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Thesis Title:
Aflatoxin Prevention in Post-harvest maize: A case study of maize storage facilities in Rwanda

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Master of Science in Internet of Things-Wireless Intelligent Sensor Networks

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Aflatoxin Prevention in Post-harvest maize: A case study of maize storage facilities in Rwanda

By

Margaret BAMUREBE

Reg No: 219013101

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN INTERNET OF THINGS-WIRELESS INTELLIGENT SENSOR NETWORKS (MSC in IoT- WISeNet)

In the University of Rwanda College of Science and Technology

Supervisor: Dr. Emmanuel MASABO

Co-Supervisor: Dr. Alfred UWITONZE

June 2021

DECLARATION

I, the under-mentioned, solemnly declare that this Dissertation report is uniquely prepared by me in partial fulfillment of the requirements for the Masters of Science degree in Internet of Things (IoT). I further declare that I have strictly observed writing ethics and outsourced materials used and quoted have been acknowledged by complete references.

Margaret BAMUREBE

Signed:  ……………..

Date: 09-June-2021

BONIFIDE CERTIFICATE

This is to certify that the project entitled" Aflatoxin Prevention in Post-harvest maize: A case study of maize storage facilities in Rwanda" is a record of original work done by Margaret BAMUREBE with registration number 219013101 in partial fulfilment of the requirement for the award of masters of sciences in Internet of Things in College of Science and Technology, University of Rwanda, Academic year 2021.

This work has been submitted under the guidance of Dr. Emmanuel MASABO and Dr. Alfred UWITONZE.

Main Supervisor: Dr. Emmanuel MASABO **Co-Supervisor:** Dr. Alfred UWITONZE.

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“TO GOD BE THE GLORY’’.

ABSTRACT

The Aflatoxin contamination of maize has been a major challenge to Rwandans due to health problems arises from it as well as the production losses. This study focused on providing an IoT-based solution that will be used to monitor three major parameters that facilitate the growth of aflatoxin in the stored maize namely: Temperature, Humidity, and Carbon dioxide concentration. Real-time information on the health of the stored maize and automatic controlling actions are the key components that will help us prevent aflatoxin in maize stores. A sample of good quality maize was monitored over some time by paying attention to three major atmospheric parameters which are Temperature, Humidity, and Carbon dioxide. In the end, it was shown that the quality of maize was maintained/unchanged under 23℃ to 35℃ Temperature range, between 40Rh-60 Rh of Relative Humidity, and at a carbon dioxide concentration level less than 50 ppm. This indicates that the good quality of the stored maize can be maintained for a long period once the above-mentioned parameters are monitored in real-time with automatic controlling actions in place.

KEY WORDS

Aflatoxin, IoT, Node-red, DHT11, MQ135

LIST OF SYMBOLS AND ACRONYMS

AIF: Africa Improved Foods

API: Application Programming Interface

CO2: Carbon dioxide

Db: Database

DHT11: Digital Humidity and Temperature 11

GDP: Gross Domestic Product

GPIO: General Purpose Input/output

GPRS: General Packet Radio Service

GSM: Global System for Mobile communications

IoT: Internet of things

LCD: Liquid Crystal Display

PC: Personal Computer

PICS: Purdue Improved Crop Storage bags

PPB: Parts Per Billion

SDG: Sustainable Development Goals

WSN: Wireless Sensor Networks

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CHAPTER 1: INTRODUCTION

Agriculture is the backbone of any nation's economy and there is a dependency between agricultural growth and economic prosperity. Particularly for Rwanda, it drives the economy, accounting for 80% of employment, 36% of GDP, and 63% of foreign exchange earnings[1]. Like many nations, grains represent the basis for food and job security for the Rwandan population [2]. In a country such as Rwanda, food security relies on producing and storing major staple crops, such as grain. However, post-harvest commodity losses are particularly high. More than 25% of the grain produced can be lost through the entire post-harvest chain before reaching the consumer.[2][3]

Poor-post harvest processes are the main factors that facilitate aflatoxin contamination in grains. In Rwanda, where most farmers dry, shell by hand, and store their maize for up to two months, this has left much of the grain produced in Rwanda especially maize with aflatoxin levels far higher than agro-processing companies' acceptable limit of 10ppb. As a result, large agro-processing companies such as AIF and MINIMEX must look elsewhere for high-quality maize.[3]

The fluctuations in the seasonal and daily environment influence the quality of maize and these are reasons to increase mould growth, insect activities. Inside the stores and warehouses, the mould growth occurs at around 25-30°C threshold temperature, insect growth and reproduction occurs at an ideal temperature of 15°C and above. Insect metabolic activity in dry storage below 15% moisture content can result in heating up to 42°C [4][5].

Aflatoxins (AFs) are a group of highly toxic and carcinogenic secondary metabolites produced by the fungi Aspergillus flavus and Aspergillus parasiticus[6]. AFs are found in a wide range of foods and feeds, such as grains, nuts, dried fruits, and spices, under high temperature and humidity. There are four main types of AF: aflatoxin B1 (AFB1), B2, G1, and G2. Among them, AFB1 is known to be the most common toxin and potent cancer-causing factor, which can induce genetic mutation and hepatocellular carcinoma [7]. Many countries have set legal limits for AFB1 ranging from 0 to 50 ppb (parts per billion) to monitor and regulate the level of AFB1 in foodstuffs[8][3].

The objective of this research is to establish an IoT based system that will be used to monitor maize storage facilities and give real-time information on three main factors namely temperature, humidity, and carbon dioxide concentration that facilitate the growth of Aspergillus flavus and

Aspergillus parasiticus that produces aflatoxin, and then automate Fan whenever there is a change in the above mention parameters.

1.2 Background and Motivation

The agricultural sector is the backbone of Rwanda's economy and contributes over 33 percent of GDP with 45 percent export earnings, while 73 percent work in the agricultural sector, which makes the sector the biggest employer in Rwanda. The sector registered a 6 percent annual growth in 2014, closely following the national growth rate of 7.8 percent per annum[9][10].

Maize is the most important cereal and widely distributed crop in Rwanda. As regards to cultivated area and production, maize ranks third (14%) in Rwanda production following bean (21.2%) and banana (19.6%)[11]. Almost all agro-climatic zones of the country have great suitability in the production of maize[10]. Grown by 62% of farm households for various purposes (direct human consumption, for sale on the local market, or dried and stored for a stock of food security), maize plays an important role in the socio-economic life of rural households[11]

According to FAO (2010), maize presents the highest average grain yield (around 4.5 t/ha) as compared with major cereals grown in Rwanda such as wheat (2.1 t/ha) and rice (3/ha). However, the constraints to the production of this crop are many, including poor post-harvest handling especially during storage[12].

During the maize storage, temperature, humidity, and carbon dioxide concentration are important atmospheric factors that can affect the quality of the stored maize inside the warehouses. If those three parameters are not monitored well, it can cause aflatoxin contamination of stored maize[13]. The traditional methods are limited to simply testing manually the temperature and humidity conditions, which are relatively backward as the other factors have to be checked and monitored independently for contributing to their effective storage and maintenance.

A major contributor to the spoilage of grains is the growth of a variety of mould species, including several that produce mycotoxins. Mycotoxins are natural chemicals produced by fungi that are detrimental to the health of maize. These activities release CO_2 in maize depot, so CO_2 concentration can be effectively used to monitor the early detection of spoilage during storage.

In developing countries, many individuals are not only food insecure, but also are chronically exposed to high levels of mycotoxins in their diet. Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for active and healthy life (FAO1996). Food safety results when microbial contaminants and chemical toxicants are present below tolerance levels in foods. Aflatoxin, a mycotoxin, compromises food security in the most vulnerable groups of people in Africa.

