, 2022). It has a Integrated Development Environment which will help the development to write the program. |  |

| | | |
|---|---|---|
| **GSM Module** | The GSM Module that will be used during the project is GSM with GPRS shield based on SIM900 from SIMCOM. The GSM once connected to the Arduino board will allow it to connect to the internet, sends and receive messages and can make calls using GSM library(jojo, 2020). GSM in this study will be used to send notification to the Cassava processing Industries managers, The stores owners and store keepers about the measured conditions and the action to take. |  |
| **NPK Sensor** | The soil NPK sensor can detect the levels of nitrogen, phosphorus, and potassium in the soil. It aids in determining soil fertility, allowing for a more methodical assessment of soil quality. |  |
| **CO2 sensor** | MQ-135 sensor is able to detect varieties of gases such as LPG, smoke, alcohol, propane, Hydrogen, Methane, CO2, and NH3 concentrations from anywhere from 200 to 10000ppm. |   |

### 3.2. 2.Exploratory Data

This section presents how data have been collected and the tools used to collect them. To get data, the researcher deployed sensors in the rural areas in surrounding environments of the Kinazi cassava plant and Kinazi cassava plant flour store after production in the southern province of Rwanda that has been able to get data relating to the soil and environmental conditions that can be in cassava products' contact and that once are not well controlled may be harmful. Sensors measured NPK and PH for soil fertility, Temperature, Humidity, and Moisture content in cassava products stores and the cassava flour color to determine its quality. This study employed secondary data gathering methods to learn more about the traditional methods used by cassava farmers to grow the crop, which offer many difficulties and only yield little amounts of cassava-related items.

### 3.232. Software tools

Language libraries, Code editors, test monitor, Programming tools.

### 3.2.4. Cloud platform

The cloud platform provides distant data storage, analysis, and processing as well as remote coexistence of hardware and software products. The platform used here is cloud that the developed to receive data from IoT sensors, store them, process them and analyses them decision making purpose. In this case sensor data is sent using arduino UNO microntroller to the dashboard through GSM/GPRS network. The owner of the cassava flour store or industry receives SMS in the cell phone to remotely control the business.

## 3.3. Existing system

From Secondary source of data, the researcher was able to understand the current using system for cassava quality monitoring. The current solution is a manual-based system where industries, after receiving and processing cassava from farmers, store the product in an environment from which it will be taken for sale. The changes in environmental conditions are not controlled and which causes the flour and other products derived from cassava to lose their quality, and sometimes consumers are exposed to consuming a harmful product. The implementation of an IoT-Based solution to monitor the quality of the cassava value chain, especially during cassava farming and flour production, and provide massive and high-quality products without any kind of loss and ensure environmental protection is a best solution to solve poverty related consequences.

# CHAPTER IV: SYSTEM ANALYSIS AND DESIGN

## 4.1. Introduction

This chapter goes into great detail about both the SMS alert system and the IoT-based Quality Monitoring system for the cassava value chain. The system's design is described in detail in this chapter, along with illustrations of the hardware and software specifications in use.

## 4.2. System Architecture

The architecture of a system is a high-level description of the complete system that identifies its fundamental parts and functions as well as the rules that each element must abide by in order to communicate and work together. The Internet of Things is firmly rooted in embedded systems and other technologies like pervasive systems and sensor networks. IoT is a system in which "things" are interconnected through a network (through Internet protocol) to cooperate and carry out activities while interacting with the physical and digital worlds. The quality monitoring system for cassava was developed using the IoT architecture paradigm along its value chain.

### 4.2.0. Block Diagram of the system

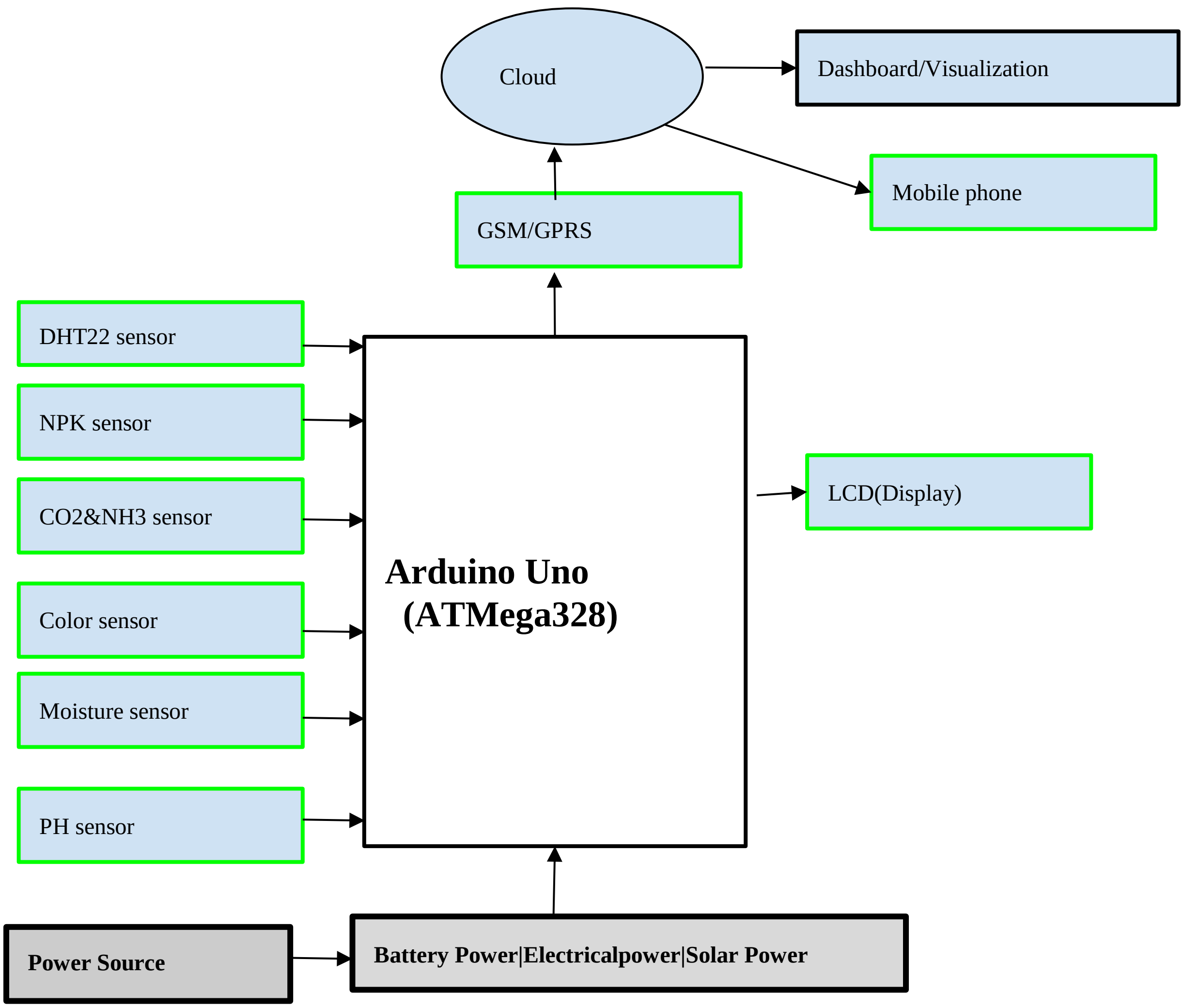



**Figure 2: Block Diagram of the System**

### 4.2.1. Hardware Architecture(HA)

To create a full Internet of Things system and service, numerous components are required. A crucial component of the IoT Architecture is data sampling, which may be aperiodic sampling based on event and is therefore useful to relax resource restrictions like power and bandwidth. Sampling is the process of gathering information from the environment to represent a specific condition that is relevant to the system (input), such as the rate of water flow, the motion of the soil, and so forth. The quality monitoring system for the cassava value chain can be categorized as aperiodic sampling since it responds as soon as a change in any value parameter is noticed.

### 4.2.2. Software Architecture

Software is ultimately used for administration, control, and security at the business layer, to fulfill needs by executing use cases at the application layer, and for data filtering, aggregation, and other tasks at the processing layer. Software architecture must therefore be taken into account, especially when describing the organization of the system at its top layers.

