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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN THE INTERNET OF THINGS(ACEIoT)

MASTER THESIS

IOT-BASED QUALITY MONITORING SYSTEM FOR BANANA BEER

A thesis submitted in partial fulfilment of the requirements for the award of Master of science degree in Internet of Things: in the Wireless Intelligent Sensor Networking.

Submitted By:

UWIZEYIMANA ABDULKARIM

Reference. No: 220020691

April 2023

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Submitted By:

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Supervisors:

Dr. Omar Gatera

Dr. Omololu Akin-ojo

April 2023

DECLARATION

I, **UWIZEYIMANA Abdulkarim**, who holds a master's degree in Internet of things of Wireless Intelligent Sensor Networking, hereby declare that the content in this document is the original work and has never been presented or submitted for any academic award in any university or other institutions of higher learning as a whole or in apart of work. I also declare that, as required by rules I have fully cited and referenced all material and results that are not original to this work.

Student Name and Number

UWIZEYIMANA Abdulkarim,
220020691

Signed

Date:……./04/ 2023

BONAFIDE CERTIFICATE

This is to certify that the dissertation report work titled "**IoT-based quality monitoring system for banana beer**" is a record of the original work done by Mr. **UWIZEYIMANA Abdulkarim** a post-graduate student at the African Center of Excellence in Internet of Things (ACEIoT), College of Science and Technology (CST), University of Rwanda (UR), specializing in MSc. Of Wireless Sensor Network (WSN). We certify that the work reported does not form a part of any other research project.

Supervisors,

Main Supervisor:
Dr Omar Gatera

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Co-Supervisor:
Dr Omololu Akin-ojo

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Head of master studies and Trainings, ACEIoT.
Dr. RWIGEMA James,

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Date:……/04/ 2023

DEDICATION

I dedicate this thesis report document to my supervisors, for their empathy and friendly assistance during my research period, to my lecturers who encourage me always to work hard in academics, and who pray for me unceasingly.

ACKNOWLEDGMENTS

First, I would like to thank the Almighty God, who gave me the grace to accomplish this work. I would like to express my sincere and special thanks to my supervisory team consisting of Dr OMAR Gatera and Dr OMOLOLU Akin-ojo, for their great guidance towards the achievement of this work from which I gained invaluable knowledge. Secondly, I wish to thank the African Center of Excellence in Internet of Things, College of Science and Technology, University of Rwanda, especially the ACEIoT authorities for allowing me to pursue this master's and for the skills they gave to me. I also wish to thank my lecturers on the Internet of Things for the good job done during my career of 2 years of our courses. Furthermore, my family as well as my classmates have been integral in all academic activities for their direct and indirect contributions to the achievement of my objectives. My acknowledgment goes to everyone who supported me in my everyday life to reach this moment.

May the Almighty God bless you all.

ABSTRACT

The economic vision of Rwanda includes a “made in Rwanda” policy aimed at increasing economic competitiveness by enhancing Rwanda’s domestic market through value chain development. It is in line with this that Banana Beer Production (BBP) in Rwanda has been increasing day after day and spreading the drinking of locally made banana beer (Urwagwa) to the extent that demand for the beer has become high. However, there is very little monitoring of the quality of the beer produced. Implementation of methods to recognize the amount or level of parameters (like sugar, ethyl alcohol, methanol, acetic acid, and other volatile acid) that plays a major role in the beer quality is very scarce making the drinking of unsafe banana beer a real possibility. The intake of unsafe banana beer can cause harmful side effects such as burning of the mouth and throat, breathing difficulties, drooling, difficulty swallowing, stomach pain, vomiting and can also be a root cause of chronic diseases such as high blood pressure, blood sugar level, mental health problems and others. This tends to make BBP and banana beer consumption a public health concern in Rwanda.

This master thesis research project focuses on prototyping the design and development of a Low-cost Banana Beer Alcohol Ingredient Detector (LBBAID) droppable into existing ready-made beer to assess the quality of the beer using the Internet of Things (IoT) and Machine Learning (ML) which is a branch of Artificial Intelligence (AI). The prediction of the quality of the beer can be done by observing patterns in the alcohol content and physicochemical properties of the drink. Our simulation results from Machine Learning show the best-fit ingredients and their amount in banana beer. AI, which is an effective non-linear multivariate tool in bioprocessing, with enormous generalization, prediction, and validation capabilities, is also compared with traditional optimization methods such as response surface methodology (RSM).

Keywords: AI, ML, IoT, Banana Beer Production (BBP), LBBAID.

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LIST OF SYMBOLS, ABBREVIATIONS, AND NOMENCLATURE

ACEIoT	:	African Center of Excellence in Internet of Things
IA	:	Industrial Attachment
API	:	Application Programming Interface
Dr	:	Doctor
GPS	:	Global Position System
GSM	:	Global System for Mobile Communications
HTML	:	Hypertext markup language
KIST	:	Karume Institute of Science and Technology
IoT	:	Internet of Things
OS	:	Operating system
WISENeT	:	Wireless Intelligent Sensor Networking
WHO	:	World Health Organisation
ML	:	Machine learning
AI	:	Artificial Intelligent
DFA	:	Discriminant Factory Analysis
IDE	:	Integrated Development environment

CHAPTER 1 : GENERAL INTRODUCTION

1.1 INTRODUCTION

Rwanda is a land-locked country that uses its resources for above 80% of economic and social development activities. Among the main economic activities in Rwanda are agriculture, business, and breeding. Rwanda relies on food crops such as bananas, Irish potatoes, cassava, maize, rice, and beans. Production of banana beer and cereal-based beers for sale has increased economic income for households [1], [2]. After the daily activities are over, and other community festival such as birth, weddings, and other traditional festival [3], urwagwa is used to signify hospitality to the community and families. Local beer made from bananas is the biggest drink that contributes 24% to the national income. Urwagwa [4] is one of the most popular and oldest traditional alcoholic beverages in Rwanda. Mainly produced from the fermentation of banana juice [5]. Other main alcoholic drinks produced in Rwanda are ikigage and kanyanga which contributes likely to the economy of Rwanda [6]. Studies show that in some African settings, local drinks require a high level of attention due to the production infrastructure of these products. Banana beer (urwagwa) fermentation techniques is one of the oldest and most economical methods in Rwanda [7]. According to WHO in [8] data published in 2018, Ethyl Alcohol Deaths (EAD) in Rwanda reached 156 or 0.27% of total deaths. The [9] employed Social Development Model (SDM), which incorporates both risk and protective factors into ethyl alcohol behaviours. examined [10] poor processing technologies used (untreated water, wild yeast, unhygienic handling activities, and poor personal hygiene) for banana beer production. The result shows that the increase in the local Banana beer production creates a dangerous situation for the consumer (like high blood pressure, blood sugar level, and mental health problems and others) if producers continue not guidelines provided by health regulatory entities.

1.2 BACKGROUND AND MOTIVATION

High blood pressure, high blood sugar level, and mental health problems are serious diseases caused using sub-standard beer, those chronic diseases can quickly lead to sudden or timely death. The World Health Organization (WHO) estimates harmful use of ethyl alcohol account 5% of the global disease burden, or 1 in 20 deaths [11]. The incidence of death decreases due to the ability of the community to obtain a clean product of a quality beer. Currently, banana beer is one of the oldest and major alcoholic beverages produced in most east African countries and is given names in different ways according to the country's traditional manners, for example it is called Tonto in Uganda [12], Mbege ni Tanzania [13], Urwaga in Kenya [14], Isongo in Burundi [15] and most famous name Urwagwa in Rwanda as shown in figure 1.

Banana beer is made in different districts in Rwanda, but it is also given different names like Urwedensiya, Rwabitoki, Urwarimu, and Birenge. In those districts, it helps to spread the availability of beer to be very easily in the villages and even in the city. So, the number of alcohol users increases day by day. However, health centers in Africa shows that the level of preparedness have many weaknesses expressed in the small number of facilities in rural settlements [16]. So most victims of alcoholic drinks are rural families.

Figure 1.2-1. Urwagwa local fermentation processing

1.3 PROBLEM STATEMENT

According to the National Industrial Research and Development Agency (NIRDA) Irregularity of quality parameters in an Urwagwa drinks of the same ingredients on the market [17] is big a challenge. This irregularity can be a root cause of burning of the mouth and throat, breathing difficulties, drooling, difficulty swallowing, stomach pain, vomiting beyond this so-called minor effects, chronic diseases like blood pressure, blood sugar levels, cancer, mental health issues, and even consumer death can be experienced afterwards. This is caused by not following standards guidelines in the production of these beers [18]. The current solutions are based on developing customized tools for diagnostics which are concerned with insight into the performance of food safety in traditional banana alcohol beverage factories. Furthermore, there is no mechanism for data creation and data storage of the real-time assessment. Those solutions are not practical for mass deployment in all communal banana beer factories to notify users in real-time about a potential level of ethyl alcohol ingredients with its effect after use of it. to a given example, is the diagnostic tool applied in seven Banana Based Alcoholic Beverage (BBAB) and four Urwagwa processing factories coded (A to G) and (coded H to K) [19] respectively, the case studies located in Kigali city, Eastern, Northern, Western and Southern provinces of Rwanda. The experiments ran manually with physical written documents and involve skilled staff to carefully drive all processes. Such an example of this solution is not scalable to the hundred or thousand banana beer factories, especially in rural areas.

Hence to prevent and mitigate these incurable and chronic diseases, production factories need adopt new technologies that can help in providing reliable data accuracy and transparency [20] on the beer quality produced products on the markets which is a must [21] for the benefit of the consumers and the good of the whole Rwandan community in larger.

