ULK POLYTHECHNIC INSTITUTE

POBOX 2280 KIGALI

Website: //www.ulkpolythechnic.ac.rw

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

OPTION: ELECTRONICS AND TELECOMMUNICATION TECHNOLOGY

DESIGN AND IMPLEMENTATION OF A SMART MAIZE CROP STORAGE MONITORING SYSTEM

Final project submitted in partial fulfilment of the requirement for the award of an Advanced Diploma in Electronics and Telecommunication Technology.

Submitted by: **ALINE UKEYE**

Roll number: 202150452

Supervisor: Eng. KARANGWA Augustin

Kigali, September 2024

DECLARATION-A

I, here declare that we carried out the work reported in this report in the Department of Electrical and Electronics Engineering at **UPI** under the supervision of **Eng. KARANGWA Augustin**. I solemnly declare that to the best of my knowledge, no part of this report has been submitted here or elsewhere in a previous application for an award of an academic qualification. All sources of knowledge used have been duly acknowledged

Names: ……………………….

Roll number:

Date: ………. /September /2024

Signature: ....

DECLARATION- B

I confirm that the work reported in this research project, was carried out by the candidate under my Supervision and it has been submitted with my approval as the UPI supervisor.

Supervisor : ………………………..

Sign: ………………………………………….

Date: ………/ ……/2024

DEDICATION

I dedicated this project to:

Almighty GOD.

My beloved parents.

My relatives.

My friends and Supervisor.

Teachers and Supervisor.

My Classmates

My brothers and sisters

ACKNOWLEDGEMENTS

First, I extend my deepest gratitude and appreciation to the Mighty Fortress, our God, a bulwark never failing, for His enduring mercies that have made this work possible. This endeavor was made achievable through the support and contributions of many individuals, to whom I am profoundly indebted.

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I am deeply thankful to all my fellow **ULK POLYTECHNIC INSTITUTE** students for their support in achieving my goals. Furthermore, I am indebted to the academic staff of the Department of **Electrical and Electronics Engineering**, as well as the entire administration of the **ULK POLYTECHNIC INSTITUTE.**

May God Almighty bless you all abundantly!

ABSTRACT

The agricultural sector in Kamonyi District, Rwanda, faces significant post-harvest losses, especially in maize storage, due to inadequate monitoring and management of essential storage conditions. During my research, I visited a store called Rumbuka Seeds in Kamonyi District, which uses a system that fills maize into slots and monitors only humidity and temperature. This limited approach highlights a gap in comprehensive monitoring, as other crucial parameters like CO_2 levels are not tracked.

To address these challenges, this project aims to develop and implement a smart maize crop storage monitoring system using the Thingspeak cloud platform. The system will utilize NodeMCU, DHT11 sensors, and smoke gas detectors to monitor key storage parameters, including temperature, humidity, and CO_2 levels. Integrating the Thing Speak platform allows the system to monitor and manage these parameters in real time effectively.

NodeMCU, a microcontroller with Wi-Fi capabilities, acts as the core unit, collecting sensor data and transmitting it to the Thingspeak cloud server. This data is then processed and stored, enabling farmers to access real-time and historical trends through a user-friendly mobile interface. This interface, provided by the Thingspeak application, allows farmers to view data, analyze trends, and receive alerts, facilitating timely interventions without needing to be physically present at the storage site.

By continuously monitoring storage conditions and providing actionable insights, the smart maize storage system aims to reduce spoilage and post-harvest losses, promote sustainable storage practices, and enhance productivity and profitability for maize farmers in Kamonyi District. The alert system within the Thingspeak platform ensures that farmers are promptly informed of adverse conditions, enabling swift corrective actions. This innovative approach leverages IoT technology and the Thingspeak cloud to provide a more efficient and reliable maize storage solution, addressing a critical need in the region's agricultural sector.

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LIST OF ABBREVIATION

GND	Ground
HOD	Head of Department
PCB	Printed Circuit Board
IDE	Integrated Development Environment
USB	Universal Serial Bus
GPIO	General Purpose input/output
HTTP	Hypertext transfer protocol
IOT	Internet of Things
ULK	University libre de Kigali
LED	Light-emitted diode
PCB	Printed circuit board
API	Application programming Interface

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

Efficient storage is vital for food security and economic stability, especially for staple crops like maize. In Rwanda’s Kamonyi District, traditional storage methods face issues like pests, mold from humidity, and poor temperature control, degrading maize quality. To address this, we developed a Smart Maize Crop Storage Monitoring System using IoT and sensors to monitor conditions like temperature, humidity, and pest activity. The system provides real-time alerts and insights through a mobile interface, helping farmers reduce post-harvest losses and protect their maize harvests.

1.1 Background of the Study

Agriculture is a cornerstone of many economies, especially in regions where maize is a primary food source. Despite the critical importance of this crop, post-harvest losses due to inadequate storage conditions remain a pervasive issue (Communities, 06/28/2016). Traditional storage facilities often lack the necessarymechanisms to control environmental factors such as temperature and humidity, which are for maintaining grain quality (Okparavero, 2024). Consequently, farmers face significant losses due to spoilage and pest infestations, which undermines food security and economic stability.

Many farmers rely on outdated and ineffective storage solutions. The lack of real-time monitoring and precise control over storage environments exacerbates the problem, leading to diminished grain quality and economic losses. The integration of modern technologies such asthe Internet of Things (IoT) and advanced sensor systems presents an unprecedented opportunity to revolutionize crop storage practices (Prem Rajak, September 2023).

The importance of this project is designed to address these critical challenges by providing a reliable solution for monitoring and managing storage conditions, thereby reducing post-harvest losses, enhancing food security, economic impact, sustainability, and technological advancement.

1.2. Statement of the problem

In Rwanda, maize is a crucial crop within the Crop Intensification Program (CIP), aimed at maximizing harvest yields on small land areas. To achieve this, farmers need to adopt modern agricultural practices such as soil testing for optimal maize productivity, proper cornfield planting techniques, efficient fertilizer usage, effective irrigation methods, and robust disease and pest management strategies. Furthermore, they must employ appropriate harvesting, filtering, and storage techniques to ensure the quality of their maize crops. Despite the importance and availability of maize, farmers continue to face significant post-harvest losses due to inadequate storage facilities. For instance, when farmers harvest 2 tons of maize, they sell a portion and store the rest. However, within just three months, the stored maize often starts to deteriorate due to factors such as moisture content, temperature (grain and air), relative humidity, storage conditions, fungal growth, and insect pests. This forces farmers to sell their remaining maize at a lower price to avoid total loss.

Farmers have expressed frustration over these storage issues, stating that their productivity and profitability are severely impacted. They seek modern storage solutions to preserve their agricultural products for extended periods and improve their livelihoods.

To address this issue, I propose to design and implement a smart maize crop storage monitoring system, which will collect sensor data and upload it to a cloud-computing server, to provide farmers with real-time information on temperature, humidity, and other critical storage conditions. Efficient monitoring without the need for physical presence at the storage site will enable farmers to take proactive measures to protect their maize harvests from pest damage and spoilage. This initiative aims to enhance the storage management of maize crops in Rumbuka seeds located at Kamonyi District, ensuring better outcomes and increased productivity for farmers.

1.3. Objectives of the Study

I conducted this study at Rumbuka Seeds in Kamonyi district, aiming to achieve the following objectives.

1.3.1. General Objective

The main general objective of the entitled ‘’Design and Implementation of Smart Maize Crop Storage Monitoring System’’ is to enhance the quality and longevity of stored maize.