Aspergillus flavus, Aspergillus parasiticus, and rarely, Aspergillus nomius produce aflatoxins as secondary metabolites in agricultural products prone to fungal infection. Aflatoxins may cause liver cancer, suppressed immune systems, and retarded growth and development by contributing to malnutrition. Children are the most sensitive to the effects of aflatoxin-contaminated food. The effects of chronic exposure to aflatoxin are common in Africa, but acute toxicity leading to the death of humans also has been reported.[14] Some of the highest and most persistent human exposures to aflatoxin occur in West Africa, where nearly 99% of the children were positive for an aflatoxin biomarker. [15] Maize consumption is an important source of aflatoxin exposure for these children.[16]

Aflatoxin-producing fungi also cause direct economic losses by spoiling grain. Animals fed aflatoxin-contaminated grain have lower productivity and slower growth. Commodities contaminated with aflatoxins have a lower market value and often are consumed locally since they cannot be exported. Levels of mycotoxins acceptable in foods in developed countries have been lowered, which can result in lowered export earnings by African countries that cannot comply with the stricter regulations. Overall costs for mycotoxin management and monitoring in the United States are estimated at between $0.5 million to > $1.5 billion for aflatoxin in maize and peanuts, fumonisin in maize, and deoxynivalenol in wheat

In many parts of Africa, maize has become the preferred cereal for food, feed, and industrial use, displacing traditional cereals such as sorghum and millets. Maize production in Sub-Saharan Africa tripled from the early 1960s to the late 1990s because of a nearly 2-fold increase in area under cultivation and a > 40% increase in productivity. The greatest gains occurred in West Africa (350% for production, 64% for productivity, and 170% for the area), particularly in Nigeria where the increases were 385% for production, 46% for productivity, and 231% for the area (FAaSTAT, 2003). Consequently, maize consumption is high in Africa, ranging from 85 kg/year per person in Eastern and Southern Africa to 105 kg/year per person in West Africa (FAa, 2005). Maize is one of the cereals most susceptible to aflatoxin contamination (Wilson et aI., 2006). High consumption of maize coupled with frequent and elevated aflatoxin levels, leads to a high aflatoxin risk. The development and dissemination of aflatoxin management practices are essential to reduce exposure to aflatoxins by consumers and producers dependent on maize for food and income generation. In this chapter, we briefly describe the prevalence and distribution of aflatoxin contamination in West Africa and different management approaches that can be used to reduce aflatoxin contamination in maize, with emphasis on smallholder farmers in Africa.

This thesis provides a solution to prevent Aflatoxin contamination of maize in stores using IoT. The approach is to monitor maize storage facilities in real-time using DHT11 and MQ135 sensors based on IoT and automate the necessary action using a relay to switch on or off Fan or heater manually.

This will improve the quality factor of stored maize and reduce the maize wastage during storage interval, manpower, and manual attention.

1.3 Problem Statement

Maize is a raw material for many agro-processing companies in Rwanda, but major agro-processing companies are seeking the majority of their maize from elsewhere [3] because Rwandan maize has a high level of aflatoxins due to improper post-harvest handling especially lack of well-monitored storages to avoid contamination. Africa Improved Foods (AIF), a manufacturer of nutritious foods in Rwanda, sources 80% of the maize it requires from Zambia [3][17]. Maize being among the major crops grown here in Rwanda, this is regarded as a big challenge to farmers and government that put all their resources in cultivating the crop but after harvest, their production is not acceptable on the market.

Aflatoxin not only has adverse effects on human health but also causes serious economic losses when tons of foods have to be discarded or destroyed as a result of aflatoxin contamination. To ensure food safety, maximum levels for aflatoxins in food and feed have been set by national and international organizations and various approaches have been developed for the determination of aflatoxin concentrations in food and feed commodities.

1.4 Study Objectives

The objective of this study is to establish an IoT system that will be used to maintain the quality of the stored maize by monitoring three major atmospheric parameters (Temperature, humidity, and C02) that can lead to aflatoxin contamination once not monitored well.

The study shows a need for efficient monitoring of maize storages for better maintenance of the maize quality, as shown by the comparison of the results of two samples stored in two different containers, one monitored, and another one unmonitored for one month.

1.4.1 General Objective

The main objective of this research is to develop an IoT based system that will monitor maize storage facilities to control and prevent aflatoxin contamination, by measuring temperature, humidity, and carbon dioxide concentration using respective sensors then take automatic action to prevent damage

1.4.2 Specific Objectives

- To establish a monitoring tool that uses sensors to monitor and maintain the health of stored Maize by monitoring the three major parameters that facilitate the growth of aflatoxin which are temperature, humidity, and carbon dioxide
- To provide real-time information regarding the health of the stored maize through a mobile notification to the store manager or anyone in charge.
- To automate the response whenever the above-mentioned parameters go below or above the set threshold. Like switching on /off the heater or air conditioners.

1.5 Hypotheses

For aflatoxin to take place the temperature range should be below 23°C and above 35°C, Relative humidity should be less than 40 Rh and above 60 Rh, also it will be indicated by a rise in carbon dioxide concentration, where measurement above 50 ppm is critical and shows the presence of insects activities.

In this research, it has been shown that by monitoring the 3 parameters you can maintain the good quality of the stored maize

1.6 Study Scope

Aflatoxin contamination may occur in the field before harvest, during harvesting, or during storage and processing, thus methods for the prevention of contamination can be divided into pre-harvest, harvesting, and post-harvest strategies. In our case, we are specifically targeting the post-harvest stage mainly on storage, where the main objective is to maintain the quality of the stored maize using an IoT system. We assume that the maize collected from farmers is tested and all necessary conditions are checked before being accepted in the store.

1.7 Limitations of the study

During this research, some limitations were encountered especially due to COVID 19 pandemic, where the researcher was unable to implement the system on-site as earlier planned. There was also an issue of not finding all needed components like a heater to take control when temperatures drop below the desired level, in this case, a manual heated was used to take control actions whenever there is a notification that the temperature went below 25°C.

1.7 Significance of the Study

Real-time monitoring of the stored maize and quick automatic interventions whenever there is a critical change in the parameters, will help to prevent aflatoxin contamination hence reducing maize production losses. Since the majority of the Rwandan population feed on maize, the implementation of this project will reduce hunger, and this is in line with the sustainable development goal (SDG), Goal number two which targets to end hunger, achieve food security and improved nutrition and promote sustainable agriculture[18].

In brief, there will be an efficient way to maintain the quality of maize stored in warehouses in good content with maintaining their nutritional level and with fewer wastages, this will also reduce manpower and labor.

1.8 Organization of the Study

This Thesis is organized into six Chapters that will help the reader to understand the project:

- Chapter I: Introduction that details the background of area of focus which is maize storage facilities in Rwanda, explains the motivation of the researcher in regards to the problem statement, aims and objectives, scope and limitations as well as the significance of the study and impacts to the beneficiaries.

- Chapter II: Rationale and Literature review highlights different works related to this research area and identifies the gap in them hence allowing us to state our improvements.
- Chapter III: Methodology gives a clear plan of the researcher, explaining the methods and techniques used while conducting the research.
- Chapter IV: System Analysis and Design: in this chapter, we will analyze data and all requirements needed to come up with our desired design.
- Chapter V: Results and Analysis: in this chapter, we will talk about our findings and in regards to our objectives this will be shown by using graphs and charts to show obtained results.
- Chapter VI: presents the conclusion of the work and recommendations.

1.9 Conclusion

This chapter gave an overview of my area of research which is aflatoxin control in maize storage facilities, the objective of this research was well explained, some limitations were also stated and the contribution to the community is highlighted.

CHAPTER 2: LITERATURE REVIEW

Agriculture being the backbone of any country's economy, particularly for Rwanda where 70 percent of the whole population are farmers, and also the fact that the government is putting more effort in the agriculture sector like land consolidation program[19], and after all the production got is being lost during post-harvest processes[20]. The population of Rwanda is increasing, hence affecting the demand for more food, better nutrition, employment, and enhanced resilience, this presents a need for applying new technology for better enhancement to the sector.

This motivated me to do my research in the agricultural area to tackle the particular post-harvest issue of maize during storage. As a master's student and a researcher, this is the right channel to offer my contribution to the development of the agriculture sector and the nation at large. Below are some papers related to my area of research that helped me to address the above-mentioned challenges.