1.4 STUDY AIM AND OBJECTIVES

1.4.1 AIM OF THE STUDY

The aim of this research is to develop an affordable IoT based Device that can support banana beer processors and users to determine homemade beer quality anytime and anywhere and create cloud data storage for future use and further analysis of the products. This aim will be achieved through prototyping diagnostic tools to detect alcoholic banana beverages quality by relying on open-source IoT and ML technology. Furthermore, the aim of this project line with the Sustainable Development Goals (SDGs) to ensure good health for everybody. This study aims at a quick and real-time detection of the number of compounds in the mix of a beer drinks to prevent the increases of side effects, chronic diseases, and even unnecessary deaths.

1.4.2 OBJECTIVES OF THE STUDY

The study objective is to design and prototype an IoT-based quality monitoring system for banana beer.

1.4.3 GENERAL OBJECTIVE

General is to develop an affordable IoT based Device that can support banana beer processors and users to determine homemade beer quality anytime and anywhere and create cloud data storage for future use and further analysis of the products.

1.4.4 SPECIFIC OBJECTIVES

i. To design and simulate an eLab Beers Quality Tester that can detect and record banana beer ingredients and provide meaningful output.
ii. To easy retrieve and analyze captured data as they can be sent to the cloud for visualization, analytics and future use in case needed.
iii. To validate the good operation of the prototyped end to end system in factories, standardization, and health entities.

The study guided by the following questions:

i. Why so many ingredients irregularities in banana beer products on the market?
ii. What are the parameters of banana beer quality?
iii. What should consider in designing the IoT real-time system to measure and predict the quality of banana beer?

1.5 HYPOTHESES

The hypothesis of this research are as follows:

1) The current IoT sensing technologies can efficiently collect microbial and biochemical parameters of the banana beer.
2) Integration of IoT and ML can be leveraged to detect the unnecessary amount of microbial and biochemical in the banana beer processed alcoholic.
3) There is available technology that could be used to create ML models capable of data processing.

1.6 SIGNIFICANCE OF THE STUDY

Ways to Recognize the amount of parameter in drinks is very poor, especially in African countries. Many thanks to the presence of technology of IoT, a technology that is user-friendly, does not cost, and does not waste time, which can detect, and report the other parameter in banana beer beverage report to cloud platforms will help single user to understand the capacity of that beverage before he decided to drink it and help necessary mitigation and preventing measure will be decided by the user him/her self. Urwagwa manufacturing is artisanal and characterized by the absence of instrumental and analytical control like in most traditional alcoholic beverages.

The fermentation of Urwagwa is conducted using traditional materials, Ikibindi (clay pot), Umuvure (wooden tanks), Ikidomoro (plastic tank). Urwina is a place where bananas are for ripening. The manufacture of this beer is generally done under poor hygienic conditions which result in a product with a short shelf-life and variable quality and low alcohol content. The quality of banana beer varies from one manufacturer to another manufacturer and one brew to another. Furthermore, in Rwanda, there is no scientific studies of banana beer have been done on microbiological and biochemical changes which occur during the production of the product. So the possibility of increasing the effects of alcohol use is large. Therefore, a solution that can report consistently will be given a more accurate epidemiological view.

Despite of increasing level of the chronic disease led by the bad fermentation of banana beer to people, the possibility of mitigating the current situation is quite possible. According to WHO, the death rate from chronic alcohol use is about 156 or 0.27% in the year 2018 [9] in Rwanda. This project can help the overall not only Rwanda, but also other African neighbouring countries set to be healthier and bring the death rate and the number of affected further down through early detection techniques and monitoring the banana beer ingredient alcoholic quality.

1.7 ORGANIZATION OF THE STUDY

This work is organized into five chapters:

- **Chapter I:** General Introduction, this chapter focuses on the Aim and Objectives of the study, the Problem statement, the Hypothesis, and the Significance highlighting the potential impact.
- **Chapter II**: The Literature review, offers theoretical concepts regarding the related work done by the other researchers.
- **Chapter III:** Research Methodology, this chapter will illustrate the main concepts of this study.
- **Chapter IV:** Focuses on the system design and its different block diagram.
- **Chapter V:** Focuses on the results of the study and discussions.
- **Chapter VI:** The last chapter is made up of the conclusion and recommendations for further improvements of this project.

1.8 CONCLUSION

In this chapter, a brief description of the project has been started that introduces the setting and background. Furthermore, the aim and objectives of the study are detailed. The problem statement highlights the scope of what is to be overcome and proposed techniques and technologies that will be used in the prototype in accordance with the assumptions the project is planning to achieve at the end of design and implementation. The related works and literature reviews are detailed in the coming chapter.

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION

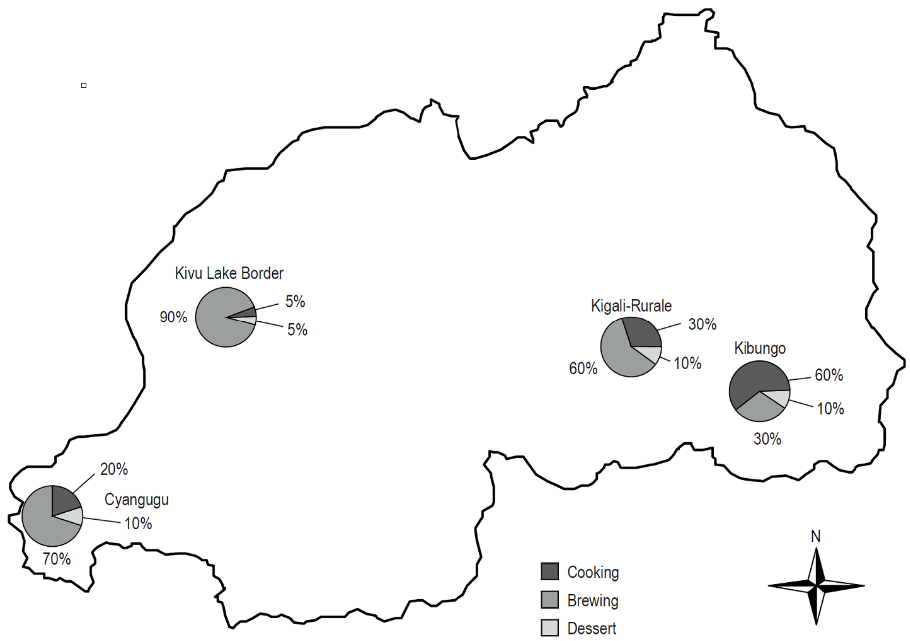
In the previous chapter, we have been able to see the actual background environment of this project. In this chapter, we will be able to see literature reviews, reference projects, and the state of the arts according to previous studies. However, we will be able to identify the specific goals of the work that has already been done on the development of banana beer, we will identify the challenges that have been overcome, and we will also identify the existing gap which is the main reason for implementing this project.

2.2 WHY BANANA BEER?

Historically, Rwanda's economy is heavily influenced by the output of beer produced from banana crops. So, it is understood that the country of Rwanda is one of the most famous countries in the production of bananas in East African countries along the Great lakes region and has one of the highest consumption rates. Bananas occupy 23% of the country's arable land and contribute more than 50% of annual crop production in terms of fresh weight [22]. Figure 2 is the layout of how the competitive market environment of beer is during the production.

Figure 2.2-1. Banana beer industrial production process

Banana's beer is the most cultivated in the three main growing areas in Rwanda, namely around Lake Kivu, about 85 to 90% of cultivars are found in these areas, In Cyangugu areas about 60 to 80% of cultivars are found in these areas, and Kigali Rural, about 60 to 70% of cultivars are found in [23]. Research has continued to show the correlation between the three main types of cooking, brewing, and dessert. The research study has continued to discuss the significant level achieved and the contribution of beer production in these major areas. It has emphasized that its market is very important for the national income of the country of Rwanda. However, the research study has discussed the state of poor production methods that exist in all areas of banana beer production. Figure 3 shows the three main kinds of banana beer growing.



Source: NISR, SAS 2020

Figure 2.2-2. Location of the main areas of the banana beer production

There is research that have been done to research the quality of new methods to examine the type of banana. after the techniques utilized are based on the use of particle acceleration for cell suspensions and former cases. These types of studies did not show the results of the process of the results of these crops. One of the main crops studied is the banana crop. These studies were carried out by relying on specialized laboratories that required specific time, specialized personnel, and specialized equipment to achieve the results of these studies as described by [24]. Research has also stated that the determination process takes 5-6 months.

2.3 TECHNOLOGIES BASED ON BANANA BEER QUALITY ENSURING

The [25] Machine Learning (ML) techniques were used to develop a predicational tool for the prediction of blood alcohol concentration. A digital signature of smart Breathalyzer behaviour tools was developed. These tools are the best fit for the classified detection of banana beer. The results produced were based on the checking equality of the banana beer produced. However, the project does not address beer quality parameters as well. Edwin [26] develop a model which favours a bioprocess to optimally produce umqombothi (a south Africa Traditional beer). The model is based on utilizing the resources regarding the necessities for beer processing. Unfortunately, the complex method was used in such a way very technical skills are needed to operate such kinds of models. However, the model was not based on time consumption. in [27] has specified steps to check hygiene and quality assurance. In this book, it was not explained what kind of technology is used to review hygiene and quality assurance in the work they reviewed. But they explained local methods that are used to ensure hygiene and quality assurance of banana beers. This study has shown that the evaluation of banana beers is done by cleaning only beer producers. So, there is a great importance to have alternative methods to verify the quality of scientific banana beers.