1.3.2. Specific Objectives

i. To design and implement a Smart Maize Crop Storage Monitoring system

ii. To develop an intuitive interface for farmers to access real-time data, trends, and alerts via smartphone.

iii. To evaluate the system's impact on reducing maize spoilage and improving storage quality over time.

iv. To encourage the adoption of modern storage technologies among farmers in the district.

1.4 Hypotheses

The implementation of a smart maize crop storage monitoring system at Rumbuka Seeds will significantly reduce post-harvest losses by providing real-time data on critical storage conditions, enabling farmers in Kamonyi District to take timely and effective measures to preserve their maize quality, thereby enhancing their productivity and livelihoods.

1.5 Research Questions

1) How effective is the Smart Maize Crop Storage Monitoring System in minimizing post-harvest losses among farmers in Kamonyi District?

2) In what ways does the access to real-time data, trends, and alerts through a smartphone interface affect farmers' ability to manage storage conditions and make timely decisions?

3) What effect does the Smart Maize Crop Storage Monitoring System have on the quality and longevity of stored maize over time?

4) What factors influence the adoption of modern storage technologies among farmers in Kamonyi District, and what are the perceived advantages and challenges?

1.6 Significance of the Study

The importance of this study lies in providing a viable solution to the persistent issue of post-harvest losses in maize storage, particularly in Kamonyi District, Rwanda. By creating and implementing an intelligent storage monitoring system at Rumbuka Seeds, the study aims to assist farmers in minimizing spoilage, preserving grain quality, and ultimately enhancing their productivity and livelihoods. Furthermore, the study demonstrates how modern technologies such as real-time monitoring, data analysis, and cloud computing can improve traditional farming practices. The insights gained could also inspire the adoption of these technologies for other crops and regions, fostering sustainable agricultural practices, improving food security, and delivering economic and environmental benefits.

1.7 Scope and Limitations

The scope is listed to ensure the project is conducted within its intended boundary. Scope is useful to ensure the project is heading in the right direction to achieve the goal. The scope ofthis project is to study the smart maize crop storage monitoring system from several published papers and books. The main focus of this project is to apply what has already been learned about the smart maize crop monitoring system.

1.8 Project subdivision

Chapter 1: General Introduction

Chapter 2: Literature Review

Chapter 3: Research Methodology and Materials

Chapter 4: System design analysis and implementation

Chapter 5: Conclusion and Recommendation

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

The smart maize crop storage monitoring system addresses post-harvest losses caused by pests, moisture, and environmental factors. Unlike traditional methods, this IoT-based system, built on the ESP8266 NodeMCU, monitors and controls key storage conditions like temperature, humidity, and gas levels using sensors. This modern approach helps farmers protect their crops more effectively.

2.1. Related Study

Maize is a vital staple crop, but improper storage can lead to significant losses due to moisture, temperature fluctuations, and gas buildup, which contribute to mold growth, insect infestations, and mycotoxin contamination (Rashid Suleiman, July 2013). Traditional storage methods often fail to maintain optimal conditions, highlighting the need for advanced solutions. IoT has transformed agricultural practices, enabling continuous monitoring of storage conditions like CO_2, humidity, and temperature. Elevated CO_2 levels can signal grain respiration or pests, while high humidity increases the risk of fungal contamination. IoT systems regulate humidity and temperature by controlling dehumidifiers and cooling systems, as seen in smart silos and Wireless Sensor Networks (WSNs). Although challenges like power supply and setup costs exist, IoT offers a promising solution for reducing post-harvest losses and ensuring food security.

2.2 Concepts, Opinions, And Ideas from Authors

Designing and implementing a smart maize storage or warehouse monitoring system involves incorporating various concepts and ideas from specialists. Here are some key aspects and insights that professionals might highlight:

2.3 Sensor Technologies

2.3.1. Temperature Sensors

Temperature plays a critical role in maize storage. High temperatures can promote fungal growth and insect activity, leading to spoilage. Various types of temperature sensors, such as thermocouples, thermistors, and digital temperature sensors (e.g., DS18B20), are used to monitor and control the storage environment.

2.3.2. Humidity Sensor

Humidity is another crucial factor in maize storage. High humidity levels can lead to mold growth, while low levels can cause drying and weight loss. Sensors like DHT11, DHT22, and hygrometers are commonly used to measure relative humidity in storage facilities.

2.3.3. Gas Sensors

Monitoring gases such as carbon dioxide (CO2) and oxygen (O2) can help in detecting spoilage and respiration rates of stored maize. Sensors like MQ135 and O2 sensors are employed for this purpose.

2. 4. Theoretical perspectives

The Smart Maize Crop Storage Monitoring System draws on several key theoretical perspectives to address the challenges of post-harvest losses in maize storage, particularly in the context of rural agricultural settings like Kamonyi District at Rumbuka Seeds, Rwanda. These perspectives help in understanding the underlying principles that guide the design, implementation, and expected outcomes of the system.

1. Post-Harvest Loss Theory

Post-harvest loss theory examines the various factors that lead to the deterioration of agricultural products after harvest. This theory emphasizes the importance of proper storage, handling, and management to minimize losses and maintain the quality of crops (GROLLEAUD). The Smart Maize Crop Storage Monitoring System is grounded in this theory, as it aims to reduce post-harvest losses by addressing key factors such as pest infestations, moisture control, and temperature regulation. By providing real-time monitoring and alerts, the system enables farmers to take timely actions that prevent spoilage and preserve the quality of their maize.

2. IoT and Precision Agriculture Theory

The integration of IoT (Internet of Things) into agricultural practices is a growing trend, supported by the theory of precision agriculture. This theory advocates for the use of technology to optimize farming practices, reduce waste, and increase efficiency. The Smart Maize Crop Storage Monitoring System is an application of this theory, utilizing IoT devices to gather and analyze data on storage conditions. By enabling precise control over environmental factors such as humidity and temperature, the system helps farmers maintain ideal storage conditions and prevent losses.

3. Food Security and Sustainable Agriculture Theory

Food security theory highlights the importance of ensuring a reliable and adequate supply of food, particularly in regions where agriculture is the primary source of sustenance. Sustainable agriculture theory, on the other hand, focuses on the need to adopt farming practices that are environmentally sound, economically viable, and socially responsible (Karolina Pawlak, 2020). The Smart Maize Crop Storage Monitoring System contributes to these goals by reducing post-harvest losses, thus ensuring a more consistent food supply and supporting the economic stability of farming communities. Additionally, by promoting efficient storage practices, the system aligns with sustainable agriculture principles by minimizing resource wastage and enhancing the long-term viability of maize production.

4. Behavioral Change Theory

Behavioral change theory highlights the role of user-friendly design, accessibility, and training in adopting new technologies. The Smart Maize Crop Storage Monitoring System integrates these elements, offering an intuitive interface and farmer training, ensuring effective use and reducing post-harvest losses, ultimately improving farmers' livelihoods.

5. Systems Theory

Systems theory views agricultural storage as a complex system with interacting components like storage structures, environment, and human management. The Smart Maize Crop Storage Monitoring System embodies this approach by integrating factors like temperature, humidity, and pests into one platform, improving the overall efficiency and effectiveness of maize storage.

2.4.1. IOT System (Internet of Things)

The Internet of Things (IoT) connects physical devices, like appliances and vehicles, through sensors, software, and internet connectivity, enabling real-time data collection and remote control. This reduces the need for human intervention and boosts efficiency. By integrating sensors and actuators, IoT forms the backbone of innovations like smart homes, cities, grids, and environmental monitoring systems. These sensors track air, soil, and water quality, aid in wildlife monitoring, and provide early warnings for natural disasters. IoT devices, often equipped with wireless modules, can operate in remote areas, expanding their applications across diverse fields.