2.1 Grain Condition Intelligent Monitoring System Based on ARM7 Processor

The general model proposed in this paper by Kumar et al for grain storage design consists of two main parts, one being the host PC which gathers Grain environment i.e. Data collected from Sensors, procedures, and a forecast of grain circumstance, the other part being the low-level control terminal in the warehouse obtaining grain information. The main purpose of this design is to collect data from different sensors then send this information over Wireless Network.

The sensors gather the data from the environment, the collected data goes through the analog to digital conversions. These converted data are sent to the microcontroller unit. The microcontroller unit is connected to LCD to display the readings of humidity, temperature, and CO2 values and using GSM/GPRS to obtain the system's remote control. This system is designed in a way that perfectly improves the flexibility and scalability of the warehouse management, which sends available data to the grain depot manager (Database management) in time and filters invalid data on the spot [21].

The general model proposed a solution of controlling and monitoring grain conditions in storages using ARM 7 Processor, sensors, and GSM/GPRS Module. The outcome was to send a notification to the store manager to take action. The identified gap in this paper is the lack of quick and automated action after receiving a notification on any change in the monitored parameters. In other words, if the values are above or below certain threshold conditions then controlling actions are taken manually. The Difference in reference to my proposed research is that the controlling actions are automatic, this will be achieved by using Node MCU as a microcontroller, nod-red as a cloud platform, and a relay as the actuator.

2.2 The ARM Controller and ZIGBEE Based System for Monitoring and Controlling a Granary Environment

The developed system comprises a host PC, a remote monitoring system based on Lab Windows and ZigBee sensor systems, and information administration. Sensors used in this system are for measuring humidity, temperature, and light, which are the major variables impacting the health of the Grain, ZigBee WSN's [22] has some advantages in big and complex systems such as offering low power operations, robustness, high security, and scalability. The author likewise illustrated a framework of the design, hardware, and software components, in his research paper he mainly covered the performance of the transmission separation of ZigBee remote hub in grain and the hub lifetime estimation. The system has several outcomes concerning the environmental parameters like moisture, humidity, and temperature, along with other important factors. A general procedure of computing these factors in the storage environment is by individuals manually recording dimensions and inspecting them at different event times[22][21].

The research paper presents a gap of automation, where each time a person needs to enter parameter measurements manually into the system. The difference in my research is the introduction of another major parameter that affects the quality of the stored maize namely C02 and also the automated controlling actions.

2.3 Reduction of post-harvest losses in Rwanda using Purdue Improved Crop Storage (PICS) bags

Among the common grain storage technologies used in Rwanda, is the usage of Purdue Improved Crop Storage (PICS) bags that are a simple and affordable way of storing grains and seeds without applying chemical preservatives to control insect pests [23]. This technology has improved food security due to its ability to preserve grains and seeds for a long period without them losing their nutrients or being damaged. However this method is only efficient for smallholder farmers, it

becomes a challenge for big farmers with huge production to packing their production in those bags, and it's also time-consuming and requires a lot of manpower.
The difference with my research proposal is that an advanced technology based on IoT will be used to monitor efficiently the health of stored maize and automate the controlling actions. And every type of farmer will benefit from it not only smallholder farmers.

2.4 Grain Storage Management.[4]

The author Can Burak Sisman and Selcuk ALBUT states that it is difficult to improve the quality of stored grain but maintaining its initial quality can be done. When the condition of stored grain starts degrading, it is usually the collective result of various management activities that include the initial condition of grain, temperature and moisture migration, aeration, and monitoring grain condition. Grain stores best if they are cool, dry, and clean. Mold growth and insect activity are dependent on both temperature and grain moisture content. It is not easy to cool down grain from a warmer atmosphere or summer storage temperatures. Keeping grain temperatures below 60º F as long as possible will help minimize insect activity and mold growth.[24].
Moisture content is one of the most important criteria effective on the spoilage during storage. In this paper author had not mentioned the use of sensors for monitoring grain condition, hence it will monitor it bi-weekly or according to seasonal requirement. So, there is not any actual correctness. By using sensors and microcontrollers with help of various internet-based applications and servers, we can automatically monitor the system. Also use of cloud-based services for storing and analyzing data will make the system more efficient and properly decision-oriented.
This is the main difference from my research proposal where IoT based system will be implemented and monitor efficiently the maize storage.

2.5 Smoking

Smoking is among the efficient methods used to protect maize from infectious fungi. It has been found that its level of efficiency is compared to chemical applications like Actellics (primiphos methyl) [25]. Almost 3.6-12 percent of farmers in different ecological regions in Nigeria applied the smoking method on their grain production to preserve them, and it has led to a significant decrease of aflatoxin levels in grain stores. The success of this method was also confirmed by the efficiency of smoking was also confirmed by Hell et al in their research carried out in Benin.

Although, the major concern with the usage of this method is that if not cautiously applied, it will result in a change of color and taste of the product.

2.6 Prevention of aflatoxin contamination in stored grains using chemical strategies

This paper discussed the usage of chemicals to prevent Aflatoxin in stored maize and peanuts. It introduced the Microencapsulation method that was used to prevent stored maize and peanuts from Aflatoxin contamination, Fungicides, and insecticides such as food-grade antioxidants and natural phytochemicals were used to prevent the entry of xenobiotics in the food chain. They also used synthetic phenolic compounds such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) against Aspergillus Section Flavi and insect vectors and it showed fungicidal and insecticidal effects when used in assays with maize and peanut[26]. Though this method somehow succeeded, it presents an issue of usage of some insect sides that may be harmful to human consumers.

2.7 Automated Granary Monitoring and Controlling System Suitable For the Sub-Saharan Region

This paper presented the use of the automation system that uses Wireless Sensor Network, where spatially distributed sensor nodes seamlessly communicate with a Linux-based Raspberry Pi computer. The communication between them is performed through a lightweight and reliable machine-to-machine communication protocol. Each node is equipped with sensors for monitoring the climatic and environmental conditions of the grain storage house. Based on the incoming data from the sensors the system executes several tasks to help the grains to be safely stored for a long period – with minimum losses. Additionally, an easily accessible and secure web interface has been developed allowing the owner to graphically visualize the status of the store, in real-time. If any risk factor is confirmed to exist inside the store, the owner is automatically informed through SMS [27]. In this paper, they say the system is automated yet the researcher did not include the usage of actuators as controlling components.

2.8 Metal silos

This paper entitled “metal silos as an effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries”, presents a study on the review of metal silos storage technology, as an effective grain storage mechanism that is used to reduce postharvest losses in maize caused pests while improving food security and economic growth in developing countries. A metal silo is a cylindrical structure, built from a galvanized iron sheet and hermetically sealed, to eliminate insects and pests that may be present in maize. The paper discusses the succession of this method to prevent production losses in developing countries[28]. The main gap seen in this research is the lack of advanced technologies to monitor the silos. Also, the suggested method is very expensive not any farmer can afford to buy a metal silo.

2.9 Efficient Food Storage Using Sensors, Android and IoT

The author of the paper had proposed a food storage system based on IoT and different sensors for observing the temperature, humidity, and other ecological conditions inside the food distribution center. The proposed method of the author is a special case of introducing an android app using which the various environmental conditions like temperature, smoke, humidity, light can be sensed and can be stored in a database. DHT11 sensor monitors for any change in temperature and humidity within the go-down area, whereas the MQ135 gas sensor is used to detect CO2 concentration emitting from decaying of grain. LDR sensors are placed at storage locations since stored grain requires proper lighting. If the surrounding environment is changed, LDR sensors generate voltage ranges. These output voltages are provided to the pins of the ADC unit of the microcontroller for further processing[29]. This paper presents a gap of lack of automation system to control the condition inside the warehouse.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter explains the research method that was used in collecting and analyzing the data used in this thesis. It defines and discusses the purposive approach, its different manifestations in an attempt to clarify the particular approach of the purposive method adopted in this study.

In addition, the appropriateness of the purposive approach method for the present study is discussed in this chapter, again we will look at the tools and techniques used in order to establish this research in relation to the set objectives.