2.4 STATE OF THE ART ON ALCOHOL QUALITY DETECTION

E-noses is an IoT-based system made from a matrix of chemical sensors based on metal-oxide materials is composed of four elements: sensor matrices, a signal processing unit, data storage, and pattern recognition which perform by a human olfactory system [28]. E-nose is the tools developed to identify the alcohol content quickly and accurately in beverages together with a reduce marketplace. However, the project combines 13 gases sensors which is a cost consume of investment.

Nurul et al. in [29] developed a method for the rapid detection of ethanol concentration in beverages. It tested beverages without alcohol concentrations. The rest of the developed device could be used to quickly detect ethanol concentrations in several beverages from a different brand sold in Malaysia. The developed device demonstrated high precision. In addition, the developer used Response Surface Methodology to obtain a coefficient of determination, which means a high correlation between the model and the real response.

In [30] analyse 21 different alcoholic beverages from different kinds of (beer, wines, and spirits) using different methods. Discriminant Factorial Analysis (DFA) and Principal Component

Analysis (PCA) allowed them to clearly identify the differences among these beverages and classify them independently of the ethanol content. The devices did not discriminate the context but only among the beverage type and group.

2.5 POSSIBLE GAP IDENTIFICATION

As described above, all literature reviews were focused on classification, fermentation differentiations among beer groups, and well as the development of the detecting systems. Due to the involving expensive, complex, high latency processes, and highly skilled people needed to be proposed by the developers somehow there are undefined friendly detector systems for the alcohol user. For better efficiency using IoT technology, real-world physical entities could be deployed by actuating, sensing, computing, and visualizing the gradient of banana beer beverages.

IoT is one of the most revolutionary technologies which is the best solution in modern wireless communication enabling the system to be well organized. The Banana beer quality detector will be a model that will help in detecting of banana beer quality before taken to the end user.

The main purpose of this study is to design a quality beer system for detecting banana beer quality here in Rwanda. In this paper, the real-time investigation technique is proposed to overcome the identified above-mentioned gap. Banana beer detector tools sensed data will be transmitted to the cloud where ML process perform and observe banana beer quality analysis (inference) to predict the quality of the fermented beer. The solution and all process, for now, will be done on the cloud.

2.6 CONCLUSION

A clear gap in how the manual technique was used to analyse banana beer quality which are not user friendly especially for who are not well knowledge on beer characteristics. We have seen that existing solutions still require laboratory-like processing and examinations, skilled labour, and more expensive resources that cannot be feasible in resources constrained countries, especially in Rwanda. Therefore, this study proposes IoT technologies to capture quality parameters of banana beer inference using online processing.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 INTRODUCTION

In the research methodology, the study describes how the research will be conducted to meet the planned objectives. The chapter was organized as follows: First, it will present the steps undertaken to enable the study to get parameters, then followed by research techniques and tools used to facilitate the target of the project. The chapter will be based on online data processing thus is why will be demonstrated with the method approaches.

3.2 RESEARCH PROCESS

The research process was overtaken after the realization of data referring. The topic was created, and the gathering information activities were occupied. Based on the proportional and systematic our research process was organized In Figure 4. Shortly the process started with having planning phase which has including all necessary requirements including resource selection idea creations, selection of the project target areas and so forth, followed by data collection whereby searching the existing data, the analysis of the currently collected data is another process taken in order to make a mind map of the project directional, data normalization and prepossessing into a machine learning of creating ML model, training it and final testing the model before deploying it to the cloud.

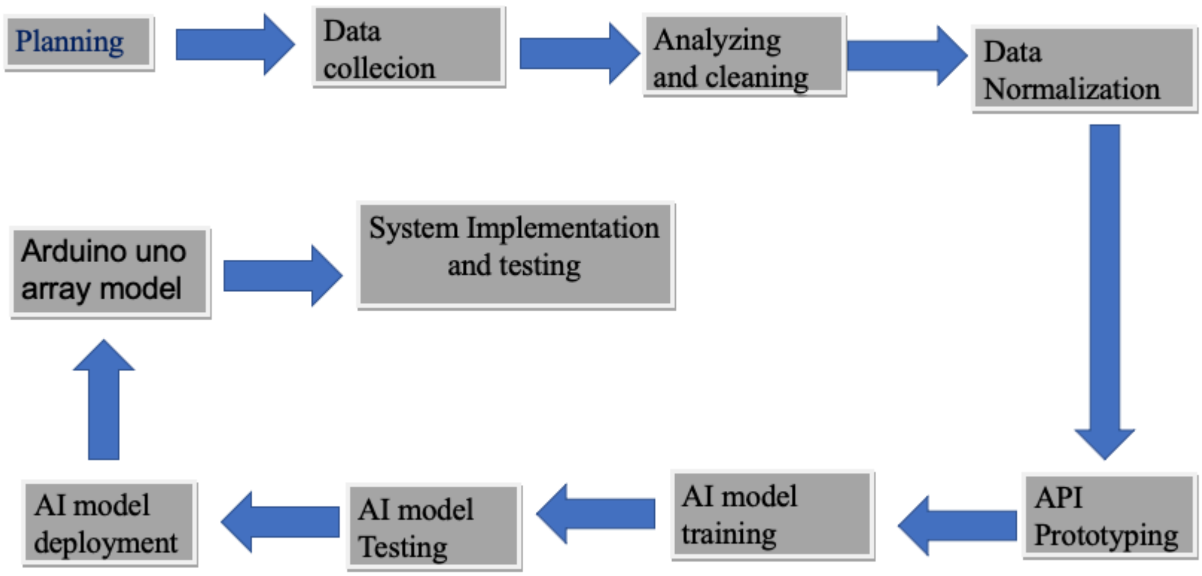


Figure 3.2-1. The Research processes

3.3 DATA RETRIEVAL AND ONLINE PROCESS

Our project has constructed into two main phases. The initial part is based on data collection as a sample to be used as ML data processing inference. On other hand, those data captured by the sensors are to be stored in the online cloud database platform. In this project we created a dependent data storage space for storing those banana beer elements regarding to the minimum scale of our project target. In the second part, based on ML data processing which is likely use the online platform in the cloud. ML data process requires a dataset for implementing data training. We are going to use a dataset created by us during the development of our prototypes, this dataset is the collected data of the element contained by the banana beer alcoholic by using a five IoT sensor. The sensor collects basic banana beer gradients through the programming code the sensors is distinguished accordingly into the main classes, ethyl Alcohol, Sugar, Acetic acid, Methanol, and volatile gases. The dataset will be used in the training process on an ML framework and create a model optimized for embedded processors. The created model will be packaged in the form of a software library, and after that could be integrated into our online application. The integrated model to the online application will create results and these results will be and display result in the online web page layout. The main function is getting the validity by reading test data from a file and comparing the result accuracy with one obtained by ML.

3.4 PROTOTYPING TOOLS STACK

The prototyping tool stack is the tool which demonstrates the whole steps of project functionality. In this study the tool stack is based on the online process after gathering data. The significance of using tools stack is to outline the main part of the project with their main out puts after processing. The tools stack diagram is demonstrated in the figure 5.

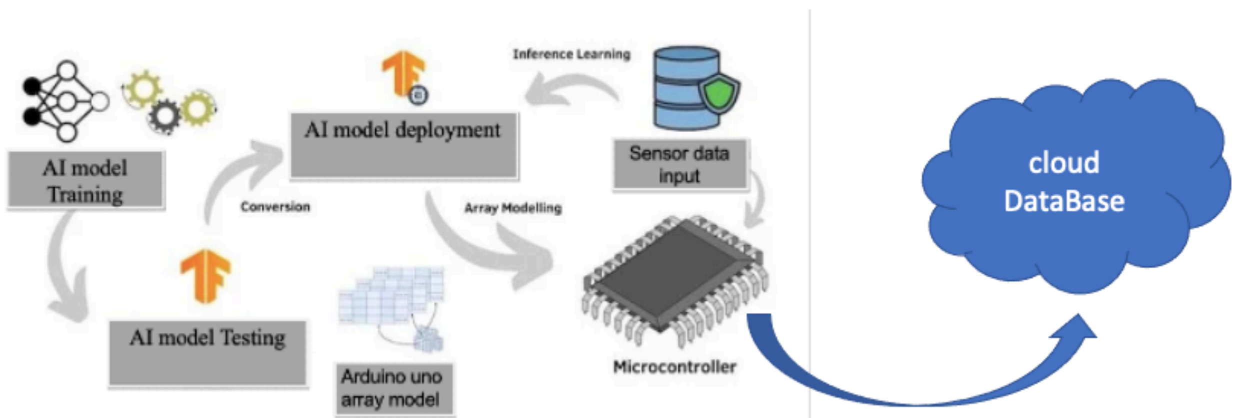


Figure 3.4-1. The prototyping tool Stack

3.5 TECHNOLOGIES FOR PROJECT DEVELOPMENT

To meet the project goal, the following technologies were applied to facilitate the completion of this project. The selection of the technologies based on the requirement of the target goals of this project. Therefore, the following descriptions have been considering to the important of each technology mentioned in as follows:

a) **Tensor flow, the online open-source platform:** It is an open source that can be used for the development of ML models. It allows the direct acquisition of data from the sensing device or the uploading of collected data in various formats. Tensor flow allows data from different processing blocks to be available for training. This study will try in advance to apply different kinds of ML platforms such as the expert mode, custom processing blocks, etc.

b) **The Arduino Integrated Development Environment (IDE), the open-source software tool application:** It is open-source software that provides an easy way of writing codes and uploading to the IoT devices and enables them to operate as the instructions say. The IDE could enable running into the different operating systems as the main support tools for creating such IoT projects including Windows OS, Linux, Androids, and MAC OS. The common language based on the IDE is the java programming language. The IDE helps to integrate the device and program it in the way the project goal is set.

c) **Technology for developing simulations**

Edge Impulse is the leading development platform for embedded machine learning, used by over 1,000 enterprises across 45,000 ML projects worldwide. With Edge Impulse, a digital signal processing method is used to keep safe processed data. The observation of the collected data on the digital signal processing block enables us to have a clear view of the features that we want to feed into the Neural Network Technology (NNT). The flattened modules that looked at averages, standard deviation, minimum, maximum, skewness, and kurtosis are suitable for the kind of data being used. Upon review, feeding raw data of the available datasets without further processing showed a clear separation of features of raw data for both classes as shown in figure 5.