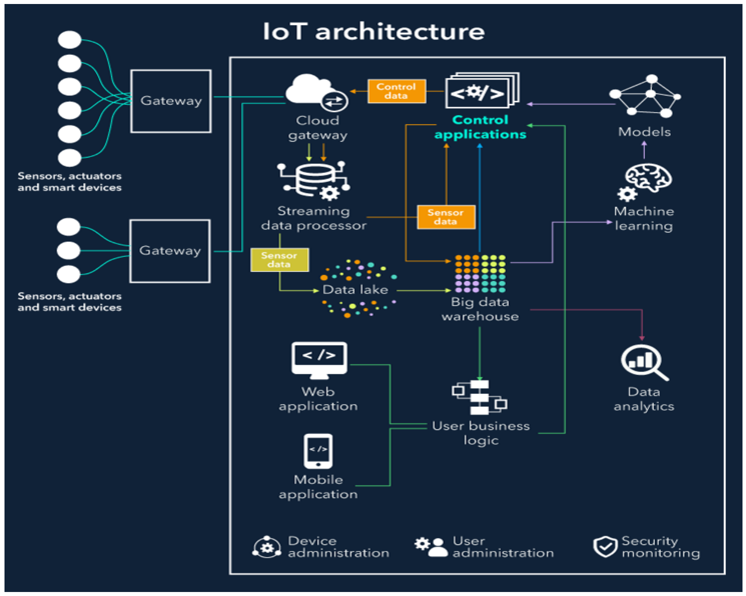


Figure 1:IOT Architecture

IoT technology is essential for maize crop storage. This research introduces an IoT-based system to monitor storage conditions via a handheld terminal, providing daily updates. The system addresses issues with traditional methods, focusing on temperature, humidity, and CO2 monitoring to maintain maize quality. Paired with an Android app, it ensures real-time monitoring and proactive management, reducing post-harvest losses.

2.4.2. Hardware Components

- **NodeMCU ESP 8266**

According to Huang, S. (2015), The esp8266 stands as an incredible microcontroller and Wi-Fi module, created by express IF systems, that has become a foundation in the dominion of the Internet of Things (IoT). This compact powerful device integrates a 32-bit Tensillica microcontroller, offering robust processing capabilities, and a built-in WI-FI module for seamless connectivity. Its key features include low power consumption, making it suitable for battery-powered applications, and GPIO pins that enable interfacing with an array of sensors and actuators. Programming flexibility is a standout feature, allowing developers to code using the Arduino IDE or Express if's IoT development framework (esp-idf). Notably, the esp8266 is embraced for its affordability, making it accessible to hobbyists, students, and professionals alike. The support of an active community ensures a wealth of resources, tutorials, and libraries for developers. For those delving into IOT projects like the warehouse monitoring system, the esp8266 emerges as an invaluable component, enabling real-time data processing and efficient communication.

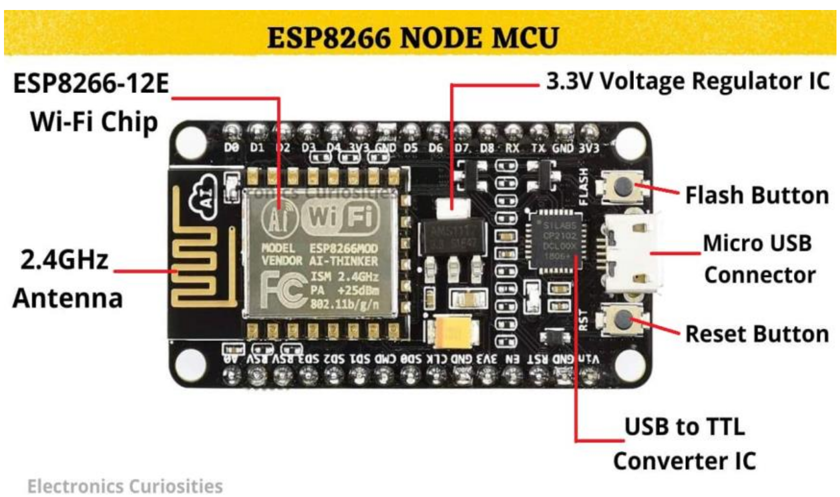


Figure 2: Node MCU

2.4.3 Temperature and Humidity Sensor

Temperature and humidity play a crucial role in preserving maize crops. Maintaining an optimum temperature is essential to prevent crop losses in granaries. The operation of a temperature sensor relies on the voltage across a diode, where temperature changes are directly proportional to the diode's resistance. This resistance is measured and converted into readable temperature units for display. Humidity sensors further enhance predictive analytics accuracy by detecting changes that affect electrical currents or air temperature. For monitoring temperature and humidity levels in warehouses storing maize, the DH11 sensor is installed. It measures bothrelative humidity and temperature, allowing for the establishment of minimum and maximum temperature ranges optimal for maize storage. Monitoring humidity is also critical, as excessive moisture in the air can promote mildew growth on crops.

The DHT11 sensor's humidity sensing component consists of a moisture-holding substrate with electrodes applied to its surface. When water vapor is absorbed by the substrate, ions arereleased, increasing the conductivity between the electrodes. The change in resistance between these electrodes is proportional to the relative humidity: higher humidity decreases the resistance, while lower humidity increases it. The DHT11 sensor converts this resistance measurement to relative humidity using a chip mounted on the back of the unit, and thentransmits both humidity and temperature readings directly to an Arduino Nano.

To initiate communication with the DHT11, a start pulse is first sent to the sensor. Upon receiving this start pulse, the DHT11 sends a response pulse back to the microcontroller, indicating that it is ready to transmit data. The sensor then sends the data, which includes the humidity and temperature values along with a checksum for verification. In a smart maize crop storage monitoring system, accurately measuring and controlling humidity is crucial to prevent mold and mildew growth, which can spoil the crops. By using the DHT11 sensor, real-time monitoring of the warehouse environment is achieved, ensuring that bothtemperature and humidity levels remain within optimal ranges for long-term maize preservation.

The Humidity of the warehouse is calculated using the formula.

$$RH = \left(\frac{\rho_w}{\rho_s}\right) x\ 100\%$$

$RH: \ Relative\ Humidity$

$\rho_w: \ Density\ of\ water\ vapor$

$\rho_s: \ Density\ of\ water\ vapor\ at\ saturation$

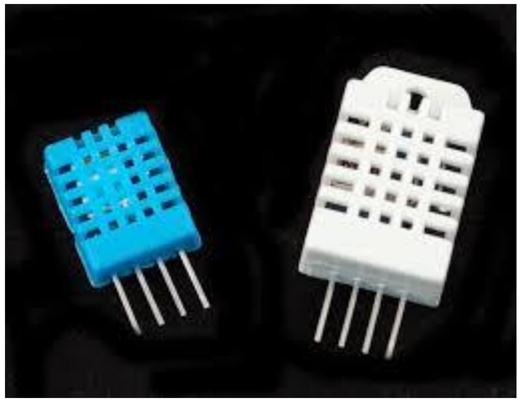


Figure 3:Temperature And Humidity Sensor

(nodemcu 8266 pinout rodnal, J. (. (2019)

2.4.4 Gas Detection Sensor

A gas detector is a device that detects the presence of gases in an area, often as part of a safety system. It can be used to monitor and measure specific gas levels, including hazardous gases, in the air. The primary function of a gas detector is to alert users to dangerous levels of gases, which can be toxic, flammable, or explosive.