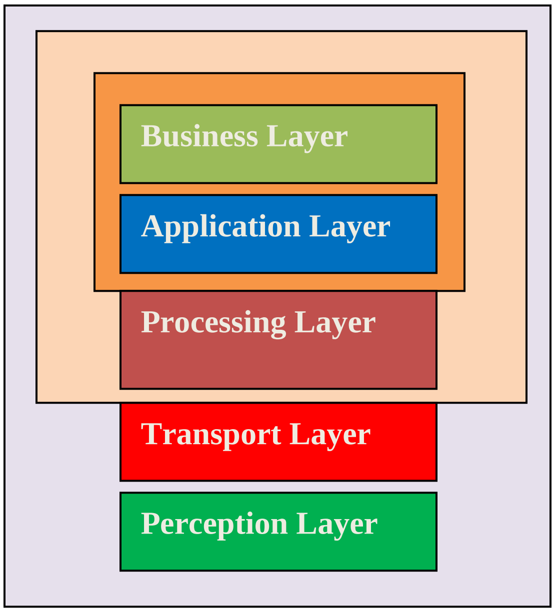



**Figure 3: Upper Layers responsible for software architecture (Anthony, 2016)**

Depending on the programming language, software design is typically based on modules:

- Modules can refer to the encapsulation of data and functions;
- In other circumstances, they can also refer to a collection of several functions/classes, which is known as a package.

#### 4.2.3. System Design Requirements

##### 4.2.3.1. Functional Requirements

To monitor the quality of cassava products parameters, the below functional requirements should be put in place:

- Sense environmental condition parameters through sensors,
- Send sensed data for cloud storage,
- Analyze and visualize data on the dashboard.
- Play a sound whether any condition matches
- Send alert SMS to the cassava Products owners.

##### 4.2.3.2. Non-Functional Requirements

- Performance:Based on its hardware, network, software, stability, startup, and storage.
- Availability: Every time, this system will be turned on.
- Reliability: This product will deliver accurate results under specific environmental conditions and fulfill acceptable performance criteria.
- Scalability: The deployment will include a large number of sensor nodes.
- Usability:This system is accessible to anyone with ICT knowledge.
- Recoverability: The system can be quickly fixed when something goes wrong

##### 4.2.3.3. Hardware and Software Requirements

**Sensor requirements and application Specifications**

An actuator is a machine part that moves or controls a mechanism or system, whereas a sensor is a device that produces a proportionate output signal (electrical, mechanical, magnetic, etc.) in response to a physical phenomenon (soil moisture, displacement, force, etc.). For a closed-loop control system to work properly, sensors and actuators are required. The controller gets data from the sensing unit, analyzes it using the control algorithm, and then transmits commands to the cloud-based actuation unit.

### 4.3. System Three Layered Architecture

The services required to fulfill the demand are arranged into three layers using this architecture:

- Perception Layer: Data input
- Network Layer/ Processing Layer: Processing and connectivity
- Application Layer: Output of Information as a Service

| | |
|---|---|
| **Application Layer** | *Responsible for delivering application specific service* |
| **Network Layer** | *Responsible for connectivity and processing the raw data captured from sensors in such a way it is meaningful for use* |
| **Perception Layer** | *Capturing information from the environment. Predominantly sensors are used to sense and gather information from the physical environment* |

### 4.4. System Components Design

IoT-Based quality monitoring system for cassava value chain prototype architecture design consists of four subsystems which are sensing part, wireless communication part and application part.

#### 4.4.1. System Components Design Diagram

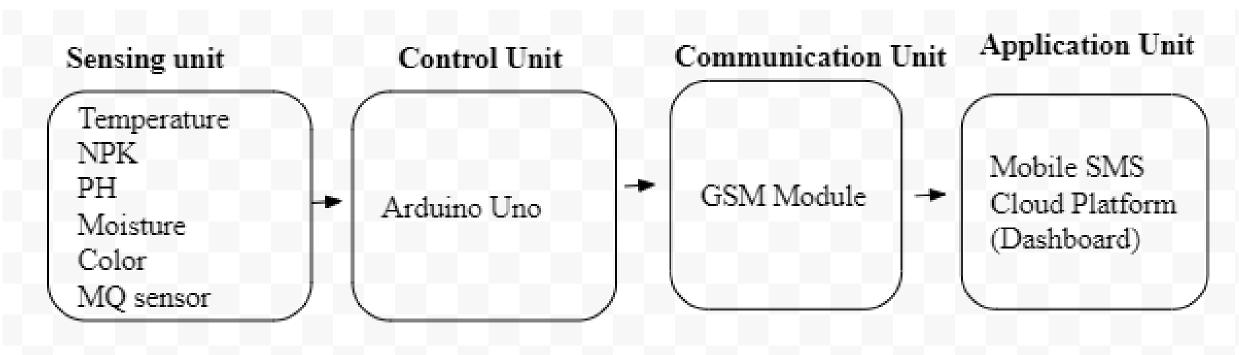



**Figure 4: System Components Design Diagram**

#### 4.4.2. Wireless Communication Unit

This unit describes the wireless communication part of the system. The collected data are sent to the Microcontroller for further processing. In a case the values are over the thresholder values, for soil and cassava flour quality measurements, the alert message is displayed on the LCD and sent to the mobile phone of the cassava product of land owner to let him what can be done for further protection as well as to the dashboard cloud platform for being analysed via Arduino Uno and the gateway.

### 4.4.3. Wireless Communication Block Diagram

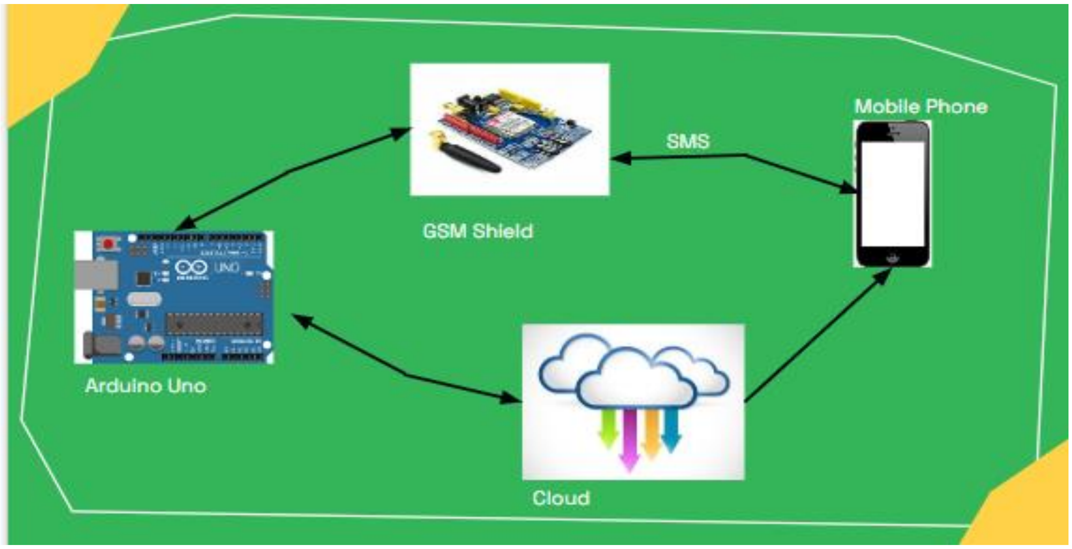



**Figure 5: Wireless communication block Diagram**

During land state and cassava flour quality communication, Arduino, GSM are used.

1. **Arduino Uno**

The Arduino Uno is a board based on the ATmega328P microprocessor. (datasheet) (datasheet). It has 6 analog inputs, a quartz crystal with a frequency of 16 MHz, a USB connector, a power jack connector, an ICSP header, and a reset button. It also has 14 digital I/O pins, six of which are PWM outputs (Arduino - ArduinoBoardUno, 2022). It has an Integrated Development Environment that will aid in the program's development.

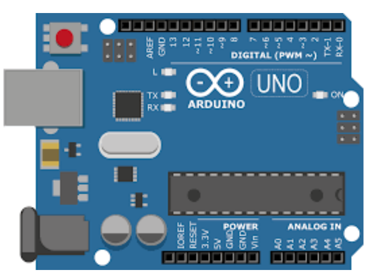


**Figure 6: Arduino Uno ATMega 328**

2. **GSM**

The GSM Module that will be used during the project is GSM with GPRS shield based on SIM900 from SIMCOM. The GSM once connected to the Arduino board will allow it to connect to the internet, sends and receive messages and can make calls using GSM library(jojo, 2020).

GSM in this study will be used to send notification to the Cassava processing Industries managers, The stores owners and store keepers about the measured conditions and the action to take.