Edge Impulse operates a typical software as a service (SaaS) business model, with a generous free tier for individual engineers which is free up to and including production.

d) A web browser platform, the online inference display tools: To display the result of Banana beer gradients a web page is used. The dashboard developed on this project will have five important layouts. There will be a part to display Banana beer gradients, test button for input samples and the graph represented the flow of the amount of the tested results.

3.6 SYNTHETIC DATA GENERATION APPROACH

Synthetic data is the data generated using a purpose-built mathematical model or algorithm, with the aim of solving a (set of) data science tasks. Important of discussing this scientific method is to protect privacy. Synthetic data is generated by a model often with the purpose of using it in place of real data. By controlling the data generation process, the end-user can adjust the amount of private information released by synthetic data and prevent its resemblance to real data. Also, it helps to adjust for biases in historical datasets and to produce plausible hypothetical scenarios.

Our project is considering using this approach because it will help in our prototype of the data-driven models and be used to verify and validate ML pipelines, providing some assurance of performance. It is the best approach that could have responsible innovation by creating digital sandbox environments used by start-ups and researchers in hackathon-style events. Synthetic data generation is a developing area of research, and systematic frameworks that would enable the development of this technology safely and responsibly are still missing.

The datasets of banana beer research mostly are massive, are not so easy to process, and they need much time and well strong laboratory which cost a lot. So that the model of synthetic data is used to increase data in cases where there are low datasets. The steps of data synthesis start with a sample raw data that is uploaded into the synthetic data platform in a CSV format and a hold-out machine learning method is used for machine learning model evaluation and selection. Then followed by the provisioning step in which free computing resources are allocated, and thereafter the encoding process in which data transformation is done. For the case of this project , the Logistic regression model have been found the most fitting for the best output result for that reason it is trained and used in our case study. Finally, the accuracy and privacy contrast took place from the data analysed which enable the quality assurance of banana beer report to be generated.

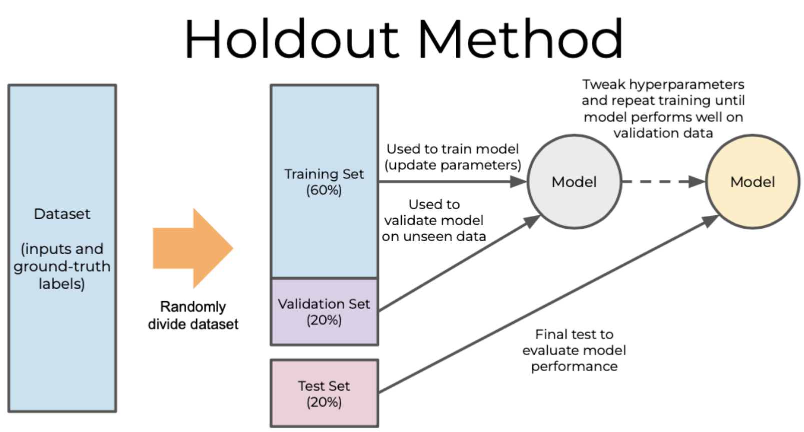


Figure 3.6-1: hold-out method system development cycle

3.7 SYSTEM DESIGN METHOD

The Agile software development method in figure 6 was the selected technique for the development of the embedded system given its evolutionary and iterative nature. The approach allowed us to improve the system in proportional phases and the ML model with each iteration. Frequential meeting was organized to discuss the ongoing on of the project process. The technique gave us the simplicity to decide on areas of improvement within the iteration. It could make the development process rational and quick allowing the addressing of the most pressing issues immediately.

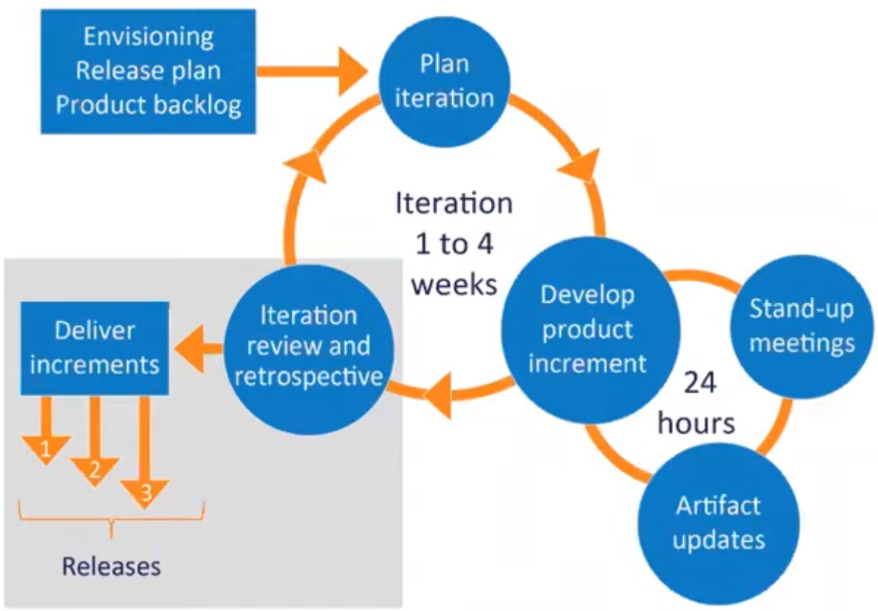


Figure 3.7-1: The Agile system development life cycle

3.8 CONCLUSION

In this chapter we have been able to explain various methods, approaches and techniques that have been used to make this project successful. We have been able to see that the success of IoT projects requires a platform or the integration of various methods so that the work can bring good results. We have also been able to discuss the development technique taken during the project implementation. The Agile methods system has enabled us to achieve this work well and meet our goals.

CHAPTER 4 : SYSTEM ANALYSIZ AND DESIGN

4.1 INTRODUCTION

This chapter will explain step by step the expected system analysis and design, this will highlight different system architecture block diagram and the way they are interconnected to enable intended IoT-based quality monitoring for banana beer product project hardware implementation.

4.2 SYSTEM ARCHITETURE

This subsection will describe the relationship between components and other aspects of the software system for better design and development of the intended IoT-based quality monitoring for banana beer product.

4.2.1 HIGH LEVEL DESIGN

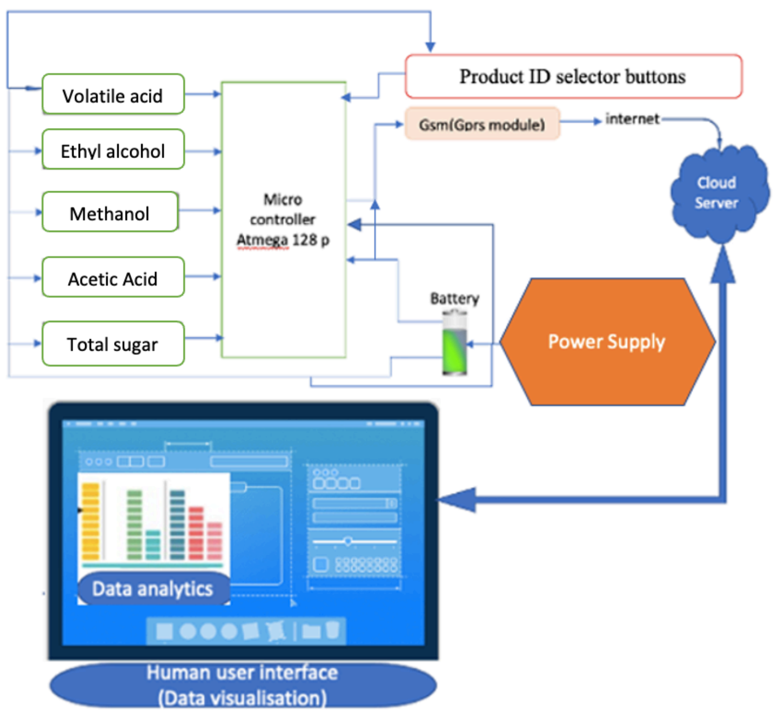


Figure 4.2-1:system high level design block diagram

The figure above is the proposed high level system design which highlights the components to be used and their layout on the motherboard; those components include but not limited to low data capturing sensors, microcontroller for low data collection, power supply and backup power supply for powering the system and data transmission network module to send collected low data over the cloud via GSM (GPRS module) for further processing and analytics.

4.2.2 IOT SYSTEM ARCHITECTURE

The researcher used a five-layered architecture in the proposed system, namely, business, application, processing, transport, and perception layers. These layers describe the data flow from hardware devices to the application layer with the services of business layer in application layer. In this research, this layered architecture has been used because; the proposed system needs to manage apps based on the data sent to the cloud severs.

Table 4.2-1: PROPOSES SYSTEM LAYERED ARCHITECTURE

No.	Name	Description
1	Business layer	In this layer, the proposed system manages applications based on the data sent to the cloud server.
2	Application layer	This layer is responsible to provide application specific services to the factories and standard bureau. Other application services include dashboard and data visualization application services established specifically.
3	Network layer	The GSM communication protocol with 3G network services used transmit data from perception layer to application layer.
4	Perception layer	This layer also known as physical layer, where the proposed system sensors; MQ-8 for sugar sensing, MQ-138 for methanol sensing, MQ-3 for ethyl alcohol sensing, MQ-6 for acetic acid sensing and MQ-135 for volatile gas sensing. The collected data then sent to the microcontroller.