Figure 4:Gas Detection Sensor

(Smith J. .., (2015))

In agricultural fields, gases such as nitrous oxide (NO), carbon dioxide ($CO2$), and methane ($CH4$) are commonly released. The MQ2 sensor can detect these gases, along with LPG, smoke, alcohol, propane, hydrogen, and carbon monoxide concentrations ranging from 200 to 10,000 ppm. Operating on 5V DC and drawing around 800mW, the sensor features a stainless steelmesh for explosion prevention and particle filtration. It uses a voltage divider network to measure gas concentrations based on changes in resistance when exposed to gases. Calibration involves adjusting a potentiometer to set the sensitivity.

Implementing the MQ2 sensor in a smart maize crop monitoring system allows for real-time detection of hazardous gases and smoke in storage warehouses. By alerting users when gas levels exceed safe thresholds, the system helps prevent crop loss and ensures safer post-harvest storage conditions.

2.4.6 LCD (Liquid Crystal Display)

An LCD (Liquid Crystal Display) plays a crucial role in providing real-time visual feedback on various parameters such as temperature, humidity, and gas levels detected by sensors like the MQ2. The LCDs this data clearly, enabling users to monitor the conditions inside storagewarehouses effectively. By showing immediate alerts for any detected anomalies, such as high gas concentrations or temperature spikes, the LCD helps in making timely decisions to protectthe stored maize from spoilage or damage. This ensures that users can maintain optimal storage conditions and prevent significant post-harvest losses.

Figure 5:LCD (Liquid Crystal Display)

(Smith A. , . (2018).)

2.4.7 Bulb

A **bulb** can play a crucial role in maintaining optimal storage conditions for maize. The bulb provides heat to ensure that the temperature inside the storage area stays within a range that prevents moisture buildup, which could otherwise lead to mold growth and spoilage. By integrating a bulb with sensors that monitor temperature and humidity, the system can automatically regulate storage conditions based on real-time data.

When the temperature drops below a set threshold, the bulb turns on to gently warm the storage environment, reducing humidity levels and keeping the maize dry. This automated control mechanism helps preserve the quality and extend the shelf life of the stored maize by preventing conditions that promote spoilage. Using a bulb instead of a traditional heater offers a more energy-efficient and cost-effective solution for smaller-scale storage setups, while still ensuring reliable temperature control.

Figure 6: A Bulb

(Johnson, (2015).)

2.4.8. Fans

Fans are crucial for maintaining optimal storage conditions by regulating airflow and temperature. Proper ventilation helps prevent the accumulation of moisture, which can lead to mold growth and spoilage. By circulating air, fans help to evenly distribute temperature and humidity throughout the storage area, ensuring that no pockets of warm or humid air develop.

The fans can be integrated with sensors that monitor temperature, humidity, and gas levels. When these sensors detect that the temperature or humidity exceeds safe levels, the system can automatically activate the fans to improve ventilation and restore the desired conditions. This automated response not only helps in maintaining the quality and shelf life of the stored maize but also prevents potential issues such as pest infestations and fungal growth. By ensuring consistent and adequate airflow, fans are a key component in protecting post-harvest crops from significant loss.

Figure 7:Fan

([Hood, 2000)

2.4.9 Jumper Wire

A **jump wire** (also known as **jumper**, **jumper wire**, **DuPont wire**) is an electrical wire, or group of them in a cable, with a connector or pin at each end (or sometimes without them – simply "tinned"), which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering. Individual jump wires are fitted by inserting their "end connectors" into the slots provided in a breadboard, the header connector of a circuit board, or a piece of test equipment.

Figure 8::Stranded 22awg Jump Wires With Solid Tips

(Bird, J. (2010))

Solid tips: are used to connect on/with a breadboard or female header connector. The arrangement of the elements and ease of insertion on a breadboard allows for increasing the mounting density of both components and jump wires without fear of short circuits. The jump wires vary in size and color to distinguish the different working signals. (Bird, J. (2010))

2.4.10 Resistors

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time, act to lower voltage levels within circuits. Resistors may have fixed resistances or variable resistances, such as those found in thermistors, varistors, trimmers, photo resistors, and potentiometers.

Figure 9:Fixed Resistor

(nodemcu 8266 pinout rodnal, J. (. (2019)

2.4.11 Relay Module

This is a 2 Channel 5V Relay interface board, that can control various appliances (For example Lamp for a motor and other equipment with a large current). It can be controlled directly by Microcontroller (for Arduino, 8051)

1. 5V 2-Channel Relay interface board and each one needs 15-20mA Driver Current
2. Equipped with high-current relay, AC250V 10A; DC30V 10A
3. Standard interface that can be controlled directly by microcontroller (8051, AVR, PIC, DSP, ARM, ARM, MSP430, TTL logic)

Figure 10:relay module

2.4.12 Printed Circuit Board

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads, and other features etched from copper sheets laminated onto a non-conductive substrate. Components (e.g. capacitors, resistors, or active devices) are generally soldered on the PCB. Advanced PCBs may contain components embedded in the substrate. The printed circuit board is the most common name but may also be called "printed wiring boards" or "printed wiring cards". PCB is an acronym for printed circuit board ([Seri, 1995.)

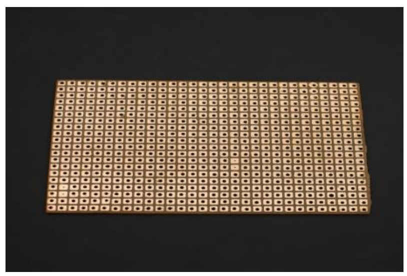


Figure 11:Printed Circuit Board

(Seri, 1995)

It is a board that has lines and pads that connect various points. In the picture above, some traces electrically connect the various connectors and components, A PCB allows signal and power to be routed between physical devices. PCBs can be single-sided (one copper layer), double-sided (two copper layers), or multi-layer (outer and inner layers). Conductors on different layers are connected with Multi-layer PCBs allowing for much higher component density (Seri, 1995)

2.5 SOFTWARE USED

2.5.1. Arduino IDE

The Arduino Integrated Development Environment (IDE) is a cross-platform application (for Windows, Mac OS, and Linux) that is written in functions from C and C++. It is used to write and upload programs to Arduino-compatible boards, but also, with the help of third-party cores, other vendor development boards. In this project, Arduino IDE was used in writing and uploading the program to Arduino Mega 2560 [John, M.(2019)].

2.6. Thingspeak

Thingspeak is a powerful IoT cloud platform that plays a crucial role in the "Design and Implementation of a Smart Maize Crop Storage Monitoring System." It enables real-time monitoring of environmental conditions such as temperature, humidity, and gas levels within the storage facility. Through the use of sensors like the DHT11 for temperature and humidity and gas detectors for CO2 levels, data is collected and transmitted to the Thingspeak platform using a microcontroller like NodeMCU. Once the data reaches the Thingspeak cloud, it is stored and visualized through user-friendly graphs and charts, allowing users to track trends and monitor conditions remotely on their smartphones or computers. This remote access feature ensures that farmers or facility managers can receive alerts whenever storage conditions deviate from the optimal range. Additionally, Thingspeak can be integrated with other devices, such as fans or dehumidifiers, enabling automatic control of the storage environment based on sensor readings. This helps maintain ideal conditions, reducing post-harvest losses and improving maize storage management.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodology for developing the Smart Maize Crop Storage Monitoring System in Kamonyi District. It covers the case study location, data collection, and data analysis methods. The methodology is organized into three areas: devices (hardware components), programming (software and integration using the Thingspeak platform), and procedural steps (design, testing, and deployment). These elements work together to create an effective system for monitoring and managing maize storage conditions in rural communities.