**Figure 7: GSM Module**

#### 4.4.4. Application and Cloud Unit

1. **Cloud platform**

Cloud computing is Internet-based computing in which virtual shared servers offer clients pay-per-use access to software, infrastructure, platforms, devices, and other resources (Bigelow, 2022). Users can access on-demand computing resources such as infrastructure, software, and storage through the internet. In this study, dashboard cloud platform is used as an IoT analytics platform service that permits the aggregation, visualization, and analysis of real-time data.

2. **Integrated Development Environment Requirements(IDE)**

For Windows, macOS, and Linux, the Arduino Integrated Development Environment (IDE) is a cross-platform program that uses C and C++ functions. It is used to create and upload applications to boards that are compatible with Arduino (Kenneth Leroy Busbee, 2018), as well as to other vendor development boards with the aid of third-party cores. Version 1.8 of Arduino was employed in this study.

3. **Arduino C Programming**

Instructions are sent into the Arduino C programming language compiler, which turns them into executable code for the microprocessor or microcontroller. Although it is an extra step, the software it produces is more effective than an interpreter. While your program is executing, an interpreter converts your code into machine language, literally one line at a time (Lab, 2017).

### 4.4.5. Prototype showing the Quality of cassava flour

Figure 8: The researcher testing the quality of cassava flour

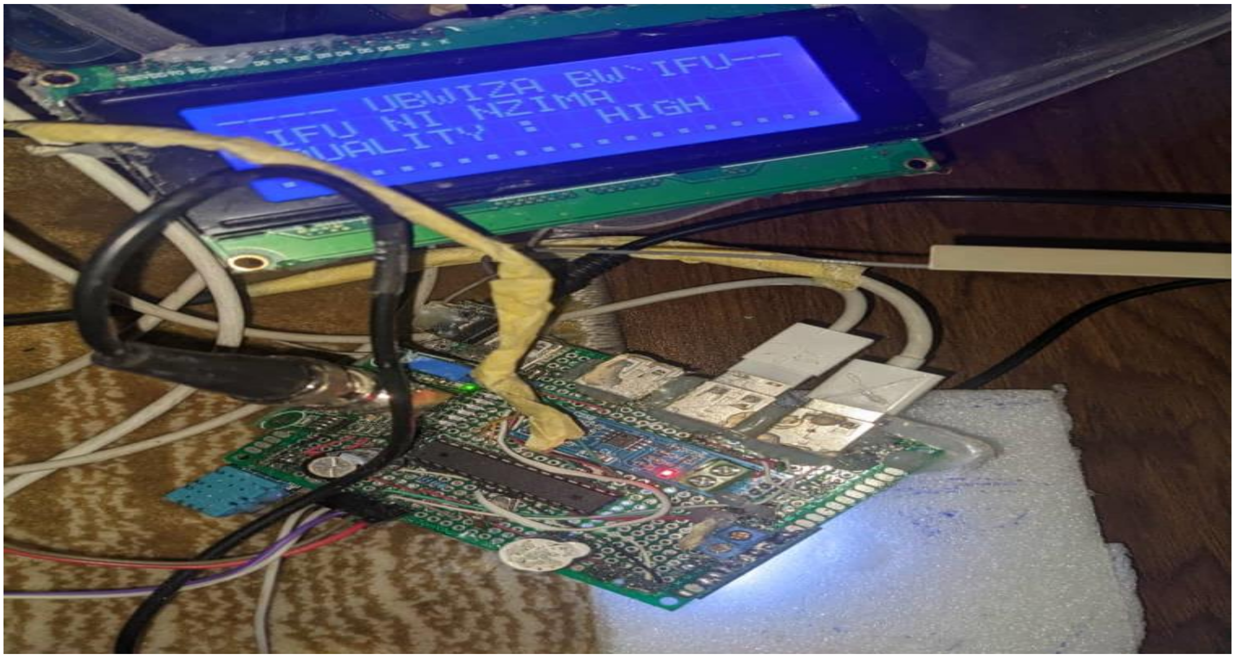



**Figure 9: Prototype showing that Cassava quality is High**

**4.4.6. Prototype showing that Cassava flour Quality is Medium**

Figure 10: The researcher testing the cassava flour quality.

The researcher mixed different cassava flours in one box for quality detection.