3.1 Research approach

Purposive methods were used in this research to select respondents, this approach was used because it gives the researcher flexibility of interviewing specific skills[[30]. The purposive approach also known as the judgment sampling approach is the intentional choice of an informant due to the qualities possessions of the informant. It is a non-random technique that does not necessarily need fundamental theories or a set number of informants. It is in this regard that one respondent from the private sector and another one from a government institution were chosen. From the private sector, Africa Improved Foods as one of the agro-processing company was chosen, they provided the researcher with useful information on how they store their maize and also highlighted some of the challenges they face especially in quality maintenance of the stored maize. On the other hand, Rwanda Agricultural Board as a government institution was also chosen, and the researcher was briefed on how local maize storage facilities work and the efficiency of the practices they use to maintain the quality of the stored maize. In their responses, they all seem to have a similar challenge of not having an efficient method of monitoring their maize storages, which leads to production losses.

At Africa improved foods, they highlighted the challenge of using a lot of power in the aeration system because the fans are always on and they consume a lot of power, they suggested that if there was a way fans can be controlled automatically like switching them on whenever cooling is needed and switch off once temperatures are normal, it could save a lot of power hence reducing cost on power consumed. At Rwanda Agricultural Board, their main challenge is maize production losses due to poor post-harvest practices, including lack of advanced technologies in the storage sector.

3.2 Tools used

3.2.1 Hardware used

1. **Node MCU ESP8266:** It is an open-source IoT firmware used for a number of various IoT applications. It includes 30 GPIO pins for the connection to the other hardware parts. It has an inbuilt WiFi module for transmitting data over the server.
2. **Arduino Nano:** It is a microcontroller which in this project with the help of serial communication, sends the collected Data to Node MCU so that it can be sent to the cloud dashboard for the users to view. Due to differences in power consumption of the sensors and actuator (fan and heater), we decided to use 2 micro-controllers in this project. For instance, with the use of Arduino Nano, which supplies 5 Volts, we were able to control the fan and heater, which wouldn't have been possible if we used Node MCU only because it supplies 3.5 Volts.
3. **DHT11:** It is the sensor used to measure the atmospheric temperature and humidity. It senses the present condition and level of temperature and humidity in the surrounding area and displays the data accordingly to the input. To store the maize safely, the temperature is the key. When the condition of stored maize goes beyond control, there is always an unusual increase in temperature. Hence, for the better maintenance of maize storage, temperature is the best indicator of maize quality [6].
4. **MQ135:** MQ gas sensor series is used to measure the amount of atmospheric gases in the area. In particular, MQ135 specifically measures the amount of carbon dioxide in the surrounding. The amount of carbon dioxide is the main factor to investigate about the formation of insects or disease inside warehouses and stores.
5. **Relay Module:** The relay is a switch that operates electronically. A number of relays use an electromagnet to mechanically work as a switch, while other working principles are also used, like solid-state relays. Relays are used in case it's necessary to control a circuit with a different low-power signal, or where different circuits must be controlled by a single signal. In this project, it will be used to control the Fan to normalize the storage conditions
6. **Fan: it's** a device that is used to provide flow and distribution of air, inside the warehouse in order to regulate temperature.

7. **Breadboard:** breadboard helps us to create our circuit by providing more space for different connections of our components.
8. **Laptop:** laptop this case acts as a source of power to my circuit and is also used in coding and uploading my program to the micro-controller.

3.2.2 Software used:

1. Node-red: Node-red is an Open Source flow-based tool and IoT platform and Dashboard developed by IBM and written in Node.js. It is a programming tool for wiring together hardware devices, APIs, and online services in new and interesting ways. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single click.

2. Influx DB: is an open-source time-series database developed by Influx Data. It is written in Go and optimized for fast, high-availability storage and retrieval of time series data in fields such as operations monitoring, application metrics, Internet of Things sensor data, and real-time analytics.

3.3 Objective Achievements

Objective one:

To establish a monitoring tool that uses sensors to monitor and maintain the health of stored Maize by monitoring the three major parameters that facilitate the growth of aflatoxin which are temperature, humidity, and carbon dioxide

How it was achieved:

An IoT based system was built, with the purpose of monitoring three major atmospheric factors that affect the health of stored maize which are temperature, humidity, and carbon dioxide, using respective sensors (DHT11 & MQ15), Microcontroller (Node MCU), and Node-red cloud platform, the system is able to provide real-time information on any change in the monitored parameters, also take controlling actions whenever there is a change in the sensed data, hence preventing aflatoxins to develop inside the warehouses and stores.

Objective Two:

To provide real-time information regarding the health of the stored maize through a mobile notification to the store manager or anyone in charge.

How it was achieved:

Node-red is used to achieve this objective by notifying the store manager of any change in the atmospheric factors measured inside the warehouse. With the node-red application, the warehouse manager is able to switch on or off the heater or air conditioners depending on the situation.

Objective Three:

To automate the response whenever the above-mentioned parameters go below or above the set threshold. Like switching on /off the heater or air conditioners.

How it was achieved:

Due to the lack of some components, this objective is partially achieved, only the fan is the one that can be controlled because I couldn’t find a heater on the local market, and ordering in online could take me at least 45 days. With the help of the microcontroller and a relay, the system is able to switch on or off the Fan in regards to the desired atmospheric environment inside the warehouse/store.

CHAPTER 4: SYSTEM ANALYSIS AND DESIGN

This chapter introduces the system model design interfaces that were used in this project. It clearly shows how the researcher designed his project in order to meet the set objectives.

4.1 Analysis of the System

The general model presented in this research project is an IoT system that uses sensors (DHT11&MQ135) to collect data inside the maize storage regarding temperature, humidity and C02 then sends the data to Arduino Nano which with the help of serial communication Nano sends the collected Data to Node MCU so that it can be sent to cloud Dashboard for the users to view.

Due to differences in power consumption of the sensors and actuator (Fan), we decided to use 2 micro-controllers in this project. For instance, with the use of Arduino Nano which supplies 5 Volts, we were able to control the fan, which wouldn't have been possible if we used Node MCU only because it supplies 3.5 Volts. Node MCU also comes in to help us send the data to clod because of its Wi-Fi module built-in.

4.2 System Architecture

The system consists of various sensors and microcontrollers. Node MCU ESP8266 and Arduino Uno were used. The sensors that were used are DHT11 (Digital Humidity and Temperature) and MQ135 (gas sensor). For the controlling actions, the notification over node-red applications was delivered regularly through mobile phone to the store manager or anyone in charge of the warehouse also and an email notification is sent whenever there is a critical change in the parameters. A relay Module was used to automate the action after abnormality detected in the measured parameters, then controlling actions were put in place by the system like switching on/off fan and heater manually.