3.2 Case Study Location

The case study focuses on Kamonyi District, specifically in Rwabashyashya, where I visited Rumbuka Seeds stock. This facility stores maize and utilizes DHT sensors to monitor crucial environmental data.

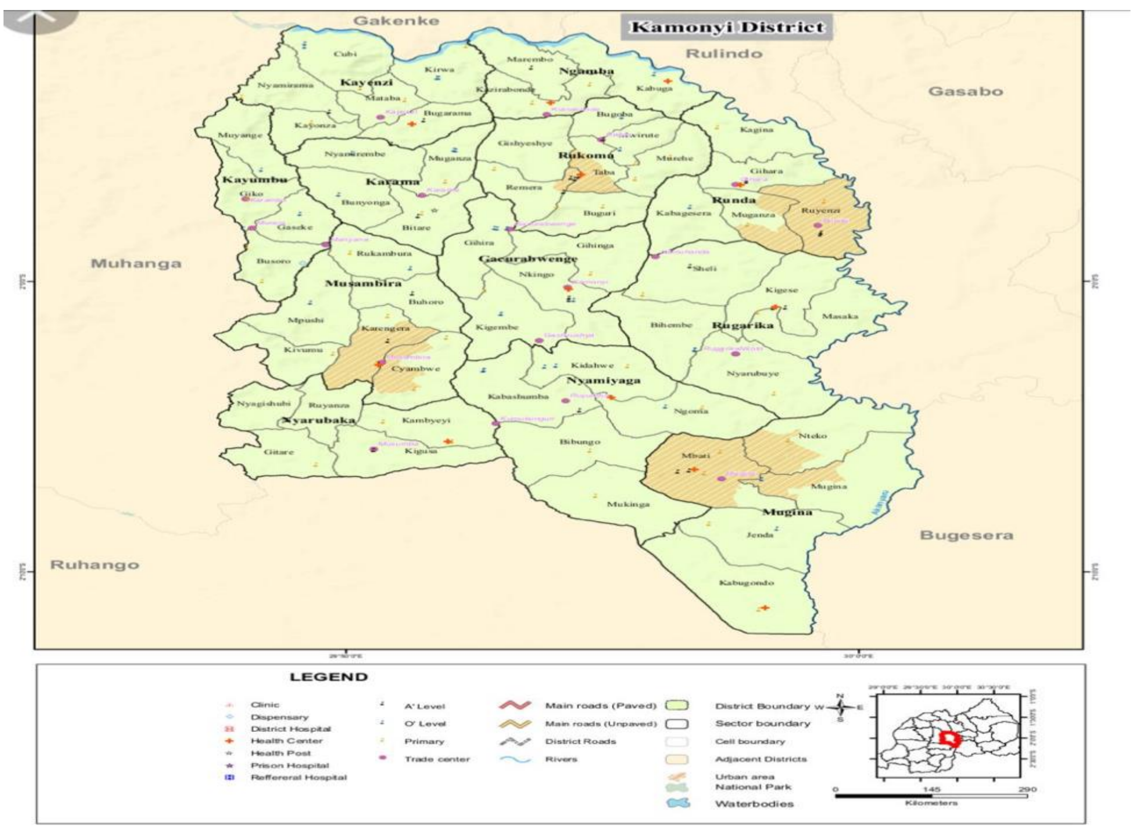


Figure 12: Map of Kamonyi District

([(--w35daa-11ae0.jpg 1714478873, 2017)])

3.3 Data Collection

3.3.1. Primary Data Collection

Primary data are those collected directly by researchers from sources, ensuring their unique and firsthand nature. These data significantly influence the research outcomes, necessitating meticulous collection methods. In Rumbuka Seeds in Kamonyi district, I employed several techniques to gather primary data, with the primary methods being observation and interviews.

The data gathered focuses on the "Rumbuka Seeds" storage facility in Kamonyi District, detailing how the facility operates and the methods it uses to store maize produce to prevent rapid quality loss. It includes information on the size and construction of the storage facility and the techniques employed for maize storage, highlighting whether modern technology or traditional methods are in use. Additionally, the data provides an overview of the management practices within the facility, particularly in terms of preserving maize produce to maintain its quality over time. This information offers valuable insights into effective maize management practices and illustrates the operational and organizational approaches of the facility.

3.3.2 Observation

During my visit to Rumbuka Seeds in Kamonyi District, I observed that their modern and well-maintained storage facility reflects good stock management practices. Using the observation method, I assessed the requirements for properly storing maize produce with modern techniques, such as arranging the maize in slots. Although the maize is stored well and lasts longer with a sensor that measures temperature and humidity, the facility is equipped with only one sensor. This may not be sufficient to ensure optimal storage conditions across the entire stock.

3.3.3 Interview

In my interview with the manager of Rumbuka Seeds and the stock manager, we focused on several key issues: the operation of their stock system and the methods used to store maize, the common challenges encountered during maize storage, the practices employed to maintain maize quality within their storage facilities, and the strategies they use to manage and oversee these processes

3.3.4 Secondary Data

Refers to the process of systematically gathering information to gain insights and make informed decisions. It involves collecting data from various sources to understand specific issues, evaluate conditions, and develop solutions. Data collection is classified into two types: primary data, which refers to original information collected directly from sources through methods like surveys, interviews, and observations for a specific study, and secondary data, which consists of information previously collected and analyzed by others, such as existing research, reports, and data from other sources.

3.3.5 Secondary Data Collection

Secondary data collection is crucial for contextualizing the findings from primary data (observations and interviews) in the Smart Maize Crop Storage Monitoring System project. It involves reviewing existing research on post-harvest losses, industry reports on storage challenges, and case studies from various regions, such as Kenya, India, Nigeria, Southeast Asia, and Latin America. These sources highlight successful smart storage technologies like moisture sensors, temperature monitoring, airtight containers, and IoT-based systems that have reduced losses and improved maize quality. By leveraging these insights, the project can develop a more effective storage solution tailored to Kamonyi District.

3.4 Documentation

In order to have all information that was required to design and implementation of this project, I have a lot of information from various sources.

3.5 Materials

Digital multi-Meter used is used to measure continuity, resistance and voltage. Soldering iron used for connecting all components on PCB Software manipulation. Programming language was used to automate system; ESP8266 and Arduino is taken as the master of this work. In this method, we have done a lot of work by identifying how will be the connection of components and devices required to design our system and for testing them whether they are at a sustainable level of performance.

CHAPTER 4: SYSTEM DESIGN, ANALYSIS AND IMPLEMENTATION

4.0 Introduction

About this chapter, we will discuss the design and implementation of the system. In this phase, steps were taken from the problem domain to the solution domain. This chapter describes how the new system was built with the new concept in order to obtain the expected results.

4.1. Block Diagram

The design of this project Smart Maize Crop Storage Monitoring System is made of three main parts such as sensing part, processing part and monitoring part.