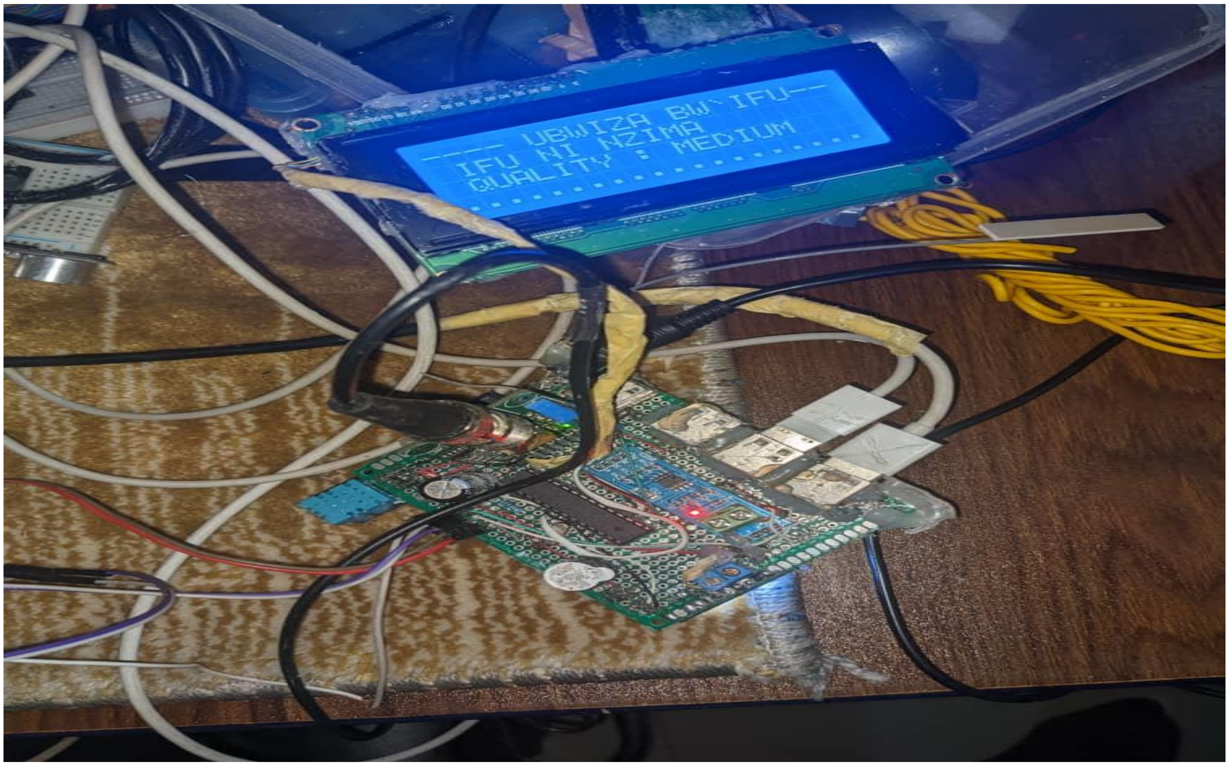



**Figure 11: Prototype showing cassava flour quality as medium**

**4.4.7. Prototype showing the quality of the Soil**

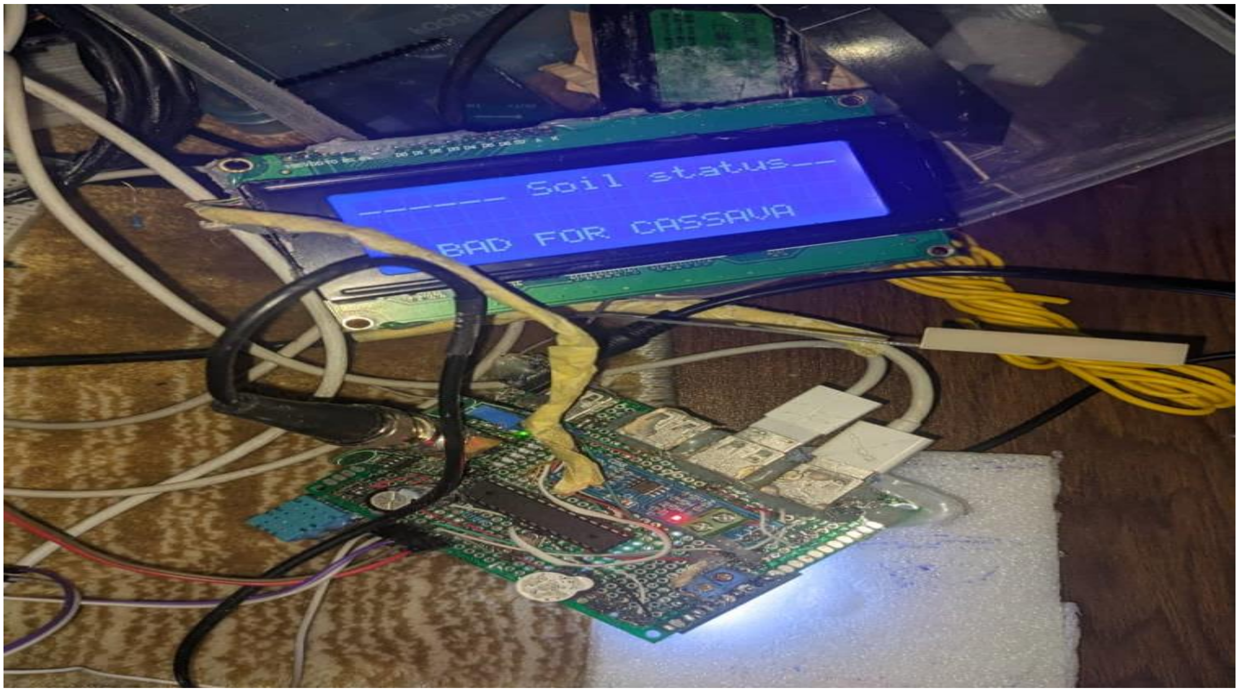



**Figure 12: Prototype showing the Quality of the soil**

### 4.4.8. IoT-Based Quality Monitoring System for cassava value chain Final Prototype


Figure 13: Device Final Prototype

# CHAPTER V: RESULTS ANALYSIS AND DISCUSSIONS

## 5.1. Introduction

This chapter presents the results of data collected by the sensors plugged into the deviceabout the fertility level of the soil to grow cassava and the flour quality measured during processing, transportation and at the market level while protecting the environment from the atmosphere gases resulted from the cassava flour processing time.

## 5.2. Results presentation

### 5.2. 1.Findings

Sensors detected NPK, PH, temperature of the soil, temperature, Humidity or moisture content and color. The NPK measured proportions 16-21-36,16-21,54,etc (mg/kg) for Nitrogen, Phosphorus and Potassium, respectively. PH measurements were around 3.0 and 7.2 and soil temperature was 30 **°C** and atmosphere temperature measured was 27**°C**. Cassava products storing temperature measured was in variations of 7**°C**-33**°C.** Cassava flour moisture content was in variations of 9-37 percent.

The findings from secondary data have shown that cassava grows best in forest soil that contains light, sandy loams. This soil is fertile, moist, and deep. Most farmers who grow cassava use organic manures such as cattle or garbage. They also apply observation to see whether the land is fertile for cassava.

### 5.2.2. Abnormal parameters for cassava farming land

**Table 2: Abnormal parameters for cassava soil**

| **Parameters** | **Controlled conditions** | **Measures** |
|---|---|---|
| NPK | Soil NPK(Nitrogen, Phosphorus, Potassium) | 17-17-17 |
| PH | Soil PH(Potential of Hydrogen) | <4.0 |
| Temperature | Soil temperature<br>Atmosphere temperature | < 30°C and >35°C<br><25°C, >29°C |

### 5.2.3. Abnormal parameters for Cassava flour

**Table 3: Abnormal parameters for Cassava flour**

| Parameters | Controlled conditions | Measures |
|---|---|---|
| Temperature | Temperature of the Cassava flour storage room | <25°C and >30°C |
| PH | PH of cassava flour | <5.5 and >8.5 |
| Moisture Content | Moisture of cassava flour storage room | >12% and <60% |
| Color | Color of cassava flour | R(<23,>25),G(<27,>29),B(<8,>9) |

### 5.2.4. Normal parameters for cassava farming land

**Table 4: Normal parameters for cassava soil**

| Parameters | Controlled conditions | Measures |
|---|---|---|
| NPK | Soil NPK(Nitrogen, Phosphorus, Potassium) | 17-17-17 |
| PH | Soil PH(Potential of Hydrogen) | 4.0-4.2 |
| Temperature | Soil temperature<br>Atmosphere temperature | 30°C<br>25°C-29°C |

### 5.2.5. Normal parameters for Cassava flour

Table 5: Normal parameters for Cassava flour

| **Parameters** | **Controlled conditions** | **Measures** |
|---|---|---|
| Temperature | Temperature of the Cassava flour storage room | 25°C-30°C |
| PH | PH of cassava flour | 5.5-8.5 |
| Moisture Content | Moisture of cassava flour storage room | 6.34%-18% |
| Color | Color of cassava flour | R(23-25),G(27-29),B(8,9) |

### 5.2. 6.Threshold values

#### 5.2.6.1. NPK values

**Table 6: NPK threshold values**

| **NPK** | **Recommended** |
|---|---|
| 17-17-17 | Fertile land for cassava |
| Outside of the above range | Can't grow cassava |

#### 5.2.6.2.PH threshold values

**Table 7: PH threshold values**

| **Soil PH** | **Recommended** |
|---|---|
| 4.0-4.2 | Fertile land for cassava |
| <4.0 | Can’t grow cassava |

#### 5.2.6.3. Soil Temperature Threshold values

**Table 8: Soil temperature Threshold values**

| **Soil Temperature** | **Recommended** |
|---|---|
| 30°C | Best for cassava |
| <22°C-27°C | Can’t grow cassava |
| >30°C | Can’t grow cassava |

#### 5.2.6.4. Atmosphere Temperature Threshold values

**Table 9: Atmosphere Temperature Threshold values**

| **Atmosphere Temperature** | **Recommended** |
|---|---|
| 25°C-29°C | Best for cassava |
| <25°C, >29°C | Can’t grow cassava |

**5.2.6.5. Cassava flour temperature Threshold values**

**Table 10: Cassava flour temperature Threshold values**

| Cassava flour Temperature | Recommended |
|---|---|
| 25°C-30°C | High-Quality cassava flour |
| 23°C-24°C | Medium |
| <23°C | Unhealthy flour |

**5.2.6.7. PH for cassava flour Threshold values**

**Table 11: PH for cassava flour Threshold values**

| Cassava flour PH | Recommended |
|---|---|
| 5.5-8.5 | High-Quality cassava flour |
| 5.3-5.4,8.7 | Medium |
| <5.3, >8.7 | Unhealthy flour |

**5.2.6. 8.Moisture Content for cassava flour Threshold values**

**Table 12: Moisture Content for cassava flour Threshold values**

| Cassava flour Moisture content | Recommended |
|---|---|
| 6.34%-14.58 | High-Quality cassava flour |
| 6.30%,14.6% | Unhealthy flour |

### 5.2.3. Soil Quality results presentation

Sensors data collected for soil quality detection consists of NPK, Soil moisture, soil ph and soil temperature. The device display good for cassava or bad for cassava to mean good soil for cassava or bad soil for cassava. If the soil is bad, there is no need to grow cassava there. There is possibility to see fertilizers that are missing and the addition of them results in rending the soil fertile and for the moment cassava may grow there. When the device displays good, it means farmer can plant cassava in that soil. Below is the result from the cloud:

Soil Status Report

Monitoring Report

10 entries per page

Search...

| # | SN | TEMPERATURE | SOIL PH | N P K | MOISTURE | Due Time | SOIL QUALITY |
|---|---|---|---|---|---|---|---|
| 1 | CASV234 | 25.8 °C | 0 | 255 , 255 ,255 mg/Kg | 0 % | 2022-11-14 12:19:27 | 1.81 % BAD FOR CASSAVA |
| 2 | CASV234 | 25.8 °C | 0 | 255 , 255 ,255 mg/Kg | 0 % | 2022-11-14 12:22:03 | 1.81 % BAD FOR CASSAVA |
| 3 | CASV234 | 25.8 °C | 0 | 255 , 255 ,255 mg/Kg | 0 % | 2022-11-14 12:22:03 | 1.81 % BAD FOR CASSAVA |
| 4 | CASV234 | 25.8 °C | 0 | 255 , 255 ,255 mg/Kg | 0 % | 2022-11-14 12:22:03 | 1.81 % BAD FOR CASSAVA |
| 5 | CASV234 | 25.8 °C | 0 | 255 , 255 ,255 mg/Kg | 0 % | 2022-11-14 12:22:03 | 1.81 % BAD FOR CASSAVA |

**Figure 14: Fertile for cassava plantation**

The figure above explains the parameters measured to determine the quality of the soil suitable or non-suitable for cassava plantations. The measurements from sensors were temperature, soil ph, soil NPK and soil Moisture. The decision was made when the set of measured values attains a certain level. In this solution the good soil quality is determined by adding measurements specific for the soil and display in percentages. The set of the values(Humidity, ph, temperature, NPK) detected by the device is called **"data."** The decision is made as follows: **data**<=100% and **data**>=67%; the soil is **good for cassava**. Whenever data is not in the above mentioned range, then the view on LCD is soil is **bad for cassava**. This figure clearly show that the measured soil was not good for cassava plantation.