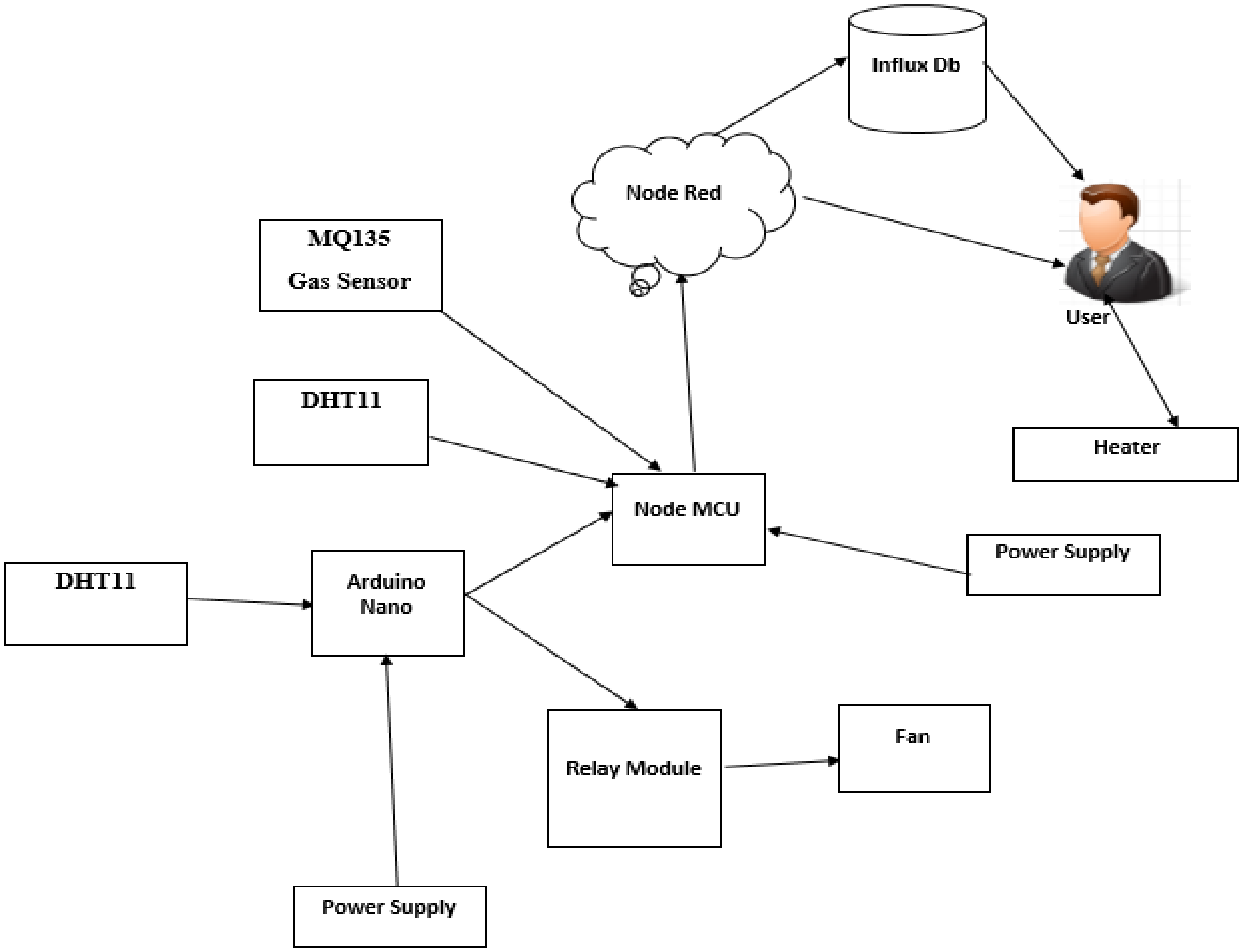

Figure 4.2.1: System Architecture

As shown in the figure above, Sensors (DHT11& MQ135) capture data in the warehouse and send it to microcontrollers (Node MC and Arduino Uno), in this case, two microcontrollers were used in respect to their capabilities where Arduino Uno supports 5V whereas Node MCU provides 3.3V. With the help of a wifi module embedded in Node MCU the captured data is sent as an input to the node-red cloud platform. The API reference key generated over Node-red acts as an interfacing medium between hardware and software. The data received is input to the system for the next controlling actions. Influx Db is also used as permanent storage for further data usage and reporting.

4.3 Implementation of the system

The Implementation part of this system includes Hardware implementation and software realization. Each implementation part is described in the lower section.

4.3.1 Firmware Implementation and Flowchart

The program source code is written in such a way that operations of the development board can be controlled. The circuit design for the hardware used is done using a breadboard, jumper wires sensors, and microcontrollers. The software development kit Arduino IDE was used which supports Arduino Nano and Node MCU controllers, with the help of this tool source code is written in C for Arduino language and compiled, code generated by the compiler is burned into Arduino Nano and Node MCU. The flowchart for the system is as shown below.

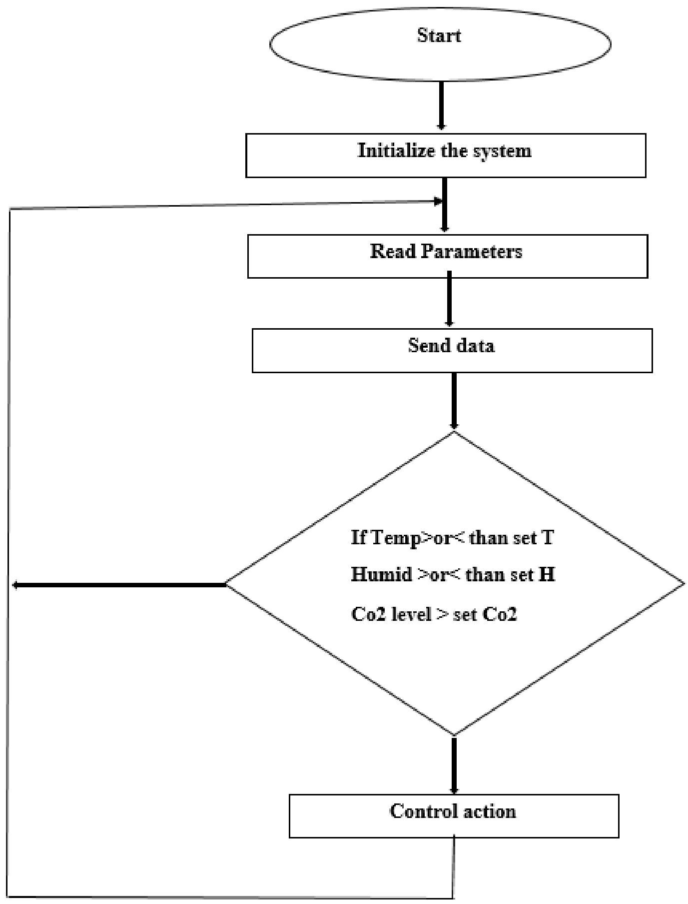

Figure 4.3.1. 1: Flow Chart

As shown from the above flowchart, the system initiates by reading environmental parameters inside the warehouse, and sends them to the microcontrollers, if sensed parameters are below or above the normal level, the controlling actions are taken to normalize the room, if the sensed parameter falls into the normal level, the system reads again the environmental paramenters and continuously go through the same process.

4.3.2 System Algorithm:

Step 1: Start Node-red which synchronizes the connections between Remote maize storage and the main computer.

Step 2: DHT11 and MQ135 sensors are continuously sensing the environmental conditions inside the warehouse.

Step 3: The data collected from sensors are sent to node-red dashboard and stored in influx Db with help of Node MCU which has embedded Wi-Fi that acts as the communication medium.

Step 4: IF Temperature and /or Humidity goes beyond or below the set threshold or CO2 concentration rises above the Threshold, the system automatically activates actuators to take controlling actions.

Step 5: A notification is sent to the store manager or anyone in charge informing him/her of the situation inside the ware-house.

Step 6: Sensed data are viewed on the cloud node-red dashboard in the form of graphs and charts, this may be used for future references to predict the health of the stored maize. Also using Influx Db as a database for more efficient storage of our data.

4.3.3 Hardware Implementation

Hardware implementation was done according to the schematic drawing on the plane paper as shown in the figure below, the schematic of the design is tested over the breadboard using the integrated circuits to check whether the design meets the objectives of the project. Also Carried out the Printed Circuit Board layout of the schematic tested on breadboard, lastly prepared the board and testing the hardware designed.

The schematic diagram shown below as it was drawn on a paper comprises of two parts; hardware part and software part.

In the hardware part we have sensors, actuators and microcontrollers whereas in the software part we have cloud server, database and node red application.