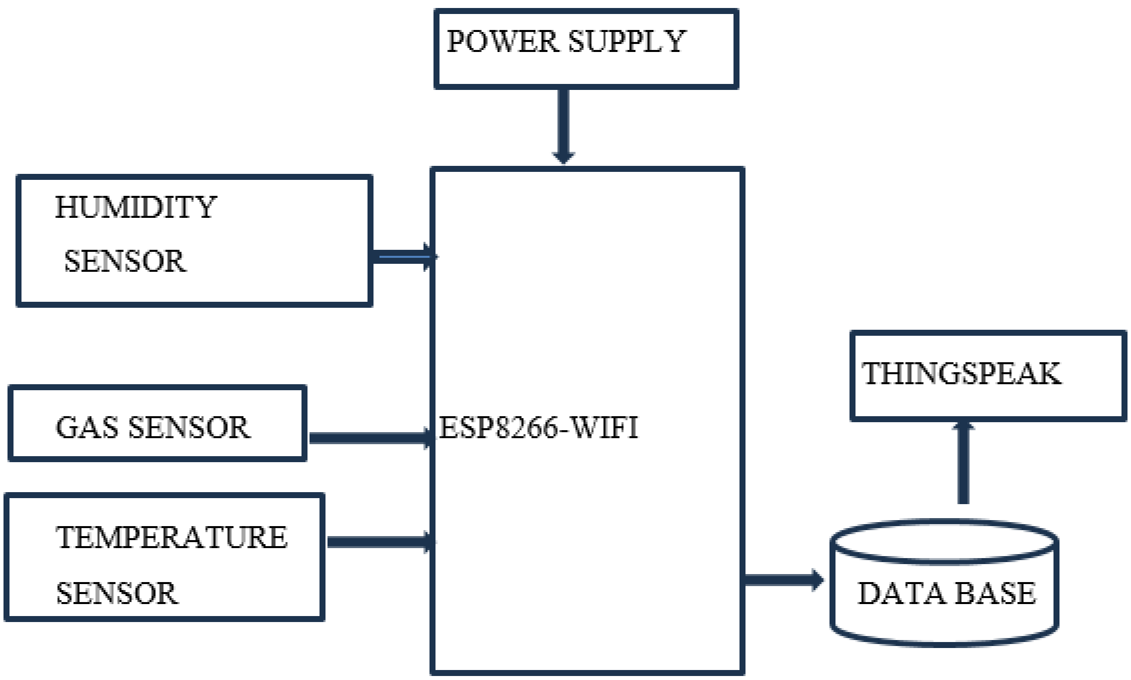


Figure 13: Project Block Diagram

4.2 Flowchart of the Project

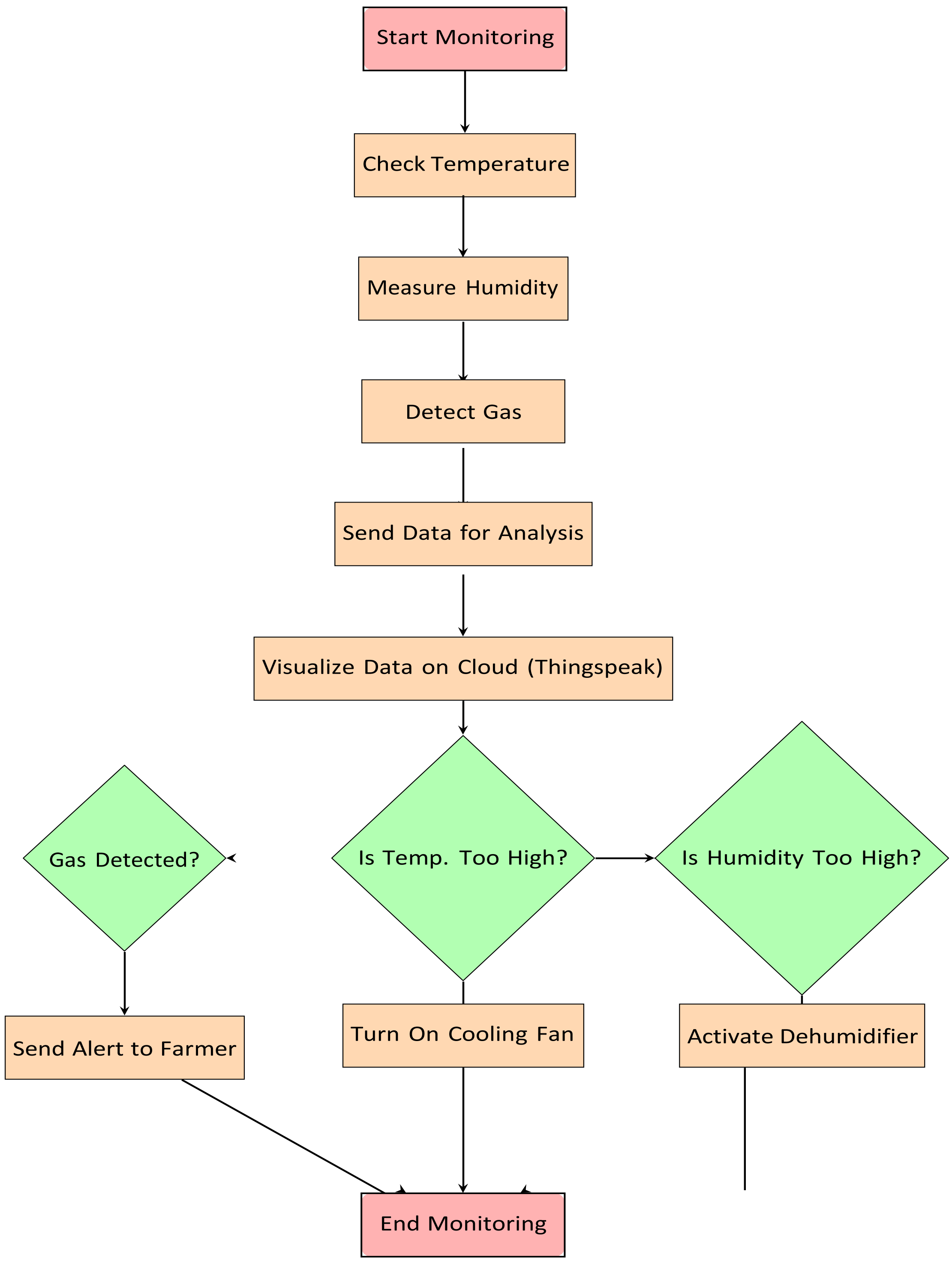


Figure 14: Electronic device flowchart

4.3 Circuit Diagram of the Project

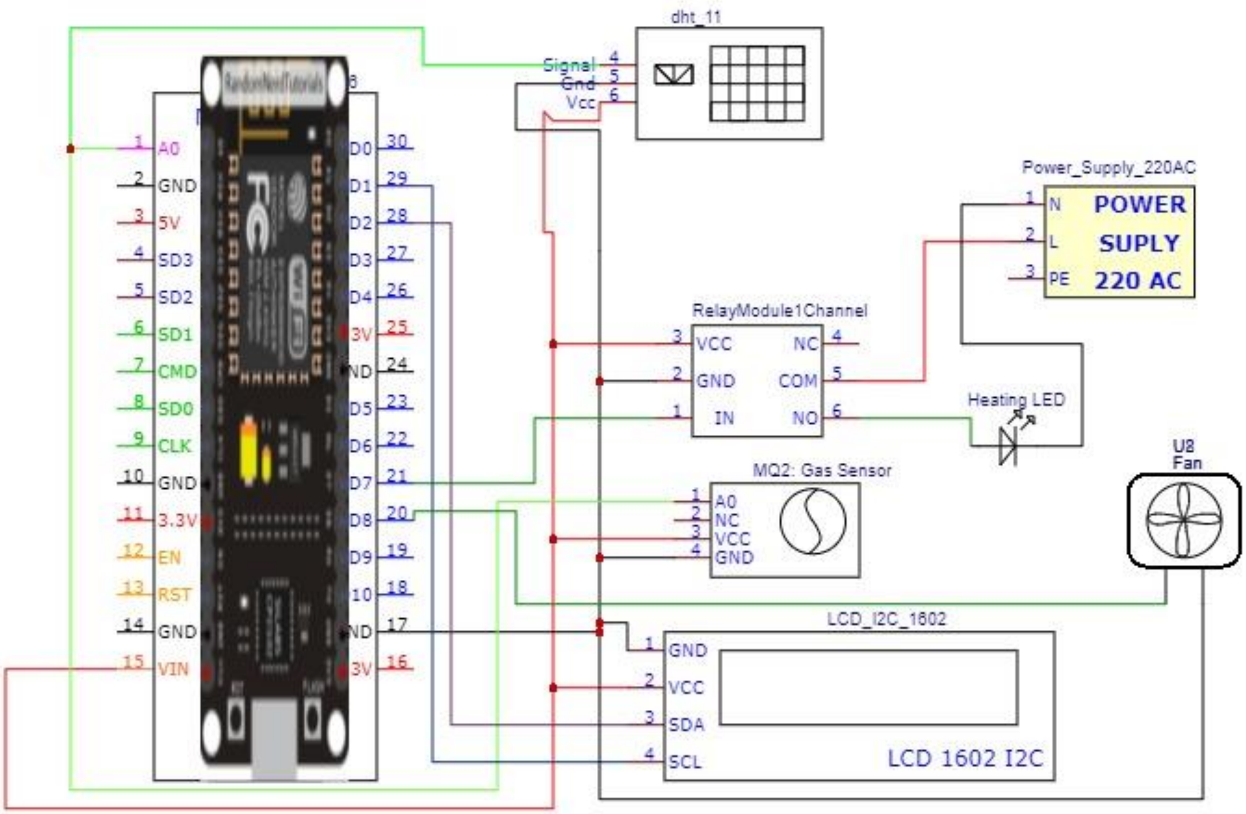


Figure 15: Full Circuit Diagram

4.4 Working Principle of Smart Maize Crop Storage Monitoring

The Smart Maize Crop Storage Monitoring System operates by continuously monitoring and controlling key environmental factors—such as temperature, humidity, and gas levels—within the storage facility to ensure optimal maize preservation. Sensors like the DHT11 and MQ-2 gas sensor collect real-time data on temperature, humidity, and gas concentrations. This data is transmitted to the NodeMCU (ESP8266) microcontroller, which processes the information.

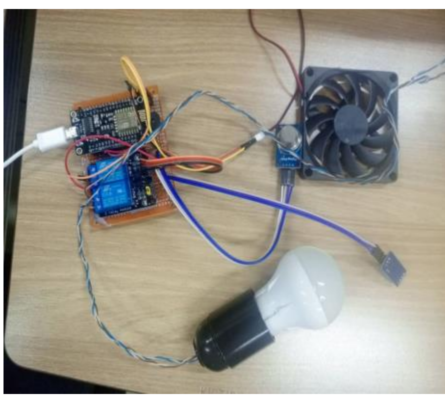
When environmental parameters exceed predefined safe limits—such as high gas concentrations, rising humidity, or temperature fluctuations—the system automatically initiates corrective actions. These actions include activating fans to improve ventilation, turning on dehumidifiers to lower humidity, or adjusting cooling systems to regulate temperature. This ensures that the storage environment remains within optimal ranges, preventing spoilage and maintaining maize quality.

The system also transmits data to the Thingspeak cloud platform, allowing for real-time remote monitoring and control through a mobile app. Users receive alerts when conditions become unsafe and can manually operate devices like fans or dehumidifiers from the app. Additionally, the system logs historical data for later analysis, helping optimize long-term storage conditions and further reduce post-harvest losses.

