INTERNET OF THINGS - BASED SYSTEM FOR REAL-TIME MONITORING OF MARGARINE PRODUCTION PROCESS: A CASE OF SAVONOR IN BURUNDI

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A Project Report Submitted in Partial Fulfillment of the Requirements of the Award of the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

The margarine production process at SAVONOR in Burundi faces challenges such as inadequate control mechanisms, leading to suboptimal temperature regulation, production delays, and diminished product quality. These issues necessitate modernization to enhance efficiency and product standards. This project introduces an IoT-based system for real-time monitoring of the margarine production process. The proposed system integrates various sensors, including color, pH, and DHT22 temperature and humidity sensors, along with a Peltier cooling mechanism for precise temperature control. Real-time notifications are facilitated through GSM technology, enabling proactive communication with maintenance and laboratory personnel. Additionally, an LCD provides a user-friendly interface for visualizing monitored parameters. The system was designed and tested to monitor critical indicators like margarine color and pH levels, ensuring prompt corrective actions through real-time alerts via email and SMS. By addressing the gaps in control and monitoring, this IoT-based solution improves efficiency, reduces delays, and enhances product quality. This project demonstrates the transformative potential of IoT technologies in addressing industrial challenges in resource-constrained environments. By enabling real-time communication, precise control, and actionable insights, this system sets a benchmark for innovation and modernization in margarine production processes.

DECLARATION

I, Ezechiel Niyonzima, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Ezechiel Niyonzima

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Prof. Shubi Kaijage

Name of Supervisor 1	**Signature**	**Date**

Dr. Elizabeth Mkoba

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology, a project report titled ***"Internet of Things - Based System for Real-time Monitoring of Margarine Production Process: A Case of SAVONOR in Burundi"*** in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

Prof. Shubi Kaijage

Name of Supervisor 1	**Signature**	**Date**

Dr. Elizabeth Mkoba

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DEDICATION

I dedicate this work to my esteemed mother Ms. Prisca Mbonabuca, and my late father Mr. Léopold Nkenguburundi, for their dedicated time and encouragement that strengthened me during the entire academic journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

CO_2	Carbon Dioxide
CPU	Central Processing Unit
CSS	Cascading Style Sheet
DC	Direct Current
DHT	Digital and Humidity Temperature
ESP	Expressive Systems Module
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HTML	Hyper Text Markup Language
HTTP	Hypertext Transfer Protocol
IA-32	Intel Architecture 32 bit
IC	Integrated Circuit
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISM	Industrial Sheet Margarine
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MQTT	Message Queuing Telemetry Transport
NC	Normally Closed
NM-AIST	Nelson Mandela African Institution of Science and Technology
NO	Normally Open
OMNet	Objective Modular Network
OpenSSL	Open Secure Sockets Layer

OS	Operating System
PC	Personal Computer
PCB	Printed Circuit Board
pH	Potential of Hydrogen
PHP	Hypertext preprocessor
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Controller
RAM	Random Memory
RGB	Red, Green and Blue
Rx	Receiver
SAD	System Architectural Design
SCL	Serial Clock
SDA	Serial Data
SMS	Short Message Service
SQL	Structured Query Language
TCP/IP	Transmission Control Protocol/Internet Protocol/Internet Protocol
Tx	Transmission
UAT	User Acceptance Testing
USB	Universal Serial Bus
Wi-Fi	Wireless Fidelity
XML	eXtensible Markup Language
XP	Extreme Programming

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Margarine is a food product typically made from vegetable oils, water, salt, and emulsifiers (Berdiansyah & Arifan, 2023). Its production is a complex process that requires strict control of various variables to ensure optimal quality and yield (Vatankhah, 2020). The production of margarine involves several critical steps that must be monitored in real-time to ensure the quality of the final product. These steps include mixing, emulsification, pasteurization, and packaging (Bongers *et al.,* 2011). The production process involves vital processing variables like heating and cooling the ingredients' mixture, which requires temperature control (Álvarez *et al.,* 2023). Apart from temperature control, industrial processes such as emulsification and crystallization procedures in producing margarine with the necessary texture and stability were highlighted (Chai *et al.,* 2022). However, the challenges in accurately monitoring the status and conditions of margarine production, which is influenced by these industrial processes, usually affect the quality and efficiency of the final products. These challenges arise from inadequate intelligent monitoring systems for vital industrial processes, especially temperature control. Deviating from the optimal temperature range could lead to undesirable outcomes, such as excessively soft or firm margarine, compromising its overall texture and quality (Tan *et al.,* 2023).