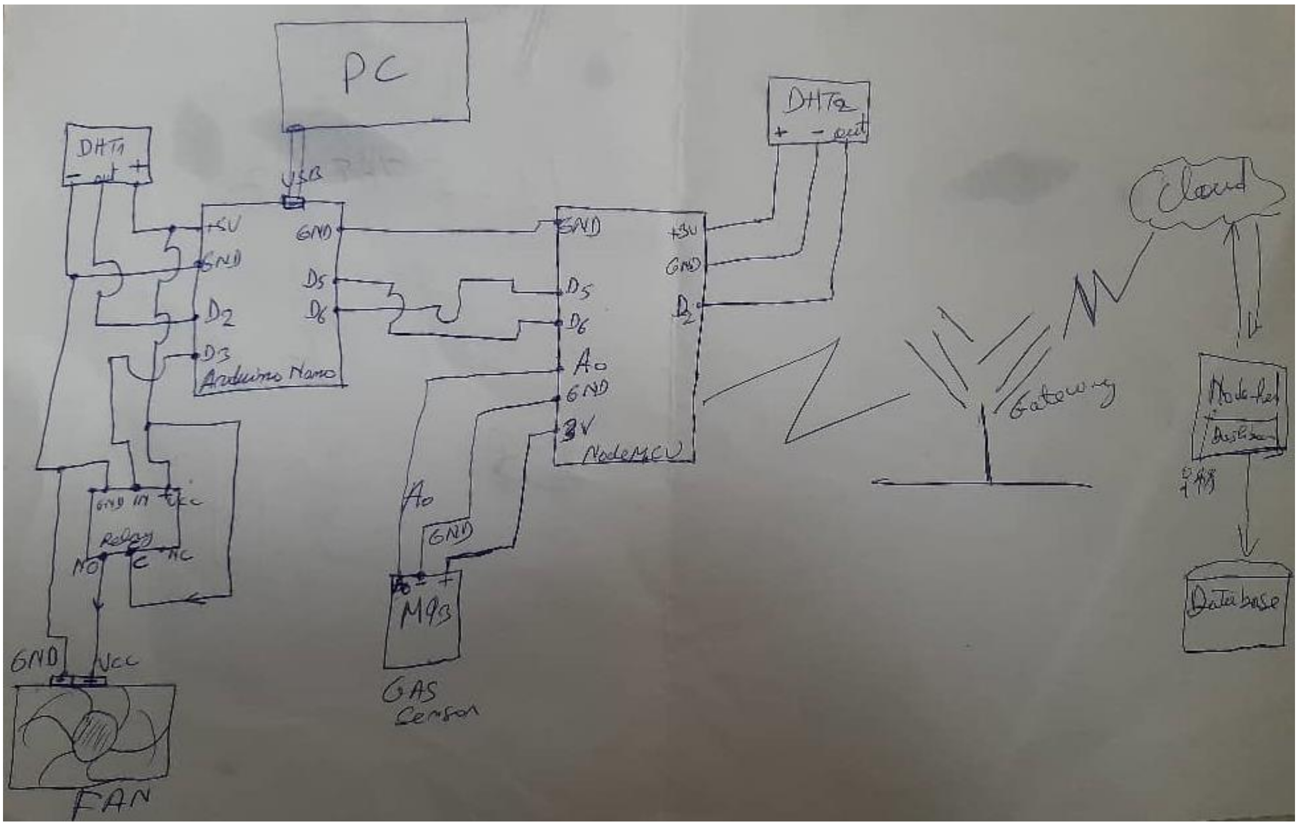

Figure 4.3.1 2: Circuit Diagram

Due to a difference in power capabilities as explained in the previous chapter; two microcontrollers were used which are Arduino Nano and Node MCU to allow a seamless connection of different components. In this case Arduino was getting the data collected from temperature and humidity sensor (DHT11), also a relay module that controls the Fan was connected to it. With the use of serial communication codes in the program we are able to transfer data from Arduino Nano and send them to Node MCU. On the other hand Node MCU has gas sensor and DHT11 connected to it and it serves another purpose of transferring the data collected from sensors using the WiFi transmitter that is in built then the data is received by WiFi access point and then it reaches the cloud server through the Internet. Data stored on the cloud server can be accessed by the use on node red application.

Below photo shows a complete connection of our circuit design implemented on breadboard using the integrated circuits. The design was tested and found to meet our desired objectives.

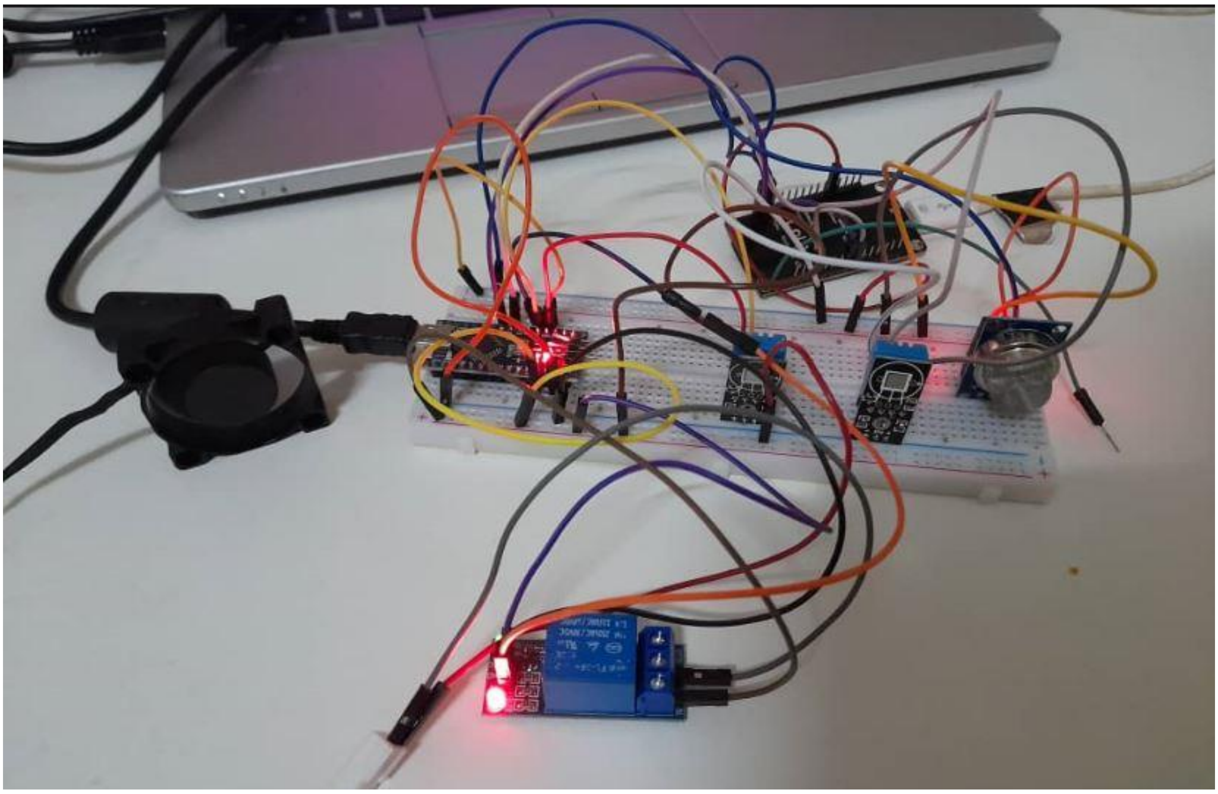

Figure 4.3.1 3 : Circuit design

The image above illustrates a circuit diagram for the proposed system, it comprises of sensors (DHT11 and M135) for temperature and humidity and also for carbon monoxide, the circuit also had two microcontrollers Arduino Uno and Node MCU, a relay module and a fan are also includedin this circuit, all mounted on a breadboard. With the use of jumper cables, connections between components are made. The Source of power is the laptop.

CHAPTER 5: RESULTS

Maize storage monitoring systems based on IoT technology is designed and implemented with the purpose of preventing maize from getting contaminated by aflatoxin,

The implementation is done on Arduino Nano and Node MCU microcontrollers, where the Arduino Nano is used to control the fan due to its unique capabilities of supplying 5 Volts, and Node MCU is used to collect sensed data and send them to the cloud with help of in-built Wi-Fi module. The system is designed in a way that meets all the requirements and specifications as mentioned in the objective. A cloud Node-red dashboard is created for the system to monitor maize acquisition parameters and to store these values for future reference.

Both email and mobile notifications are sent to the store manager or anyone responsible whenever sensed data is beyond or below the set threshold, for taking control actions like switching on or off the heater.