In summary, the system combines IoT technology with automated controls to maintain ideal storage conditions, reducing spoilage risks and preserving maize quality, offering an efficient and scalable solution for farmers and storage managers.

4.5 The Implementation

The implementation of the Smart Maize Crop Storage Monitoring System involved integrating the NodeMCU (ESP8266) with sensors of DHT11 for temperature and humidity, and MQ-2 for gas detection. The system was programmed using Arduino IDE and displayed real-time data on a 16x2 LCD. Relay modules-controlled cooling fans and heater(bulb), which activated automatically based on sensor readings. Data was also uploaded to the Thingspeak cloud for remote monitoring. After testing and calibrating the sensors, the system was deployed in Kamonyi District, Rwanda, where it provided continuous monitoring and helped reduce post-harvest losses.




4.5 Results of The Thingspeak Platform

The Thingspeak platform provided real-time monitoring of key parameters in the smart maize storage system, specifically temperature (24°C to 29°C), humidity (60% to 90%), and gas levels (200 to 280 ppm). When the temperature exceeded 29°C, cooling fans were activated to lower it, and if it dropped below 24°C, the heater was engaged to raise it. Similarly, humidity levels above 90% prompted ventilation to reduce moisture, while levels below 60% required moisture control to prevent overdriving. For gas levels, exceeding 280 ppm triggered ventilation to improve air quality, while levels below 200 ppm indicated insufficient air circulation, requiring adjustments. This automatic response system, controlled by the platform, helped maintain optimal storage conditions, minimizing spoilage and enhancing maize preservation.