4.3 EMBEDDED SYSTEM REQUIREMENT

This subsection will show the intended hardware devices to be used for this IoT-based quality monitoring for banana beer product and the way those devices are interconnected on the mother.

4.3.1 EMBEDDED SYSTEM DESIGN

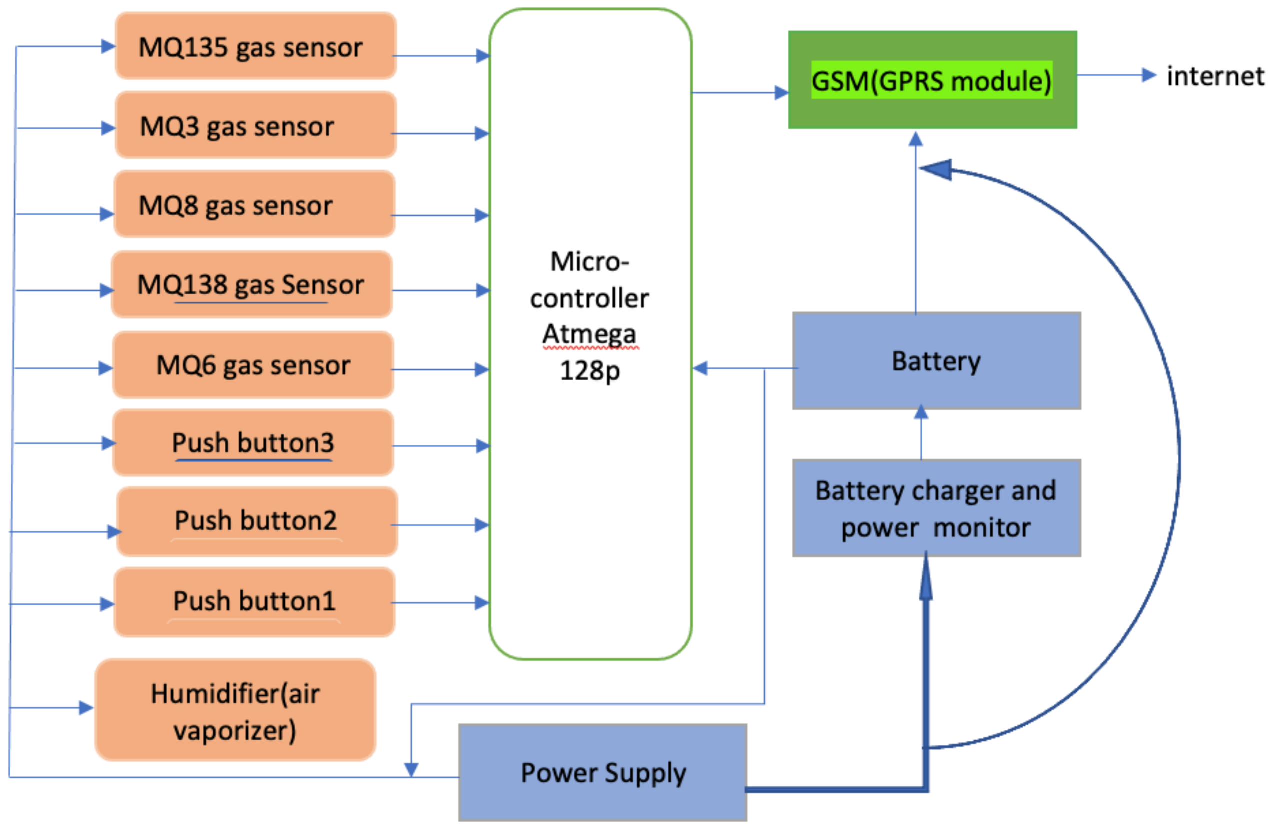


Figure 4.3-1:Embedded system design block diagram

The figure above is the proposed embedded system design which shows the physical components (electronics components) on the board those components include but not limited to push buttons, humidifier, battery charger, backup power battery, MQ-8 for sugar sensing, MQ-138 for methanol sensing, MQ-3 for ethyl alcohol sensing, MQ-6 for acetic acid sensing and MQ-135 for volatile gas sensing. The captured data then sent to the microcontroller for low data collection and then sent to the cloud via GSM (GPRS module) for further processing and analytics.

4.3.2 SYSTEM BLOCK DIAGRAM

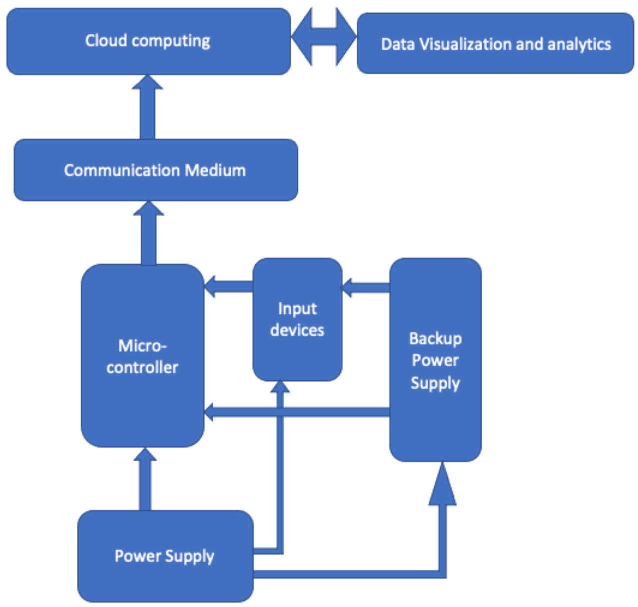


Figure 4.3-2:System design block diagram

The figure above shows a summarization layout's components used in this project in a block diagram design way whereby each block provides an overview of the components used and their function in this project design.

4.4 SYSTEM REQUIREMENT

This subsection will cover theories and operation principles for the intended hardware components to be used for this IoT-based quality monitoring for banana beer product project research.

4.4.1 SYSTEM HARDWARE REQUIREMENT

This research will use different IoT components for low data collection and transmission to the cloud; those components will include but not limited to gas sensors, water humidifier, GSM (GPRS module), Microcontroller and batteries for backup power supply.

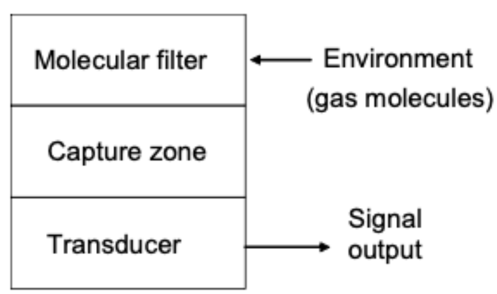
4.4.2 DATA INPUT COMPONENTS

As this research main objective is to measure local home-made alcoholic based beverages as there is no specific sensor that can be able to perform the stated job; this project will use an immersed electrode humidifier to vaporize liquid content so that gas sensors can read data contained in that vapor and input it as low data to a microcontroller for further processing and analysis.

A) **Immersed electrode humidifier**: This humidifier uses a large area of immersed electrode in the water as the terminal, uses water as the heating medium, when the current transfers electricity through water, it produces heat, makes the water boil, and produces steam. It has the characteristics of low cost and easy installation and use. But its humidification accuracy is low, and its water tank needs to be replaced regularly.

B) A **gas sensor** is a device which detects the presence or concentration of gases in the atmosphere. Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage. Based on this voltage value the type and concentration of the gas can be estimated.

Table 4.4-1: BASIC GAS SENSOR COMPONETS



4.4.3 LOW DATA COLLECTION COMPONENTS

The Microcontroller is also known as an embedded controller or microcontroller unit (MCU). Microcontrollers are designed to be used without major computing resources. The Microcontroller is an integrated small circuit (electronic device) used to govern a specific operation in an embedded system. It has a CPU processor, memory, and input/output (I/O) peripherals that are combined on a single chip (onboard memory and pins for general inputs and output operations). Microcontrollers can directly connect communicated with sensors and other components.

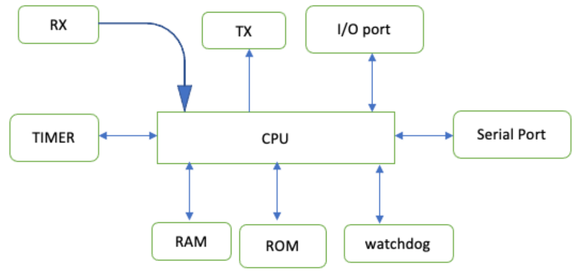


Figure 4.4-1:Microcontroller basic architecture

4.4.4 CLOUD DATA TRANSMISSION COMPONENT

Since the capabilities of Microcontroller (processing hardware resources, memory, and storage) are limited; the ongoing research is using cloud computing resources for fast execution of the operations. Cloud computing is the technology that is the on-demand availability of computer system resources (storage, processing power, databases, networking, analytics, artificial intelligence, and software applications) without direct active management by the user.

The research will use GPRS technology for data communication.

The GPRS stands for General Packet Radio Service, and it is used to send/receive data using 2G (second generation) and 3G (third generation) cellular communication networks on the global system for mobile communications.

4.5 HARDWARE SPECIFICATION

As highlighted in the previous section this research project embedded implementation is mainly composed with three main parts (data inputs, data collection and transmission);in this subsection we will their physical specification on the market or in real life.

4.5.1 DATA INPUTS HARDWARE SPECIFICATION

This project will use an ultrasonic humidifier and gas sensors to get required data from product to measured.