### 5.2.4. Flour quality detected at the Processing and Market Level

At the processing and market level, the device detects the quality of cassava flour in three indicators: High, Medium and low to mean high quality cassava flour, medium Quality cassava flour and low quality cassava flour as you can see on the figures below:

Monitoring Report

Monitoring Report

10 entries per page    m

| # | SN | Temperature | Humidity | Flour-PH | Color | Smell | Flour Quality | Due Time |
|---|---|---|---|---|---|---|---|---|
| 1141 | CASV234 | 27.6 ºC | 49 % | 7.13 | R::28 , G::29 , B::9 Undefined Flour | 220 ppm | 40 % LOW | 2022-11-14 12:22:03 |
| 1142 | CASV234 | 27.6 ºC | 49 % | 7.13 | R::19 , G::20 , B::6 White Flour | 220 ppm | 60 % MEDIUM | 2022-11-14 12:22:03 |
| 1143 | CASV234 | 27.6 ºC | 49 % | 7.13 | R::21 , G::21 , B::7 White Flour | 221 ppm | 60 % MEDIUM | 2022-11-14 12:22:03 |
| 1144 | CASV234 | 27.6 ºC | 48 % | 7.13 | R::43 , G::44 , B::13 Undefined Flour | 220 ppm | 40 % LOW | 2022-11-14 12:22:03 |
| 1145 | CASV234 | 27.6 ºC | 48 % | 7.13 | R::109 , G::157 , B::39 Undefined Flour | 222 ppm | 40 % LOW | 2022-11-14 12:22:03 |

Figure 15: Cassava flour quality as medium and low

The figure above explains the why of the medium and low quality of the flour. To determine the quality of flour there are some indicators that are followed as GlobalGAP (2020) mentioned which are low, medium and High. The set of the values(Humidity, ph, temperature, color, and smell) detected by the device are called **"iss."** The decision is made as the following: **iss**<=100% and **iss**>=70%, the cassava flour quality is **high**. When **iss**<=79% and **iss**>=50%, the cassava flour quality is **Medium**, and Finally, when **iss**<50, the quality of cassava flour is **low.** This figure clearly shows that the cassava flour measured was of two different qualities: One was of medium quality and the second was of low quality.

## Monitoring Report

Monitoring Report

10 entries per page

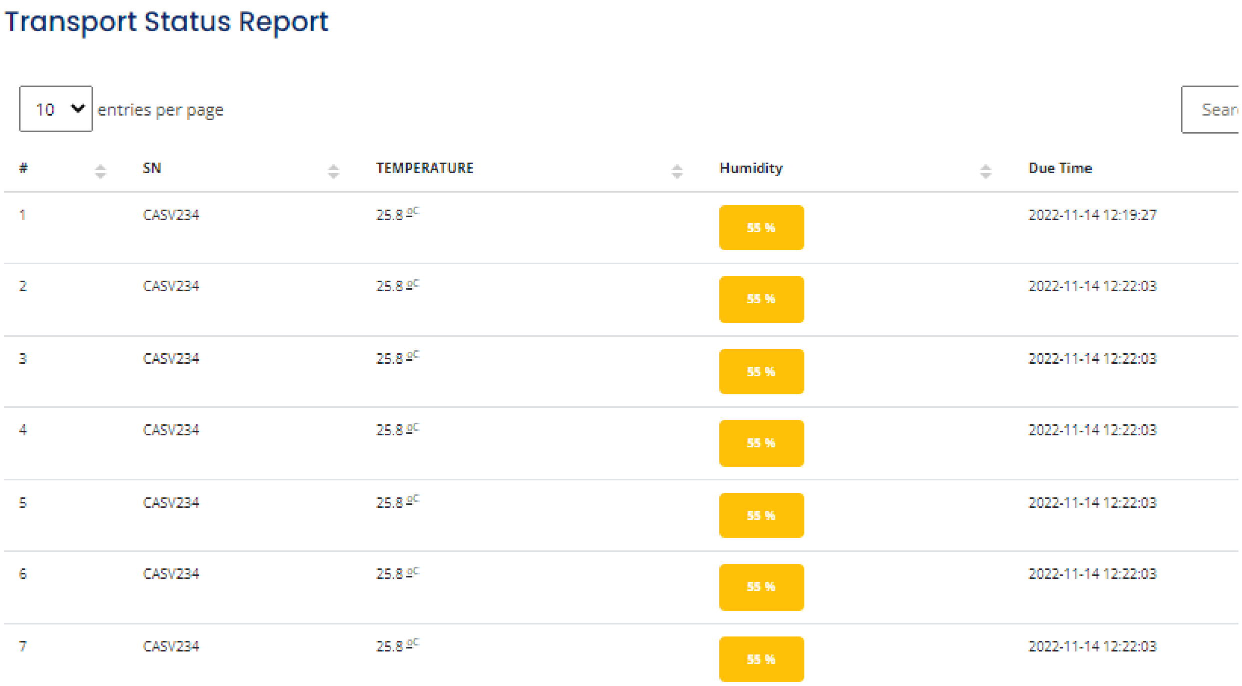
high

| # | SN | Temperature | Humidity | Flour-PH | Color | Smell | Flour Quality | Due Time |
|---|---|---|---|---|---|---|---|---|
| 722 | CASV234 | 30.2 ��C | 37 % | 7.13 | R::24 , G::28 , B::9 White Flour | 709 ppm | 80 % HIGH | 2022-11-14 12:22:03 |
| 723 | CASV234 | 30.2 ��C | 37 % | 7.13 | R::24 , G::28 , B::9 White Flour | 706 ppm | 80 % HIGH | 2022-11-14 12:22:03 |
| 724 | CASV234 | 30.3 ��C | 36 % | 7.13 | R::25 , G::29 , B::9 White Flour | 705 ppm | 80 % HIGH | 2022-11-14 12:22:03 |
| 725 | CASV234 | 30.8 ��C | 36 % | 7.13 | R::25 , G::29 , B::9 White Flour | 706 ppm | 80 % HIGH | 2022-11-14 12:22:03 |
| 726 | CASV234 | 30.8 ��C | 36 % | 7.13 | R::25 , G::30 , B::9 White Flour | 719 ppm | 80 % HIGH | 2022-11-14 12:22:03 |
| 728 | CASV234 | 31.3 ��C | 34 % | 7.13 | R::25 , G::29 , B::9 White Flour | 718 ppm | 80 % HIGH | 2022-11-14 12:22:03 |

**Figure 16: Cassava flour quality as High**

The figure above clearly shows that the cassava flour quality measured was high.

### 5.2.5. Parameters measured at Transportation Level



Transport Status Report

10 entries per page

Sear

| # | SN | TEMPERATURE | Humidity | Due Time |
|---|---|---|---|---|
| 1 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:19:27 |
| 2 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |
| 3 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |
| 4 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |
| 5 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |
| 6 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |
| 7 | CASV234 | 25.8 ºC | 55 % | 2022-11-14 12:22:03 |

Figure 17: Figure at transportation Level.

This figure shows the parameters measured during transportation of cassava products. The parameters are temperature and humidity inside the track. The temperature at transportation level best for cassava is between 20°C and 40°C. If the temperature is above or below the threshold values, the alert message is sent to the driver and the owner of cassava products.
Additionally the normal humidity inside truck is between 0% to 50%. If the humidity is outside of the threshold values, the alert message is sent to the driver and the owner of cassava products.