The quest for effective automated systems pioneered a new research direction in studying the application of the IoT as a popular industrial technology for process regulation and monitoring. The recent focus on IoT is based on its capacity to improve multiple facets of business and society; this innovative technology has attracted much attention recently. Studies examining its applicability in diverse businesses, such as the food sector, constitute a portion of this field's quickly growing body of research (Fang *et al.,* 2014). The IoT-based monitoring systems have been developed to monitor and control various aspects of food production processes, including the monitoring of water quality (Gopavanitha & Nagaraju, 2018), coffee quality monitoring and processing (Rutayisire *et al.,* 2017), industrial painting booth conditions (Velasco-Hemandez *et al.,* 2022) and low-cost cold storage atmosphere monitoring and controlling (Siddiqui *et al.,* 2022). Even though research has demonstrated this technology's many and diverse qualities, IoT-based systems often face technical limitations, such as the inability to monitor a wide range of parameters required for complex industrial processes like margarine production. These include critical factors like pH levels, precise temperature gradients, and material color during processing. Additionally, their reliance on stable internet connectivity can make them less effective in environments with unreliable connections (Yanes *et al.,* 2020).

Thus, to overcome these challenges, the proposed IoT-based monitoring and control system aimed to be comprehensive, reliable, and user-friendly. It incorporated a wide range of relevant parameters, ensuring a holistic approach to monitoring and optimization. Moreover, the system operated efficiently, even in challenging connectivity conditions, and provided timely alerts in case of any issues or malfunctions.

1.2 Statement of the Problem

The integration of IoT-powered devices has brought opportunities and difficulties to the fast-changing industrial process landscape (Serror *et al.,* 2021). Modern industrial systems face significant hurdles, including scalability, interoperability, reliability, and real-time responsiveness, which highlights the need for innovative solutions tailored to specific environments (Mirani *et al.,* 2022).

In the specific case of SAVONOR's margarine production in Burundi, the current system lacks critical components such as an automated cooling mechanism and a temperature, pH, margarine color display, leaving plant managers unable to monitor the exact temperature during production. This uncertainty forces the team to rely on manual chilling procedures and visual inspection to determine if the margarine is ready, without knowing if the pH is within the acceptable range. Once the margarine appears ready based on visual cues, the plant managers must call laboratory personnel to conduct pH tests, a process that delays production and can lead to inconsistencies in quality. Furthermore, the absence of real-time alerts, such as email or SMS notifications, hampers the ability to promptly address deviations or critical issues, exacerbating production inefficiencies. These challenges emphasize the need for a more reliable, automated, and efficient system to improve operational performance and product quality at SAVONOR.

This project aims to tackle the challenges faced by SAVONOR, while also recognizing the broader issues that arise while integrating IoT technologies in industrial environments. By identifying and addressing the technical obstacles associated with implementing IoT-powered systems across different industries, this program endeavors to enhance the understanding of the most effective ways to leverage technology in the manufacturing sector.

1.3 Rationale of the Study

Margarine production is a complex process involving critical steps such as emulsification, cooling, crystallization, and packaging, where precision in temperature, pH, and color control is vital to ensure product consistency and quality. However, the existing processes at SAVONOR are primarily manual, resulting in inconsistencies in product quality, reduced productivity, and limited scalability. The lack of automated real-time monitoring and control systems means that operators rely on visual inspections for color assessment, manual activation of cooling systems, and periodic lab-based pH checks, all of which introduce human error and delays in decision-making.

By introducing an IoT-based monitoring system, these limitations can be addressed by automating key production processes and providing real-time, remote monitoring of critical parameters. This solution not only enhances the accuracy of temperature and pH control but also improves operational efficiency by ensuring timely interventions. The scalability of the system lies in its modular nature, where additional sensors or features can be integrated as production needs grow, making it adaptable to different scales of operation. Furthermore, by providing real-time data analysis and alerts, the system can help identify inefficiencies and improve production throughput. This solution has significant potential for deployment not only within SAVONOR but also across other food production industries, offering substantial improvements in quality control, process automation, and operational efficiency.

1.4 Objectives of the Study

1.4.1 General Objective

To develop an IoT-based system for real-time 0monitoring of the margarine production process using the SAVONOR industry in Burundi.

1.4.2 Specific Objectives

The study aimed to achieve the following specific objectives:

(i) To identify system requirements for developing an IoT-based system for real-time monitoring of the margarine production process.

(ii) To develop an IoT-based system for real-time monitoring the margarine production process.

(iii) To validate the developed system.

1.5 Research Questions

The study intended to answer the following questions:

(i) What are the requirements for developing an IoT-based system for real-time monitoring of the margarine production process?