A) Like mentioned in the above paragraph, this project will use **Ultrasonic humidifier** as tool to convert liquid beverage in vapor so to detect this using gas for low data caption; ultrasonic humidifier uses ultrasonic high frequency oscillation of 1.7 MHZ to break down the water into particles of 1-5. The **ultrasonic humidifier** characteristics like high humidification efficiency, even water mist, small power consumption and long service life made this kind of humidifier the best choice for this project.

Figure 4.5-1:ultrasonic humidifier.

B) Gas Sensors

Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage. Based on this voltage value the type and concentration of the gas can be estimated; the ability of a Gas sensor to detect gases depends on the **chemiresister** to conduct current.

This project will use MQ-8 for sugar sensing, MQ-4 for methane sensing, MQ-3 for alcohol sensing, MQ-6 for acetic gas detection and MQ135 for volatile sensing gas.

Figure 4.5-2:Gas sensors used in this project

4.5.2 LOW DATA COLLECTION DEVICE SPECIFICATION

A Microcontroller is an electronic device belonging to the Microcomputer family. These are fabricated using the VLSI technology on a single chip; an ATMEGA32 is the type of Microcontroller that is to be used fin this research. ATmega32 was made by Atmel corporation, mega (AT), it has 32kb flash memory and it is in the family of an 8-bit microcontroller (mega AVR) family, this Microcontroller is also known as an embedded controller or Microcontroller unit (MCU).

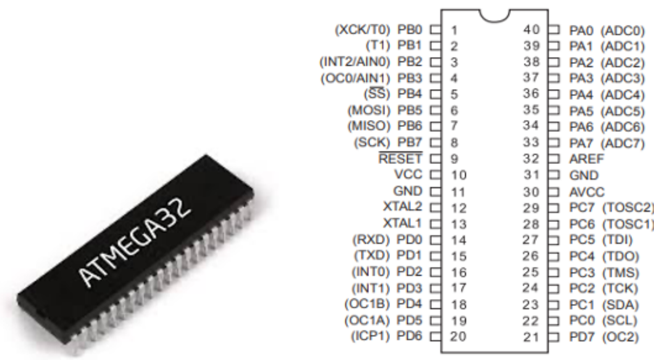


Figure 4.5-3:Microcontroller specification

4.5.3 CLOUD DATA TRANSMISSION DEVICE SPECIFICATION

This research will use GPRS technology as communication medium for data communication and transmission. The SIM800 is a cellular communication module that is used to make calls, send email, and SMS texts it has also the capabilities to connect to the internet using GPRS. The GPRS stands for General Packet Radio Service, and it is used to send/receive data using 2G (second generation) and 3G (third generation) cellular communication networks on the global system for mobile communications.

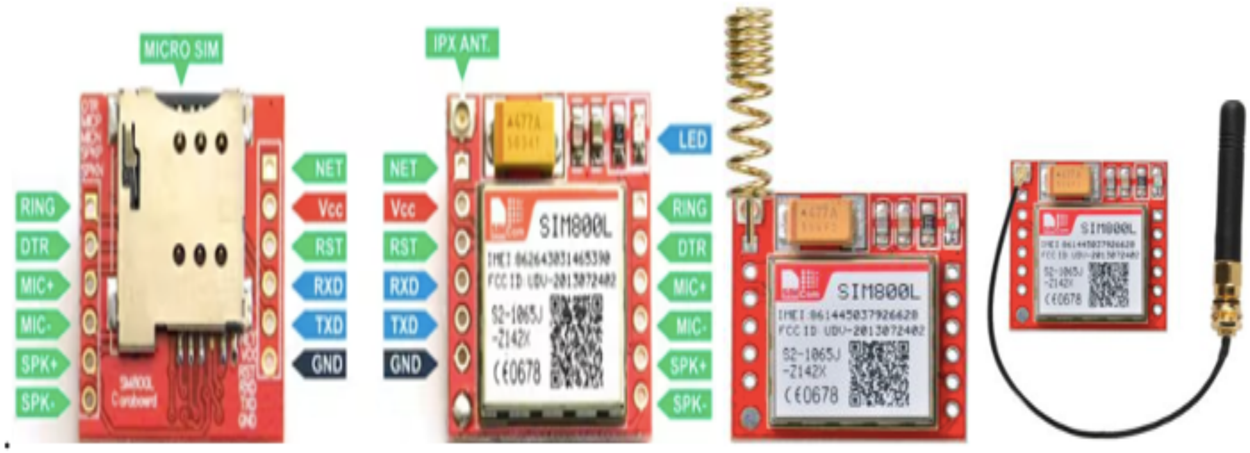


Figure 4.5-4: SIM800L GSM/GPRS

The following table is the short summary of the description of each hardware components participating in the implementation of the system.

Table 4.5-1: DESCRIPTION OF COMPONENTS AND THEIR FUNCTIONS.

Name	Type	Description
Modem	GSM800	Internet connectivity
Humidifier	Piezo buzzer	Liquid vaporiser
Sensor	MQ-3	Ethyl Alcohol lever sensor
Sensor	MQ-138	Methanol gas lever sensor
Sensor	MQ-6	Acetic acid gas lever Sensor
Sensor	MQ-8	Sugar level sensor
Sensor	MQ-135	Volatile gas level sensor
Sensor	Pushbutton	ID selector
Power source	Direct current	Power Supply
Current routers	Wires	Powers channels
motherboard	motherboard	Devices support
Microcontroller	ATMEG32	Execution of the program to control output from inputs sensors
Data Base	Cloud	Human Interface

4.6 SYSTEM FLOW DIAGRAM

This subsection will cover the programming description language whereby in this programming description is grouped in three loop, main loop which is called main program and two subloop mapped as subprogram then after this program will be explained in flow chart diagram for easy system software design of the IoT-based quality monitoring for banana beer product project research.

4.6.1 SYSTEM PROGRAM DESCRIPTION LANGUAGE

This programming description language flow will go through the main idea of programming software of this project research.

Here below is the programming description language concept.

Table 4.6-1 PDL FLOW CHART

MAIN PROGRAM

```
BEGIN
    CALL NETWORK
        REPEAT
            READ SENSORS DATA
        UNTIL BUTTON ID SELECTOR PUSHED
        SEND DATA OVER THE CLOUD FOR PROCESSING AND STOCKING
        CALL DSPLAY
END
```

SUBPROGRAM 1

```
BEGIN/NETWORK
    SEARCH FOR NETWORK
        IF NETWORK FOUND
            PRINT CONNECTED SUCCESSIFUL
        ELSE
            PRINT NETWORK FAIL
        ENDIF
END/NETWORK
```

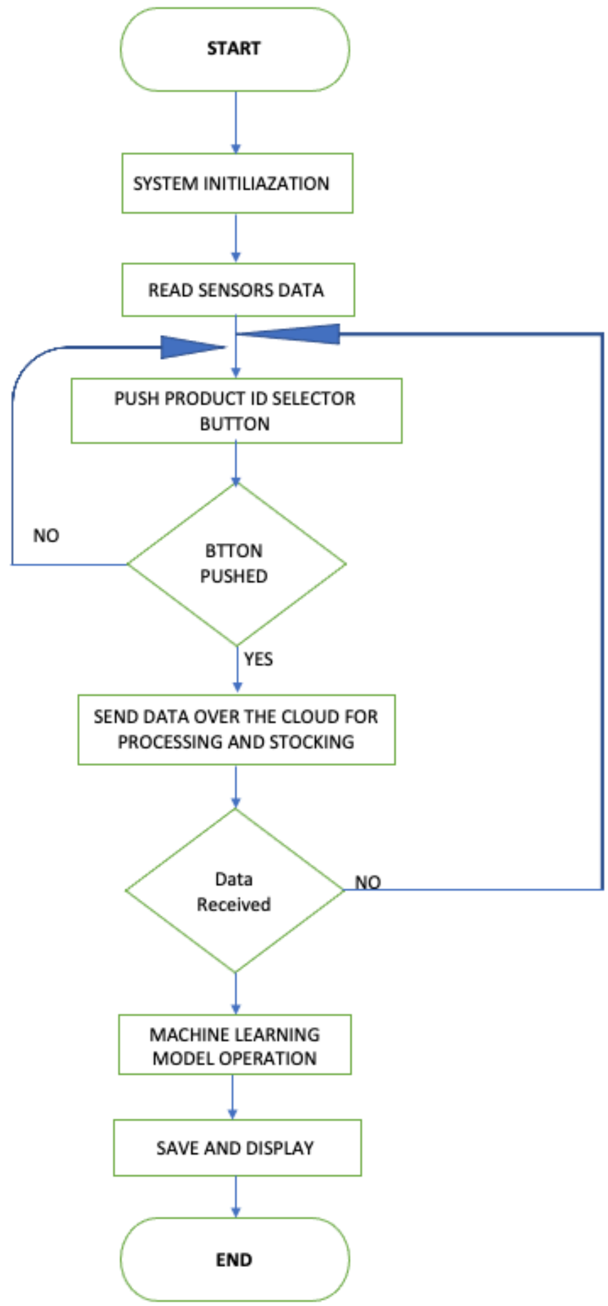
SUBPROGRAM 2

```
BEGIN/DISPLAY
    READ SELECTED ID PRODUCT DATA AND PREDICT PRODUCT QUALITY
        IF DATA ANALYSIS NEEDED
                TREND SELECTED ITEM FOR DATA ANALYSIS
        ENDIF
END/DISPLAY
```

4.6.2 SYSTEM FLOW CHART DIAGRAM

The below flow chart diagram will summarize the operation and working principle of this project research from its start up to the data visualisation and analysis.