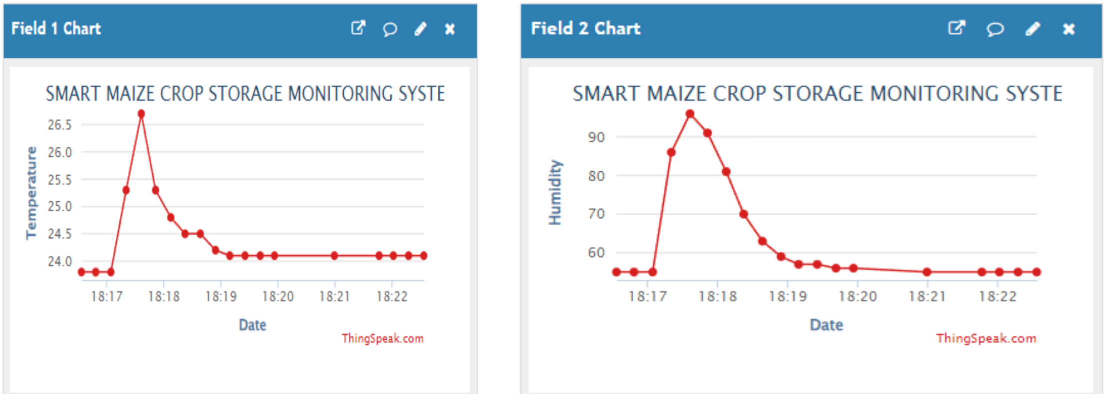


Figure 16: Temperature and Humidity Data Report Chart

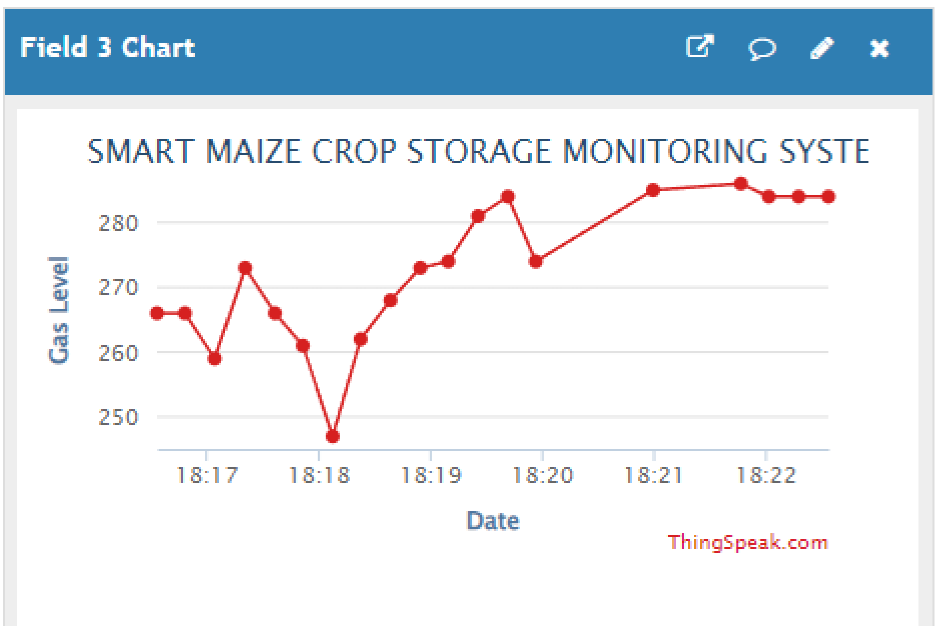


Figure 23: Gas Level Data Report

By concluding the results demonstrate that the system consistently maintained ideal storage conditions for maize by automatically adjusting temperature, humidity, and gas levels in response to environmental changes. The integration of the Thingspeak platform allowed for effective real-time monitoring and data visualization, enabling proactive interventions that reduced potential risks like spoilage and poor air quality. This confirms the effectiveness of the smart maize storage system in preserving maize quality and mitigating post-harvest losses.

4.6 Cost Estimation

Table 1: Cost of Project

Nº	Materials	Quantity	Unity Price	Total (FRW)
1	Box+houseboard	1	8000RWF	RWF
2	Node MCU Esp8266	1	11000RWF	RWF
3	DHT11 sensor	1	3000RWF	RWF
4	Gas Sensor	1	4500RWF	RWF
5	Lcd	1	7000RWF	RWF
6	Battery	1	7000RWF	RWF
7	Battery holder	1	1000RWF	RWF
8	2 relay module	1	6000RWF	RWF
9	Wires	20	1200 RWF	RWF
10	Resistor	2	300RWF	RWF
11	PCB	1	1000RWF	RWF
12	Fan	1	2500frw	RWF
13	Bulb	1	5000frw	RWF
TOTAL			**55,800RWF**	

CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Smart Maize Storage Monitoring System offers an innovative solution to address the challenges of maize storage using modern IoT technology. By integrating DHT sensors for monitoring temperature and humidity and gas sensors for detecting spoilage risks, the system ensures optimal storage conditions are consistently maintained. This reduces post-harvest losses while preserving the quality of maize, which is crucial for food security and economic stability in maize-dependent regions.

The system's real-time monitoring capabilities allow for immediate detection and response to deviations in storage conditions. This proactive approach extends the lifespan and safety of stored maize, preventing spoilage before it leads to significant losses.

Through the integration with the Thingspeak platform, the system provides an accessible interface for remote monitoring and control. Stakeholders, including those in remote areas, can easily track storage conditions and make timely adjustments, further reducing spoilage risks.

In conclusion, the Smart Maize Storage Monitoring System represents a significant advancement in agricultural storage. By combining IoT technology with traditional storage practices, the system offers a scalable, efficient, and reliable solution that ensures sustainable maize storage and enhances food security.

5.2. Recommendations

1. Schools and governments should provide more support for student projects, as students often face difficulties in obtaining sufficient information and financing their projects, especially those with the potential to reach the market.

2. Universities and institutions like UPI should enhance their IoT courses, especially in the fields of electronics and telecommunications, to better prepare students for future technology-driven projects.

3. Colleges and universities offering electronics and telecommunication programs should integrate the programming languages and tools used in this project to provide students with hands-on skills.

4. Establish educational programs, workshops, and seminars focused on maize storage monitoring technologies. These initiatives will spread knowledge, increase the adoption of smart storage solutions, and promote collaboration among students and professionals.

5. Colleges and institutions should seek funding opportunities to support research and development in maize storage monitoring systems. This will help drive innovation and ensure the long-term sustainability of agricultural practices.

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APPENDICES

Appendix A: Codes used

```
void setup () {

  Serial.begin(9600);

  dht. Begin ();

  lcd. init (); // initialize the lcd

  lcd. backlight t ();

  lcd. Clear ();

  lcd. SetCursor (0, 0);

  lcd. Print("Welcome");

  pinMode (relay, OUTPUT); // initialize relay as an output
```

```
  pinMode (fan, OUTPUT);

  pinMode (buzzer, OUTPUT);

  delay (2000);

  Serial.println("Connecting to ");

       Serial.println(ssid);

       WiFi.begin(ssid, pass);



     while (WiFi.status()! = WL_CONNECTED)

    {

          Delay (500);

          Serial. print (".");

          lcd. clear ();

          lcd. setCursor (0, 0);

          lcd. Print(ssid);

          lcd. setCursor (0, 1);

          lcd. print ("Connecting.");

    }

     Serial.println("");

     Serial.println("Wi-Fi connected");



}
```

```
void loop () {
  delay (2000); // Delay between readings
  sensor Value = analog Read(A0);
  Serial.print("Sensor Value: ");
  Serial.println(sensor Value);
  Digital Write (buzzer, HIGH);
  delay (1000);
  Digital Write (buzzer, LOW);
  delay (1000);
  digital Write (buzzer, HIGH);
  delay (1000);
  digital Write (buzzer, LOW);
    humidity = dht. read Humidity (); // Read humidity value
  temperature = dht. Read Temperature (); // Read temperature value in Celsius

  if (is nan(humidity) || is nan(temperature)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }
  lcd. clear ();
```

```
lcd. setCursor (0, 0);

lcd. print ("Temp: ");

lcd. setCursor (6, 0);

lcd. print (temperature);



Serial.print("Humidity: ");

Serial.print(humidity);

Serial.print("%, Temperature: ");

Serial.print(temperature);

Serial.println("°C");

if (temperature < 32) {

  digital Write (relay, HIGH);

  Serial.println("System started heating");



  lcd. setCursor (0, 1);

  lcd. Print ("Heating | ");

}



else if (temperature > 35) {

  digital Write (fan, HIGH);

  Serial.println("System started cooling");
```

```
    lcd. setCursor (0, 1);

    lcd. Print ("Cooling | ");

  }

  else {

    lcd. set Cursor (0, 1);

    lcd. print ("Normal | ");

    digital Write (relay, LOW);

    digital Write (fan, LOW);

    Serial.println("System stopped heating");

  }



  sendDatax ();

}

void sendDatax (){

  if (client. connect(server,80)) //   "184.106.153.149" or api.thingspeak.com

{



      String postStr = apiKey;

       postStr +="&field1=";

       postStr += String(temperature);
```

```
}

      postStr +="&field2=";

      postStr += String(humidity);

      postStr +="&field3=";

      postStr += String (sensor Value);

      postStr += "\r\n\r\n";

      client. print ("POST /update HTTP/1.1\n");

      client. Print ("Host: api.thingspeak.com\n");

      client. print ("Connection: close\n");

      client. print ("X-THINGSPEAKAPIKEY: "+apiKey+"\n");

      client. print ("Content-Type: application/x-www-form-urlencoded\n");

      client. print ("Content-Length: ");

      client. print (postStr. Length ());

      client.print("\n\n");

      client.print(postStr);

  }

  Client. Stop ();

  Serial.println("Waiting...");

  delay (2000);

}
```