### 5.2.6. Greenhouse gases detection

Environmental Status Report

Monitoring Report

10 entries per page

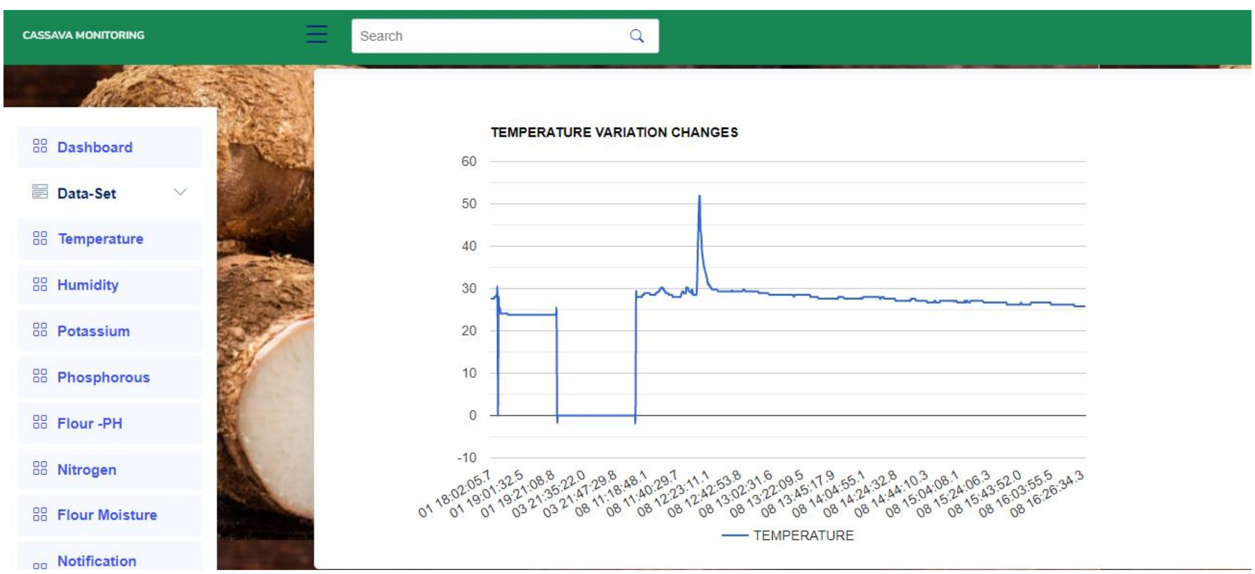
| # | SN | TEMPERATURE | Humidity | $CO_2$ | NH4 | $N_2O$ | Due Time |
|---|---|---|---|---|---|---|---|
| 1 | CASV234 | 25.8 ºC | 55 | 7.21 % | 0 % | 0 % | 2022-11-14 12:19:27 |
| 2 | CASV234 | 25.8 ºC | 55 | 7.22 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 3 | CASV234 | 25.8 ºC | 55 | 7.08 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 4 | CASV234 | 25.8 ºC | 55 | 7.14 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 5 | CASV234 | 25.8 ºC | 55 | 7.22 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 6 | CASV234 | 25.8 ºC | 55 | 7.22 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 7 | CASV234 | 25.8 ºC | 55 | 7.08 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 8 | CASV234 | 25.8 ºC | 55 | 7.21 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 9 | CASV234 | 25.8 ºC | 55 | 7.08 % | 0 % | 0 % | 2022-11-14 12:22:03 |
| 10 | CASV234 | 25.8 ºC | 55 | 7.22 % | 0 % | 0 % | 2022-11-14 12:22:03 |

Figure 18: Greenhouse gases detection

This figure shows the greenhouse gases and other environmental parameters detected in industrial processing of cassava products. The gases are CO2, NH4, N2O and the environmental detected are temperature and humidity.

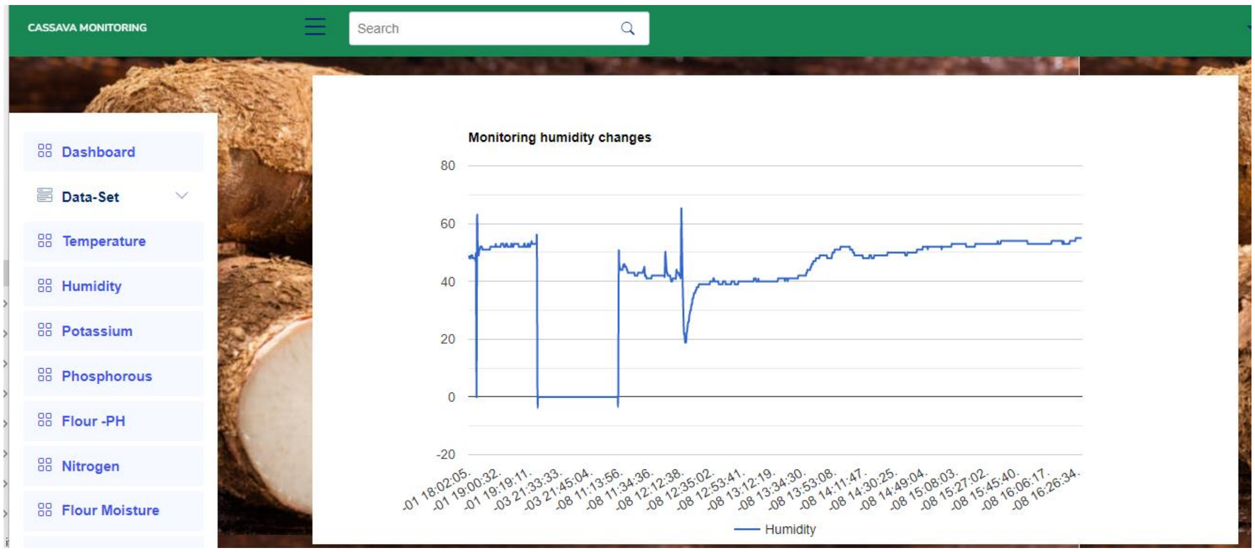
### 5.2.7. Temperature and Humidity changes charts

**Figure 19: Temperature variations**



This figure shows the variation of temperature during the control of quality of cassava products.

Figure 20: Humidity variations




This figure shows the variation of humidity during the control of quality of cassava products.

### 5.2.8. Soil Nitrogen measurements

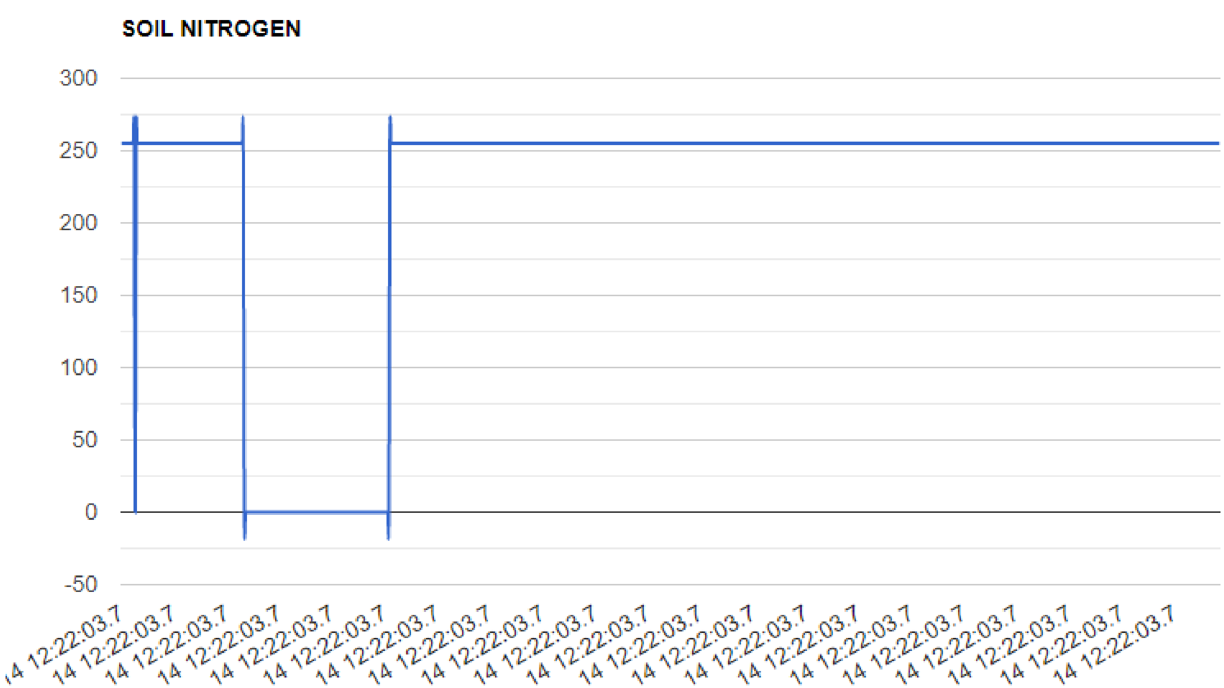



**Figure 21: Soil Nitrogen changes**

This figure shows the variation of Nitrogen during the control of quality of the soil before starting cassava plantations.