Table 4.6-2: SYTEM FLOW CHART DIAGRAM



4.7 HARDWARE AND SOFTWARE SETUP

A) on hardware side all the electronic hardware described in the above section will be housed in one compact embedded whereby all the electronic components will solder on a motherboard card and then after being housed in the box for device security and product aesthetic.

B) On the software side a created model will be packaged in the form of a software library, and after that could be integrated into our online application through Heroku using a python programed API. The integrated model to the online application will create results and these results will be saved in online database executable where those data can be retrieved and be displayed as a result in the online web page layout. The main function is getting the validity by reading test data from a file and comparing the result accuracy with one obtained by ML.

eLab Beer Quality Tester training model

```
In [15]: model = LogisticRegression()
         model.fit(X_train, Y_train)

/opt/anaconda3/envs/ACEIOT/lib/python3.9/site-packages/sklearn/linear_model/_logistic.py:444: ConvergenceWarning: l
bfgs failed to converge (status=1):
STOP: TOTAL NO. of ITERATIONS REACHED LIMIT.

Increase the number of iterations (max_iter) or scale the data as shown in:
    https://scikit-learn.org/stable/modules/preprocessing.html
Please also refer to the documentation for alternative solver options:
    https://scikit-learn.org/stable/modules/linear_model.html#logistic-regression
  n_iter_i = _check_optimize_result(

Out[15]: ▾ LogisticRegression
         LogisticRegression()

In [16]: print("Training accuracy= {:.2f} %".format(model.score(X_train,Y_train)*100))

Training accuracy= 90.10 %

In [17]: print("Testing accuracy= {:.2f} %".format(model.score(X_test,Y_test)*100))

Testing accuracy= 89.58 %

In [18]: filename = 'Beer_model.sav'
         pickle.dump(model, open(filename, 'wb'))

In [19]: loaded_model = joblib.load(filename)
         result = loaded_model.score(X_test, Y_test)
         print(result*100)

89.58333333333334
```

Figure 4.7-1:System ML model screen shot being tested for accuracy

CHAPTER 5 : SYSTEM RESULTS ANALYSIS

5.1 INTRODUCTION

This chapter will explain step by step the expected system results and results analysis summarization, this also will highlight different system dashboard and the way they can accessed and manipulated in order to understand the intended IoT-based quality monitoring for banana beer product project idea and outcome; although this project is an academic research when enhanced can greatly improve the small factories production as well as the production monitoring on the side of the FDA and health in charge entities without forgetting the lives of the consumers.

5.2 SYSTEM HIGH LEVEL DESIGN

The implemented application stores data in the cloud, and different analysis can be accessed by providing a username and password using the following login form:

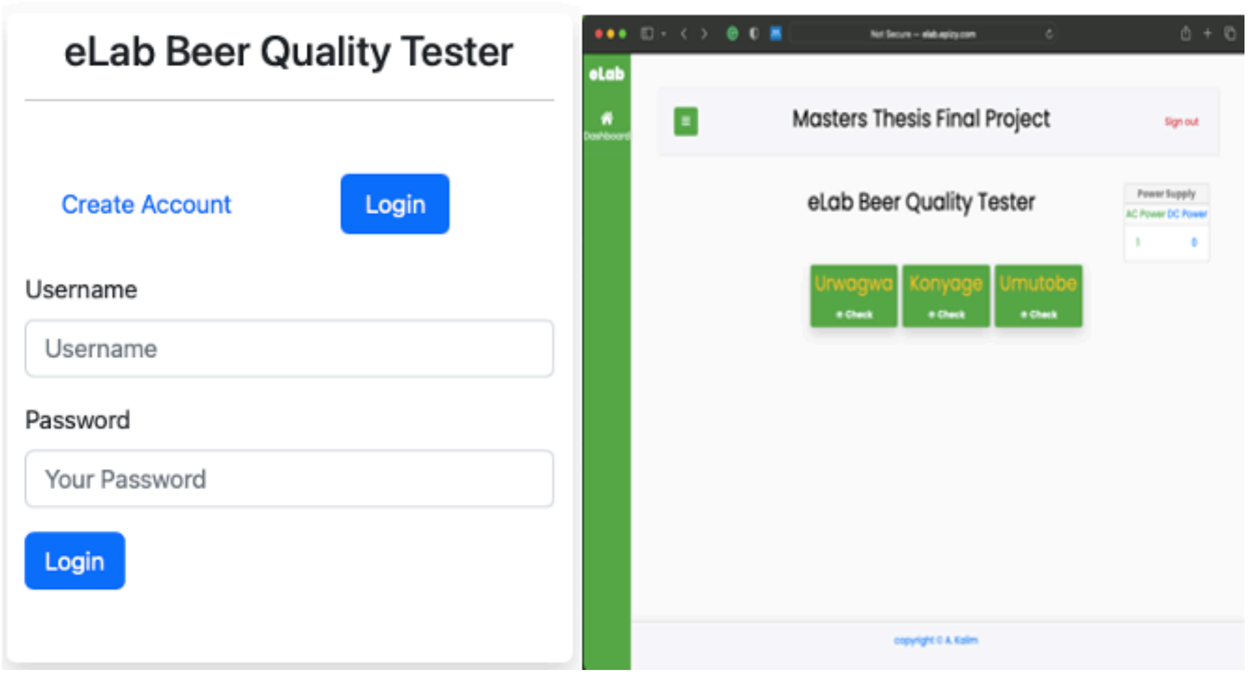


Figure 5.2-1:System login page

On the opening page, there is also a possibility for new user to create an account by providing his or her username and password.

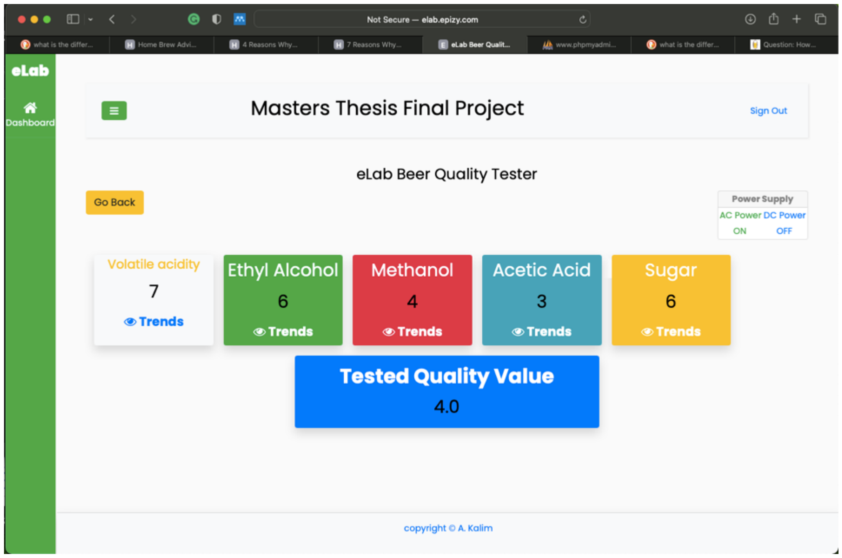


Figure 5.2-2: System main dashboard page

The above figure shows the dashboard of the current statistics for the measured parameters (i.e., volatile acidity, ethyl alcohol level, Methanol, Acetic and Sugar and their predicted quality value) that are currently stored in the system. This dashboard is called the "live dashboard."

From this dashboard the overall tested beer quality values helps us determine if the drink satisfies requirements as per standard regulations.

This project research is basing on low fermented beer usually called larger beer which fall in the category of 5% ABV (alcohol by volume) and the proposed system aim is to be able to test the 5% value in sample beer to prove its standard.

Table 5.2-1:ALCOHOL BY VOLUME IN DRINKS AND BEERS

ABV value in %	Type	Description
0.05	Non-alcohol drinks	Classified as free alcohol drinks
<0.05>=1.2	Low-alcohol drinks	Classified as soft drinks
4 to 5	Larger drinks	Classified as low fermented beers
10 to higher	Spirit drinks	Classified as liqueurs beer