5.1 Data got from sensors displayed in the serial monitor

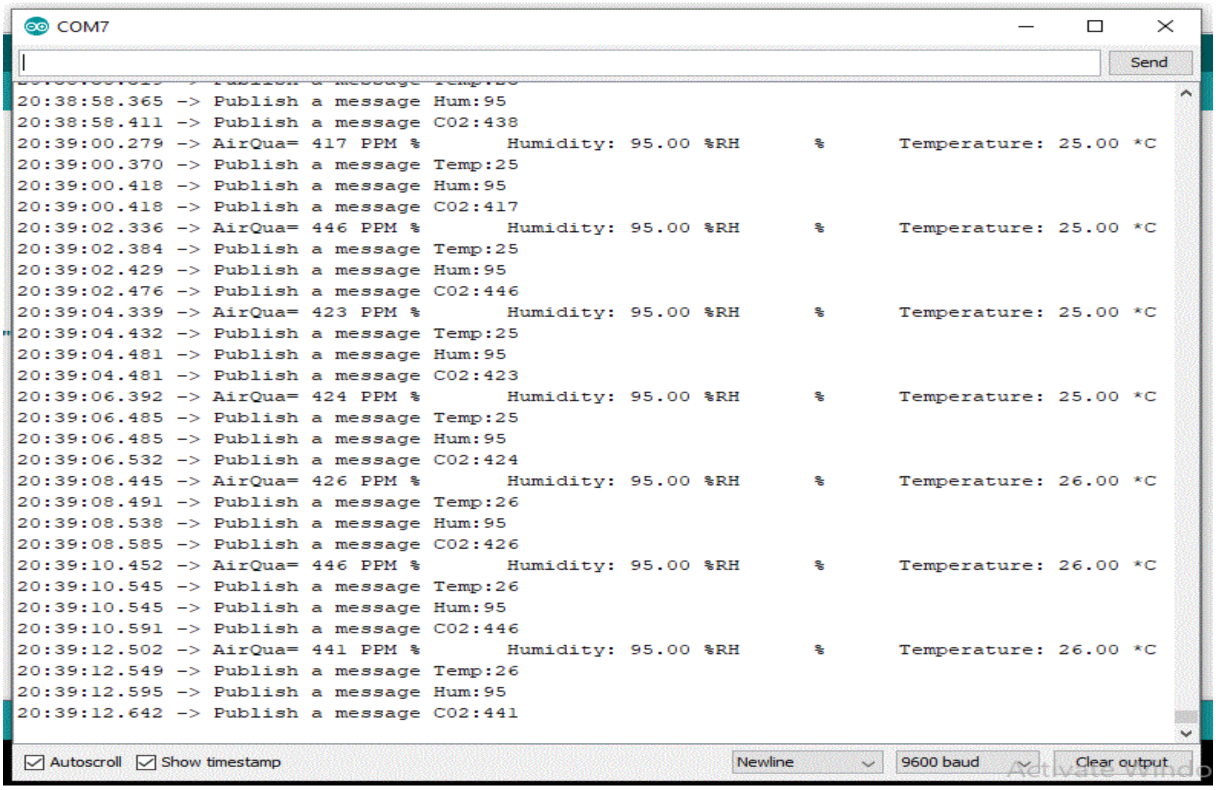

Figure 5.1 1: Serial Monitor

The figure above shows data collected from sensors viewed on a serial monitor, this comes after uploading our codes to the microcontroller and run it. The microcontroller will start receiving data from sensors and that same data will be displayed on the serial monitor.

5.2 Data sensed is visualized on node-reed dashboard

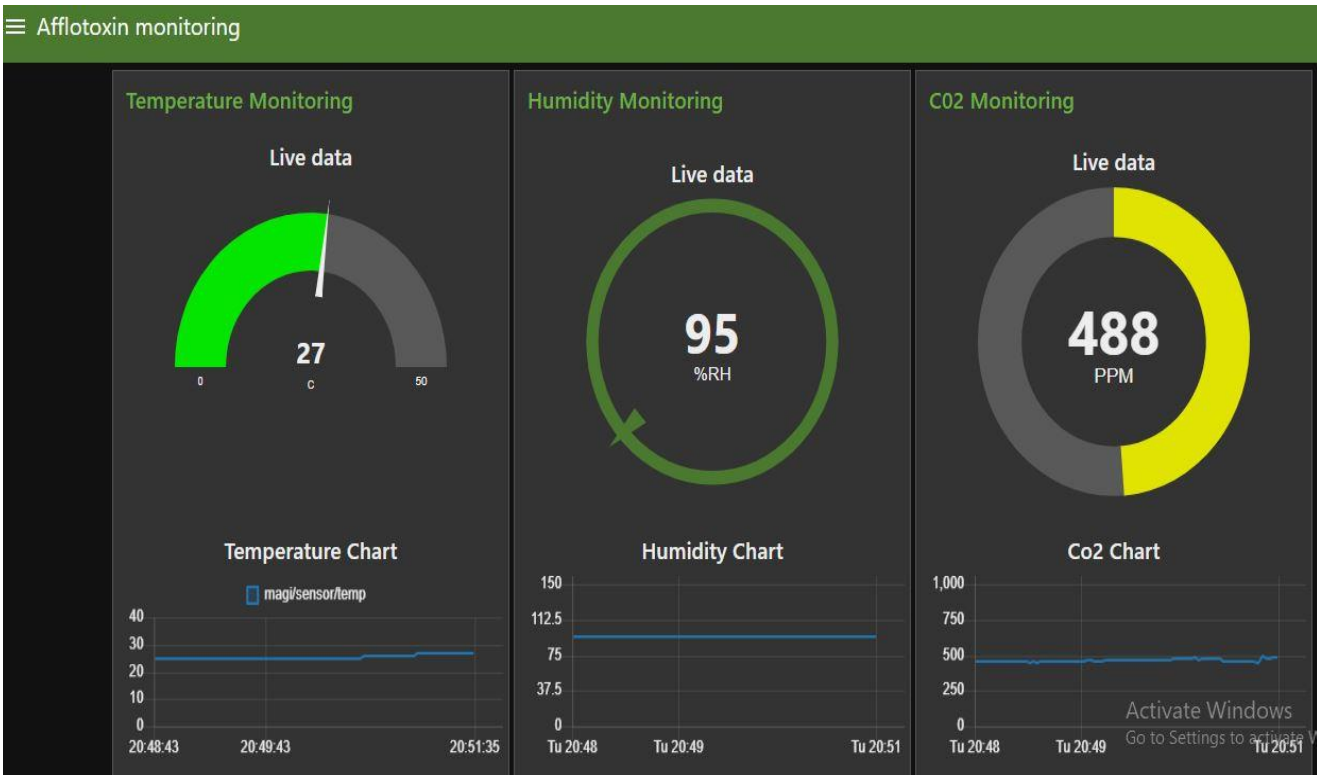

Figure 5.2 1: Dashboard

This figure shows Data obtained from sensors being viewed on Node-red Dashboard in form of graphs and charts. This well organised way of viewing the status of the warehouse at different times and also for reporting purposes. When the sensed parameter falls in the normal range, it is shown in carts by a green color otherwise it is red.