#### 5.2.9. Soil Potassium Changes

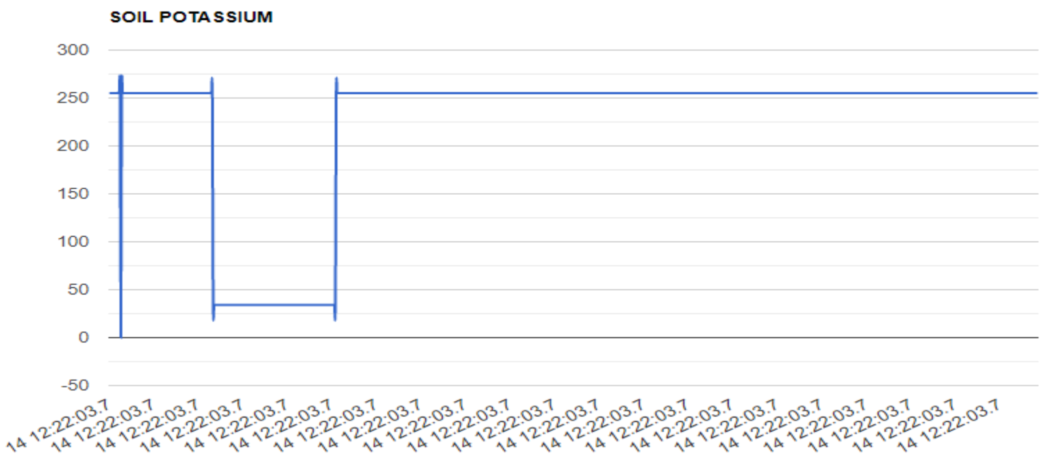



**Figure 22: Soil potassium changes**

This figure shows the variation of potassium during the control of quality of the soil before starting cassava plantations.

#### 5.2.10. Soil Phosphorus changes

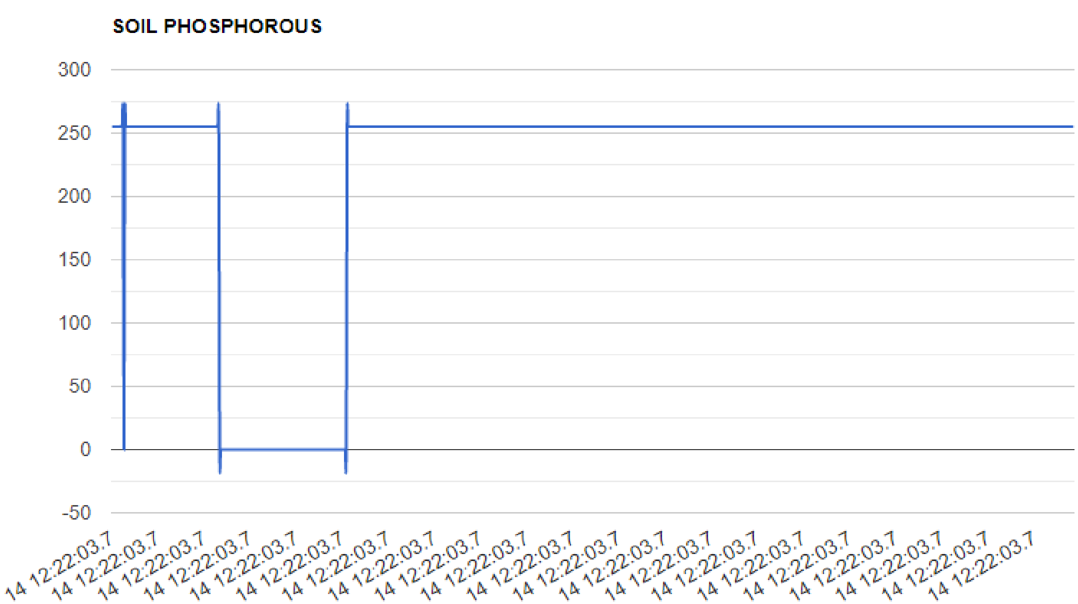



**Figure 23: Soil Phosphorus changes**

This figure shows the variation of phosphorus during the control of quality of the soil before starting cassava plantations.

### 5.2.11. Cassava Flour PH changes

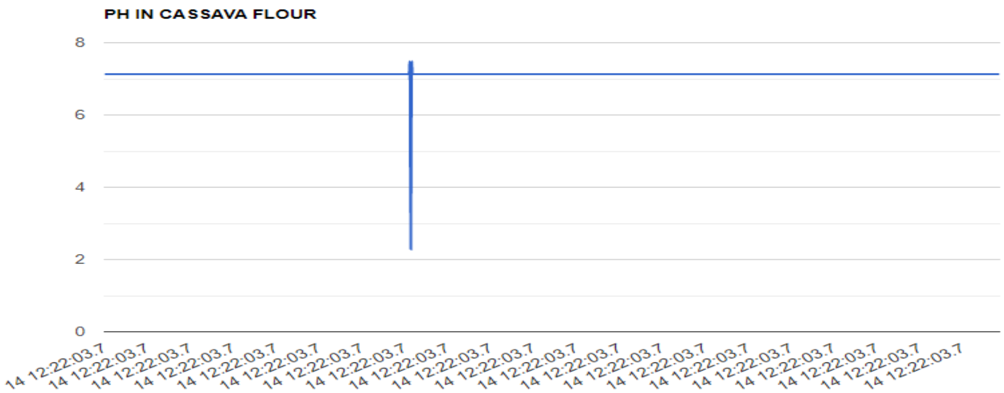



**Figure 24: Cassava Flour PH changes**

This figure shows the variation of cassava flour ph during the cassava products quality control.

### 5.2.12. Moisture sensor data during cassava flour testing

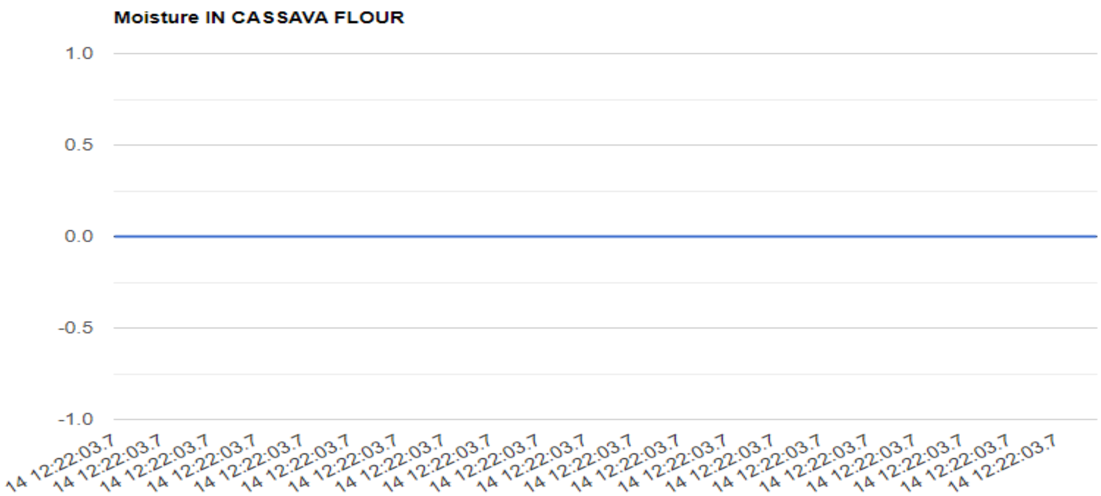



**Figure 25: Moisture content of the Cassava flour**

This figure shows the variation of cassava flour moisture during the cassava products quality control.

### 5.3. Prototype efficiency

The prototype is made up of sensors that collect data for cassava fertile soil detection, cassava flour quality detection and greenhouse gases control. It displays in the LCD the quality of the soil, the quality of flour and the gases that may harm the environment. At farming level data are displayed into LCD and the cloud too to show that the soil is fertile or not. The farmer has to decide whether to grow cassava or not in consideration of the soil quality. At processing level, the combination of measured parameters display the quality of cassava flour in the LCD of the device and store them into the cloud for auditing purpose and future researches. The SMS is directly sent to the processing industry owner for the current status of the flour in production.