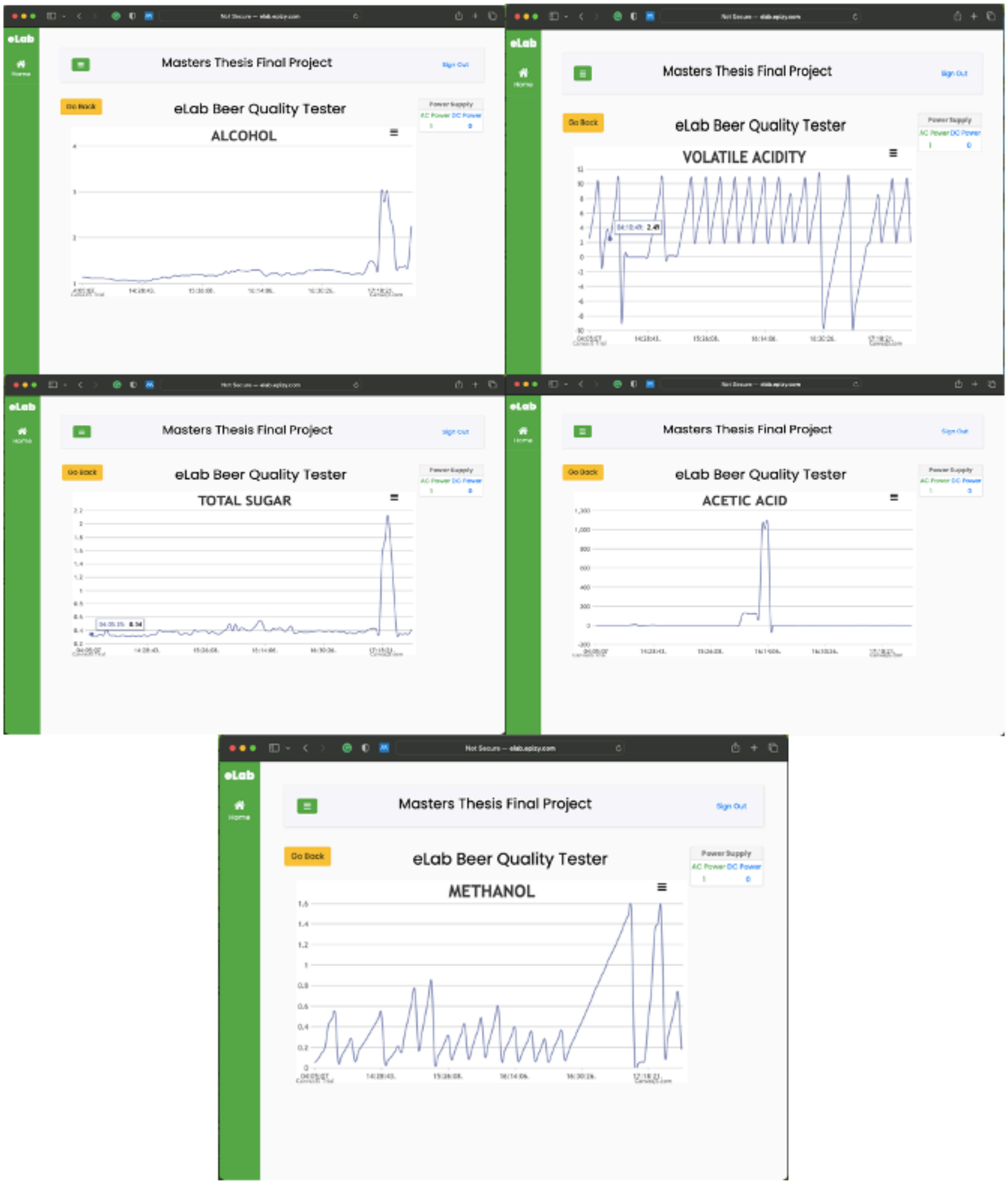


Figure 5.2-3:System different data trends caption dashboard page

After testing a product, the proposed system can save the overall tested results for production consistence and product analysis for future improvements and adjustment of ingredients.

CHAPTER 6 : CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

For many types of alcoholic beverage quality testing, sophisticated chemistry lab based method is the only and currently used but require highly knowledgeable individual to perform that job in order to get accurately and precisely measurements of the beer quality; The aim of this research is to develop an affordable IoT based Device that can support banana beer processors and users to determine their products quality in easy way and also retrieve their production data anywhere and anytime.

Furthermore, IoT is an interesting area of research; it creates many new possibilities in the form of services and inventions. IoT has several applications in all our daily lives. It can be used in a variety of industries, including mining, housing, transportation, manufacturing, healthcare, and government. The data collected strongly suggests that workers are performing their duties in a typical environment (no excessive alcohol consumption at work). This is a normal situation in all working environments. Because the data collection period was limited and brief, the associated data are still insufficient. This leads to only performing basic statistical analysis. Advanced data analysis may occur if a huge amount of data is present.

6.2 RECOMMENDATION

This project operational model is to use IoT embedded system to collect raw data, send them on the cloud for further processing, decision making and data storage; the improvement to this project can be edge data processing instead of cloud processing to reduce latency time between low data transmission, data processing and decision making.

6.3 REFERENCES

[1] Lyumugabe F, Kamaliza G, Bajyana E, Thonart PH (2010) Microbiological and physico-chemical characteristics of Rwandese traditional beer "Ikigage". Afr J Biotechnol 9: 4241-4246.

[2] Davies G (1993) Domestic banana-beer production in Mpigi district, Uganda. Infomusa 2: 12-25.

[3] Hounhouigan DJ, Nout MJR, Nago CM, Houben JH, Rombouts FM (1994) Microbiological changes in Mawe' during natural fermentation. World J Microbial Biotech 10: 410-413.

[4] F. Lyumugabe and E. B. Songa, "Traditional fermented alcoholic beverages of Rwanda (Ikigage, Urwagwa, and Kanyanga): Production and preservation," Preserv. Preserv. Approaches Beverages Vol. 15 Sci. Beverages, pp. 511–523, Jan. 2019, doi: 10.1016/B978-0-12-816685-7.00015-X.

[5] J. A. G. ARĚAS and F. M. LAJOLO, "STARCH TRANSFORMATION DURING BANANA RIPENING: I — THE PHOSPHORYLASE AND PHOSPHATASE BEHAVIOR IN MUSA ACUMINATA," J. Food Biochem., vol. 5, no. 1, pp. 19–37, 1981, doi: 10.1111/J.1745-4514.1981.TB00659.X.

[6] https://www.researchgate.net/publication/237769027_BANANA_PRODUCTION_POST_HARVEST_AND_MARKETING_IN_RWANDA (accessed May 14, 2022).

[7] Campbell-Platt G (1994) Fermented foods: a world perspective. Food Resear Int 27: 253-257.

[8] I. M. Mukisa et al., "The dominant microbial community associated with fermentation of Obushera (sorghum and millet beverages) determined by culture-dependent and culture independent methods," Int. J. Food Microbiol., vol. 160, no. 1, pp. 1–10, Nov. 2012, doi: 10.1016/j.ijfoodmicro.2012.09.023.

[9] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3036052

[10] Shanel, K. & Matemu, A. (2015). Microbial Quality of Traditional Banana Alcoholic Beverages in Arusha, Tanzania. Food Science and Quality Management, 38, 28 38.)

[11] World Health Organization. Global Status Report on Alcohol and Health (World Health Organization, 2018).

[12] Mwesigye PK, Okurut TO (1995) A survey of the production and consumption of traditional of alcoholic beverages in Uganda. Process Biochem 30: 497-501.

[13] Okafor N (1992) Commercialization of fermented foods in Sub Saharan Africa. In: Applications of biotechnology to traditional fermented foods. National Academy Press, Washington, DC.

[14] Steinkraus KH, Cullen RE, Pederson CS, Nellis LF, Gavitt BK (1983) Handbook of indigenous fermented foods. New York: Marcel Dekker.

[15] Aloys N, Angeline N (2009) Traditional fermented foods and beverages in Burundi. Food Resear Int 42: 588-594.

[16] J. Ateudjieu et al., "Health facility preparedness for cholera outbreak response in four cholera-prone districts in Cameroon: A cross-sectional study," BMC Health Serv. Res., vol. 19, no. 1, Jul. 2019, doi: 10.1186/S12913-019-4315-7/TABLES/2.

[17] "Banana Wine Value Chain Assessment Report," 2017.

[18] G. L. Poland, J. T. Manion, M. W. Brenner, and P. L. Harris, "Sugar Changes in the Banana during Ripening," Ind. Eng. Chem., vol. 30, no. 3, pp. 340–342, Mar. 1938, doi: 10.1021/IE50339A026/ASSET/IE50339A026.FP.PNG_V03.

[19] Panisello, P. J. & Quantick, C. (2001) 2001). Technical barriers to hazard analysis critical control point (HACCP) Food control 12 (3), 165 173. https://doi.org/10.1016/S0956 7135(00)00035 9.

[20] A. Blandino, M. E. Al-Aseeri, S. S. Pandiella, D. Cantero, and C. Webb, "Cereal-based fermented foods and beverages," Food Res. Int., vol. 36, no. 6, pp. 527–543, Jan. 2003, doi: 10.1016/S0963-9969(03)00009-7.

[21] "RWANDA STANDARD DRS 343 Second edition 2018-mm-dd," 2018, Accessed: May 13, 2022. [Online]. Available: www.portal.rsb.gov.rw.

[22] Mpyisi E., J.B. Nyarwaya & E. Shyringiro. 2000. Statistiques agricoles: production agricole, élevage, superficies et utilisation des terres. Année agricole 2000. MINAGRI-FSRP-USAID. 43pp.

[23] Lassoudière A. 1989. Enquête diagnostique sur la culture bananière en préfecture de Kibungo. Vol. 1, ISAR-IRFA-CIRAD.

[24] https://www.researchgate.net/profile/Rony-Swennen

[25] F. Lyumugabe and E. B. Songa, "Traditional fermented alcoholic beverages of Rwanda (Ikigage, Urwagwa, and Kanyanga): Production and preservation," Preserv. Preserv. Approaches Beverages Vol. 15 Sci. Beverages, pp. 511–523, Jan. 2019, DOI: 10.1016/B978-0-12-816685-7.00015-X.

[26] J. A. G. ARĔAS and F. M. LAJOLO, "STARCH TRANSFORMATION DURING BANANA RIPENING: I — THE PHOSPHORYLASE AND PHOSPHATASE BEHAVIOR IN MUSA ACUMINATA," J. Food Biochem., vol. 5, no. 1, pp. 19–37, 1981, doi: 10.1111/J.1745-4514.1981.TB00659.X.

[27] https://practicalactionpublishing.com/

[28] Santos, J.P.; Lozano, J.; Aleixandre, M. Electronic Noses Applications in Beer Technology. In Brewing Technology; InTech: Rijeka, Croatia, 2017.

[29] Nurul, A.; Jaswir, I.; Akmeliawati, R.; Ibrahim, A.M.; Aslam, M.; Octavianti, F. Rapid detection of ethanol in beverages using IIUM-fabricated Electronic Nose. Int. Food Res. J. 2017, 24, S529–S532.

[30] Understanding the Concept of Microcontroller Based Systems To Choose The Best Hardware For Applications