5.3 Email Notification

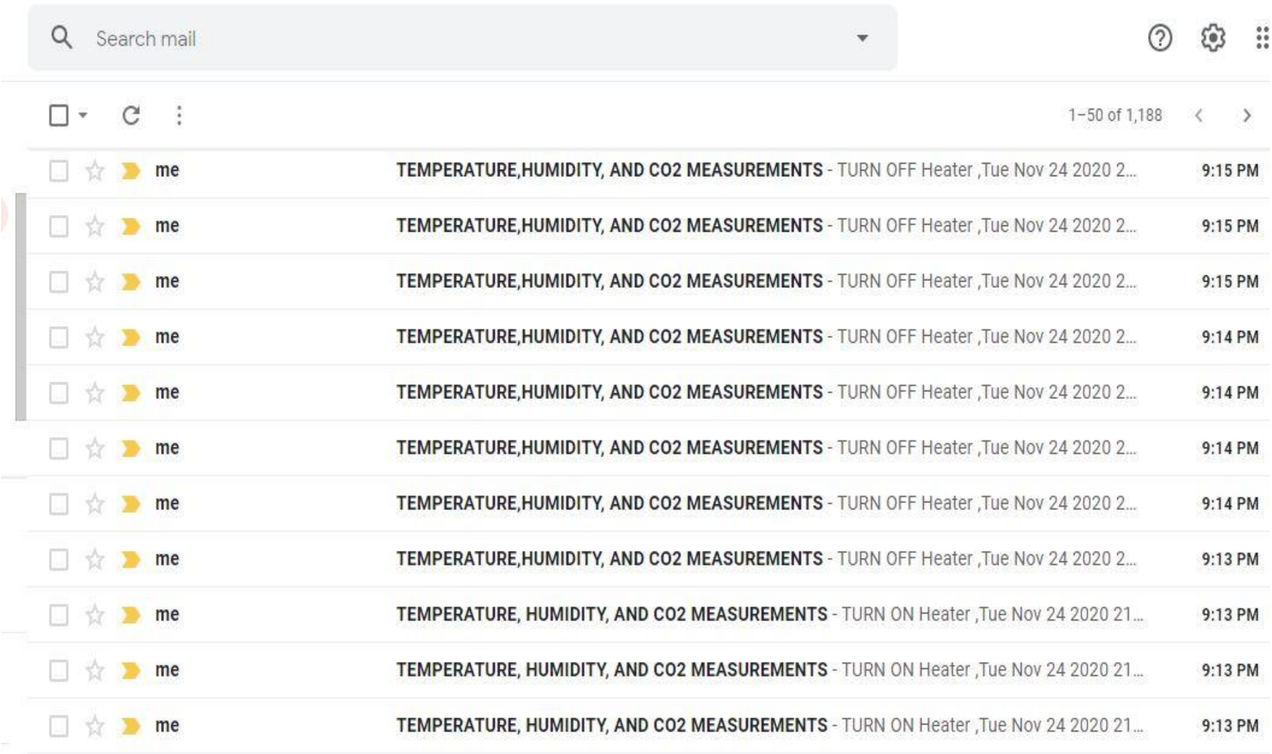

Figure 5.3 1 : Email Notifications

An email notification is sent to the warehouse manager alerting him of any critical change in the measured parameters, for example, telling the manager to switch on or off the heater, since our heater is controlled manually. In this case, the warehouse manager will be able to know the health of the store maize without going to the warehouse, hence saving time and money used to go to the warehouse every day.

5.4 Mobile Notification

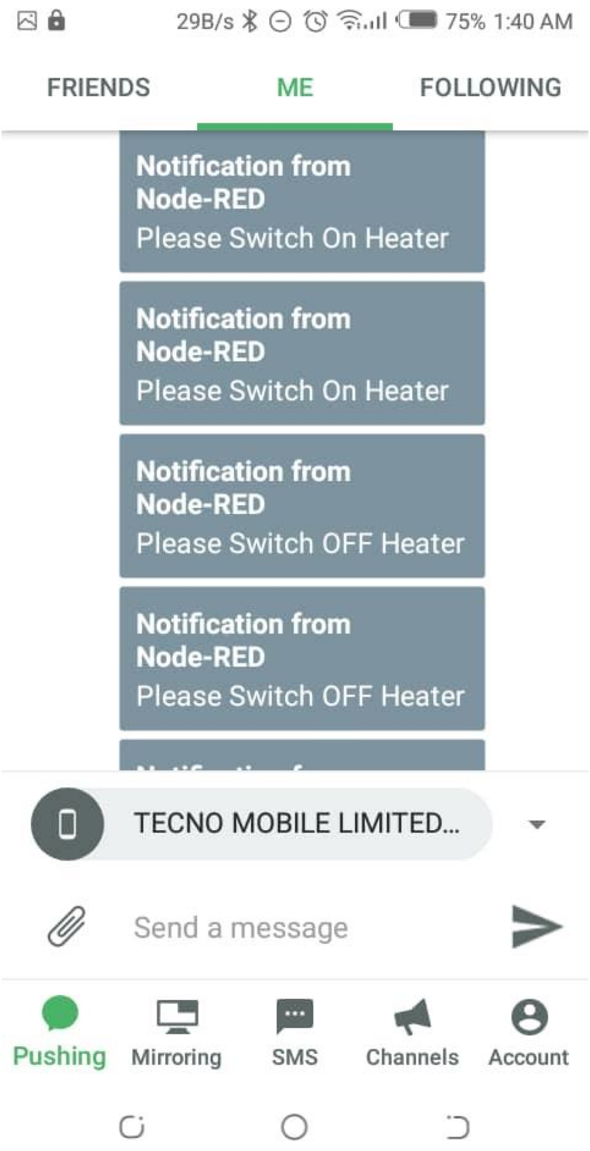

Figure 5.4 1: Mobile notifications

A mobile notification is used also as a quick way of alerting the store manager of the change in the monitored parameters for him to take controlling actions and also to know the status of the stored maize. This is achieved with the use of Push bullet mobile application.

Push bullet is a mobile application that allows you to send and receive messages and notification. It is a simple way to receive notifications on your phone from Node-RED. It's very simple to install and use, all you need to do first is to create an account on the push bullet application for free then install the app on your phone. For smooth communication between push bullet and node-red, you will need to get an access token for your Node-RED which is provided via push bullet application.

5.5 Results discussion

A sample of good quality maize was monitored over a period of time by paying attention to three major atmospheric parameters which are Temperature, Humidity, and Carbon dioxide. In the end, it was shown that the quality of maize was maintained/unchanged under 23 to 35 degrees of Temperature, between 40-60 of Relative Humidity, and Carbon dioxide concentration level at less than 50 ppm. Below are the predicted results of the maize monitoring model proposed in this research.

Table 1 shows the result of predicted Temperature, Humidity, Gas values of Maize monitoring System.

Temperature (Celsius)	23-35	>35	>40
Relative Humidity (RH)	40-60	>60	>72
C02Concentration (ppm)	< 50	>110	>130
STATUS	SECURE	CRITICAL	DANGER

Table 5.4 1: Table of results

From the above Table 1, the desired temperature measurement is between 23 and 35 degrees, beyond or below that the maize is at risk of being contaminated by aflatoxin. Also, relative humidity should be kept between 45 and 60 Rh otherwise it may facilitate the growth of aflatoxin-causing fungi. For Carbon dioxide level, it is monitored as an indicator that some insect activities are taking place inside the warehouse or storage, its desired level should not exceed 50 ppm.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Maize contamination with aflatoxin is a major factor in determining the quality of maize, this has caused significant financial losses for a country like Rwanda that produces and exports the crop. Thus indicating the importance of monitoring aflatoxin contamination in maize in order to protect consumers. Although the various methods used at present are somehow successful, they still present a big disadvantage with limited efficiency and possible losses of important nutrients and normally with high costs. Therefore, early monitoring of environmental parameters that facilitates the growth of aflatoxin is needed to prevent health-related risks and economic losses that result from the contamination.

In this research project, an IoT system was built for monitoring and controlling maize conditions in large stores and warehouses to prevent Aflatoxin contamination. The implementation is done through the use of Arduino Nano, Node MCU, and sensors. The system sends data to the cloud by the use of node MCU, the data collected by sensors are visualized on the Node-red dashboard. Not only the designed system is power efficient, but also reduces labor and Resources, while enhancing system flexibility and cost-effectiveness.

In this research, the researcher only looked at three major environmental factors which are Humidity, Temperature, and carbon dioxide concentration for real-time detection of maize quality deterioration and real-time controlling actions like reducing Temperature in the warehouse when Temperature rises, i.e. maintaining parameters at a normal level by an automatic system regardless of condition. As demonstrated in the implemented design of this work, the system provides flexibility, scalability, portability, and security/integrity of the transmitted data over a wireless network.

6.2 Recommendations

In the future, the researcher wishes to extend this research work and investigate other factors that may affect the quality of the stored maize inside the warehouse, like investigating security factors by including intrusion detection mechanism to the warehouse in case of unauthorized access to avoid any external caused contamination.

And finally, additional research, such as the application of machine learning algorithms in the existing framework, needs to be conducted to make the system smarter.

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