(ii) How can an IoT-based system for real-time monitoring of the margarine production process be developed?

(iii) How can the developed system be validated based on the specified requirements?

1.6 Significance of the Study

This project introduces an innovative IoT-based system that not only aims to revolutionize SAVONOR's margarine production but also addresses broader technical challenges related to the integration of IoT-powered devices in industrial processes. The IoT system developed is a comprehensive solution that enhances key areas such as temperature regulation, real-time monitoring, and quality control issues that many industrial operations struggles with on a global scale. The inclusion of features like the Peltier cooler for precise temperature control, real-time notifications for immediate corrective actions, and user-friendly interfaces for remote monitoring empower SAVONOR to improve operational workflows, streamline production, and ensure consistent product quality.

Beyond its direct impact on SAVONOR's production processes, this study addresses key challenges that many industries face when incorporating IoT technologies, such as interoperability, scalability, and real-time decision-making. By offering practical solutions to these challenges, the project contributes valuable insights into how IoT can be successfully applied to industrial manufacturing in a local context while also advancing the understanding of these systems on a global scale.

Embracing this IoT system enables SAVONOR to stay competitive in an increasingly technology-driven market, where the failure to innovate could lead to stagnation. This project not only strengthens SAVONOR’s position as a leader in Burundi's industrial sector but also serves as an example of how IoT can drive advancements in efficiency and quality control, positioning it to lead in a new era of industrial automation and operational excellence.

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1.7 Delineation of the Study

This project aimed to develop an IoT-based system for real-time monitoring of the margarine production process in the SAVONOR industry. The study methodically built, deployed, and assessed the IoT-based monitoring and control system to address current difficulties and improve overall efficiency. Temperature, humidity, margarine color, and pH levels were the system's primary focus to guarantee accurate control and optimization of production processes.

The best practices and unique problems in deploying an IoT-based system for margarine production were found through a thorough literature review that covered important studies conducted in the last ten years and current developments. The system requirements were established, a prototype was designed and implemented, and the research thoroughly tested its functionality and performance using these findings. The following data analysis assessed the system's success in raising the standard and productivity of margarine production.

The project encountered significant limitations, notably time and budget constraints. The fixed six-month timeline constrained research, development, and implementation, impacting project objectives. Limited budget resources prioritized prototype development over a comprehensive solution. Additionally, technical challenges, including internet connectivity issues and needing more embedded systems expertise within the company, further impeded project progress.

CHAPTER TWO

LITERATURE REVIEW

2.1 Related Works

In this section, the literature on automation, monitoring systems, and the use of IoT technology to monitor fermentation processes, such as producing beer and wine, controlling temperature and humidity for and optimizing strategies in food production processes within the industrial sector, are all synthesized. Although the papers covered here do not specifically deal with developing an IoT-based margarine production monitoring system, they offer important insights into relevant technology, approaches, and difficulties in the larger field of food processing. Furthermore, investigations into the effects of process variables on food product attributes and novel strategies for lowering saturated fat content in margarine compositions are investigated. The study aims to identify important factors, best practices, and potential drawbacks that can direct the creation and implementation of a successful monitoring system specific to margarine production by thoroughly analyzing these publications.

Buonocore *et al.* (2021) developed an IoT-based beer fermentation monitoring system to increase the effectiveness and caliber of beer manufacturing. The system continuously monitors the fermentation process using temperature and humidity sensors. A CO_2 sensor is also part of the system, which tracks how much carbon dioxide is produced during fermentation. These sensor modules, installed on every fermentation tank, use a Wi-Fi network and the MQTT protocol to connect with the monitoring interface unit. However, the system only monitors temperature, humidity, and CO_2 levels; it does not measure other parameters that may affect the fermentation process, such as pH or gravity, and it lacks any mechanism for alerting the user in the event of any problems, such as abnormal readings or system malfunctions.

Canete-Carmona *et al.* (2020) developed an IoT system that tracks CO_2 emissions to monitor the fermentation of alcoholic wine in real-time. This technology gives winemakers important information about fermentation and is installed directly in fermentation tanks. The technology determines alcohol and sugar levels and identifies slow or stopped fermentation by examining evolved CO_2. The prototype uses the ThinkSpeak server and an ESP8266 Wi-Fi module to monitor the CO_2 levels in a tunnel connected to the fermentation tank. A fan turns on to remove extra CO_2 when CO_2 levels rise beyond a predetermined threshold, enabling ongoing fermentation monitoring. Nevertheless, this method ignores other important factors like humidity and temperature in favour of concentrating largely on CO_2 levels. Machine learning algorithms may be integrated to improve future predictions of fermentation stages.