At market level, this is the phase where consumers (customers who can buy cassava flour for consumption in their homes or families, small-scale business owners, corporation that sell cassava flour) come to take the final product. The device is used to measure the conditions in the room/store of cassava flour and shows whether it is of high quality, medium quality and low quality. This information is displayed into two languages to facilitate the buyers to understand what the device displays.

Languages are: Kinyarwanda and English. Below is the information displayed into the LCD:

- High Quality flour/Ifu ni nzima
- Medium Quality flour/Ifu ni nzima
- Low quality flour/Ifu si nzima.

Which means the set of the values(Humidity, ph, temperature, color, and smell) detected by the device are called **“iss.”** The decision is made as the following: If **iss**<=100% and **iss**>=70%, the cassava flour quality is **high**. Also if **iss**<=79% and **iss**>=50%, the cassava flour quality is **Medium**, and Finally, if **iss**<50, the quality of cassava flour is **low**

At transportation Level the device detect the temperature and Humidity. If the temperature is high or low to the level of harming cassava roots or flour, the device will play a sound and send the message to the truck’s driver transporting the product. This remains the case when the humidity is high or low.

The device comprises four USB ports where three are reserved for sensors and one USB port for solar panel. Some sensors like MQ=135 and NPK measure may parameters when plugged only in one port. Additionally the device has 3 power sources such as: Electrical power source, Battery power source and solar power source to maintain powered even when it is deployed in environment where there is no electrical power or it may switch off due to the lack of power.

# CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

## 6.1. Conclusion

An IoT-Based Quality monitoring system for the cassava value chain collects data about the soil status. The combination of those data determines the soil quality that is good or bad for growing cassava. The information displayed in the LCD shows good or bad for cassava and is sent to the cloud's dashboard for future consultation. The cassava value chain passes through different phases that, after farming, comes processing, transportation, and market level. The device detects the quality of cassava flour in case it is high, medium, or low at the processing and market level. The information is displayed in two languages, English and Kinyarwanda, to facilitate the readers. It is also sent to the cloud's dashboard for future consultations. During transportation, the device records temperature variations and humidity. It sends alert SMS to the Truck Driver and the owner of cassava products whenever the temperature is high or low, humidity high or low to harm the products. The information is sent to the dashboard too. The medium to send data to the cloud is GSM/GPRS via Arduino Uno as the microcontroller. During processing, greenhouse gases are also monitored to prevent environmental harm by them, hence planet earth's protection against climate change.

This device has a crucial impact in Rwanda and other African countries, even worldwide, because using it is the source of zero hunger and zero poverty in the population. It helps farmers to produce mass cassava on their farms without any loss. It also enables cassava product consumers to consume high-quality cassava flour and protect their health. Cassava and its derived products are made affordable due to mass production. Cassava products that are thrown into the environment because they have become harmful to the health of the consumers are not yet rejected as the parameters are real-timely controlled, which is the source of increase in the economy for cassava processing industries, small-scale businesses, and cassava selling corporation plus trustworthy at the national and international level.

## 6.2. Recommendations

The following are the recommendations after conducting this research on the implementation of an IoT-Based Quality monitoring system in cassava value chain:

The authorities are requested to organize awareness campaign for farmers to understand the availability and the importance of the device.

The device detects the quality of the soil fertile for cassava, the quality of cassava products at the industrial processing and at the market level, the detection of greenhouse gases are possible for the device. However, the future researchers are recommended to enhance the work on smart irrigation mechanisms for cassava crops, smart cooling systems inside the industrial processing and storage of cassava products and the mechanisms in which greenhouse gases should be reduced during cassava products productions without affecting the production processes.

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# APPENDICES

Date: mm/dd/yyyy [Download]
Date: mm/dd/yyyy [Refresh]

| Date | NITROGEN (mg/kg) | PHOSPHORUS(mg/kg) | POTASSIUM(mg/kg) | SOIL MOISTURE(%) | TEMPERATURE(°C) |
|---|---|---|---|---|---|
| 20/10/2022 17:59:31 | 16 | 21 | 36 | 16.52 | 24.38 |
| 20/10/2022 17:59:22 | 16 | 21 | 54 | 16.62 | 25.00 |
| 20/10/2022 17:59:12 | 16 | 21 | 54 | 16.62 | 24.44 |
| 20/10/2022 17:59:02 | 16 | 22 | 55 | 16.62 | 25.06 |
| 20/10/2022 17:58:53 | 15 | 21 | 55 | 16.62 | 25.00 |
| 20/10/2022 17:58:43 | 15 | 21 | 53 | 16.72 | 24.50 |
| 20/10/2022 17:58:33 | 15 | 21 | 53 | 16.42 | 25.00 |
| 20/10/2022 17:58:24 | 15 | 21 | 53 | 16.42 | 24.94 |
| 20/10/2022 17:58:14 | 15 | 21 | 53 | 16.42 | 24.88 |
| 20/10/2022 17:58:04 | 15 | 21 | 53 | 27.66 | 24.94 |
| 20/10/2022 17:57:55 | 15 | 21 | 53 | 27.66 | 24.81 |
| 20/10/2022 17:57:47 | 15 | 21 | 53 | 27.66 | 24.88 |
| 20/10/2022 17:57:36 | 0 | 20 | 47 | 16.52 | 24.13 |
| 20/10/2022 17:57:26 | 0 | 0 | 0 | 16.23 | 24.63 |
| 20/10/2022 17:57:16 | 0 | 0 | 0 | 15.64 | 24.44 |
| 20/10/2022 17:57:06 | 0 | 0 | 0 | 15.44 | 24.56 |
| 20/10/2022 17:55:43 | 0 | 0 | 0 | 27.66 | 23.69 |
| 20/10/2022 17:55:34 | 0 | 0 | 0 | 27.66 | 24.31 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 31/10/2022 17:59 | 32 | 44 | 110 | 69.7 | 24.19 | 9.78 |
| 31/10/2022 17:58 | 32 | 44 | 110 | 70.09 | 24.19 | 9.78 |
| 31/10/2022 17:58 | 32 | 44 | 110 | 72.14 | 24.06 | 9.78 |
| 31/10/2022 17:58 | 26 | 35 | 62 | 81.43 | 23.5 | 11.78 |
| 31/10/2022 17:58 | 26 | 35 | 88 | 88.76 | 24.19 | 11.78 |
| 31/10/2022 17:58 | 26 | 35 | 88 | 82.6 | 24.13 | 11.78 |
| 31/10/2022 17:58 | 26 | 35 | 88 | 68.62 | 24.19 | 11.78 |
| 31/10/2022 17:57 | 28 | 38 | 95 | 68.62 | 24.19 | 13.78 |
| 31/10/2022 17:57 | 27 | 37 | 93 | 68.62 | 24.13 | 12.78 |
| 31/10/2022 17:57 | 27 | 37 | 93 | 68.62 | 23.63 | 12.78 |
| 31/10/2022 17:57 | 27 | 37 | 92 | 68.91 | 24.19 | 12.78 |
| 31/10/2022 17:57 | 27 | 37 | 92 | 68.82 | 24.25 | 12.78 |
| 31/10/2022 17:57 | 27 | 37 | 92 | 69.01 | 24.25 | 12.78 |
| 31/10/2022 17:56 | 27 | 37 | 92 | 69.01 | 23.63 | 12.78 |
| 31/10/2022 17:56 | 24 | 33 | 90 | 69.31 | 24.25 | 9.78 |
| 31/10/2022 17:56 | 30 | 41 | 103 | 69.5 | 24.06 | 15.78 |
| 31/10/2022 17:56 | 30 | 41 | 103 | 69.89 | 24 | 15.78 |
| 31/10/2022 17:56 | 30 | 41 | 102 | 71.46 | 23.56 | 15.78 |
| 31/10/2022 17:56 | 26 | 21 | 89 | 82.11 | 24.31 | 11.78 |
| 31/10/2022 17:55 | 27 | 33 | 76 | 70.97 | 24 | 12.78 |
| 31/10/2022 17:55 | 27 | 37 | 94 | 74.49 | 24.13 | 12.78 |
| 31/10/2022 17:55 | 25 | 28 | 0 | 68.52 | 24.13 | 10.78 |