Spagnuolo *et al.* (2023) developed an IoT-based monitoring system for industrial drying kilns. The system's objective was to gather real-time temperature and humidity data to achieve improved decision-making and process stability. The methods used to achieve the goal were the examination of the traditional method for drying fruits and vegetables and the use of smart devices for collecting operational big data from industrial operations. Humidity saturation was one of the difficulties, indicating the necessity of forced air extraction devices. The study's overall findings demonstrate how smart devices can be used to optimize industrial processes.

Pamula *et al.* (2022) presented a framework for IoT devices to monitor air, water, and soil contaminants in real time. They support data-driven strategies to improve data dependability and strongly emphasize sustainable resource management. They finally propose future research topics for environmental modelling in response to climate change and highlight possible uses in stream monitoring and watershed health improvement.

Gao *et al.* (2022) investigated the effects of varying tempering temperatures on the hardness, ductility, and application characteristics of industrial sheet margarine (ISM). They discovered that tempering at 20°C and 25°C produced the best ductility qualities by applying a physicochemical study of ISM attributes and measuring the hardness and flexibility of ISM samples. Nevertheless, the focus of this research is limited to offering useful recommendations for enhancing the flexibility of sheet margarine in industrial production.

Ninawe *et al.* (2020) proposed an IoT-based real-time data monitoring and controlling system for industrial applications, offering enhanced surveillance and data analysis capabilities. The solution automates production line control and monitoring by integrating various IoT devices with traditional industrial systems. Wireless data collecting stations are essential for monitoring production parameters such as operating activities, breakdowns, downtime, and production times. Subsequent advancements might concentrate on using machine learning techniques and broadening the scope of monitoring to encompass variables like vibration, humidity, and power usage.

Abijaude *et al.* (2019) described a Web-based IoT system for controlling and monitoring Cocoa's fermentation and drying processes. The system aims to store important process data for later use in research and development. The system's main objective is to modernize conventional agricultural methods by gathering important process data for upcoming studies and improvement. The prototype uses IoT technology to incorporate a microcontroller, heat/cooling sources, motors for container rotation, and sensors for temperature and humidity. Process data is wirelessly transmitted to a mobile application for real-time monitoring in this setup. Although the OMNet simulator was used to evaluate the prototype, machine learning methods may be used to improve cocoa production by successfully optimizing the fermentation process.

Yongfeng and Ying-Xin (2022) developed a cost-effective and useful PLC control system specifically designed for small-scale manufacturing of fine chemicals, using the fermentation process of beer as an example. The system aims to automatically control the fermentation process's temperature and pressure to maximize output quality and reduce expenses. The study incorporated a PID system and control panel into the monitoring software, the Siemens S7-1200 PLC, as the primary controller to reduce external interferences and guarantee constant control settings. A PLC actuator was also used to modify the fermentation conditions to increase production efficiency further automatically. The report also highlights the need for continued technological breakthroughs in China's small fine chemical sector.

In one study, a system was designed to monitor and control temperature and humidity for tempeh production (Riadi & Syaefudin, 2021). The system utilized the ESP8266 Wi-Fi Module and an online platform for data transmission to maintain optimal growth conditions for tempeh fungus on soybeans. The study achieved accurate temperature and humidity settings through hardware design and IoT principles by employing the Arduino Board to regulate a heater and fan system. The study demonstrated the successful integration of IoT and microcontroller technology in controlling a specific food production environment. However, a potential limitation of this study lies in its focus on monitoring and controlling a single parameter, specifically temperature and humidity, within the context of tempeh production.

2.2 Technical Gap

While several studies have explored the use of IoT technologies for monitoring production processes in industries such as wine production (Canete-Carmona *et al.,* 2020), beer fermentation (Buonocore *et al.,* 2021), cocoa production (Gutiérrez *et al.,* 2022), there remains a specific gap in addressing the unique needs of margarine production. Existing research has primarily focused on monitoring variables such as pH and temperature in generalized scenarios, but the margarine production process presents distinct challenges that require targeted solutions.

The margarine production process at SAVONOR faces challenges due to the absence of an integrated system for real-time monitoring of critical parameters such as pH, temperature, and color, along with the lack of automated cooling mechanisms like Peltier devices, which limit production efficiency and consistency. Globally, the IoT-based systems face scalability, interoperability, and real-time responsiveness challenges in industrial applications. This study addresses these gaps by developing an IoT-based system tailored for margarine production. The system integrates sensors for temperature, pH, and color monitoring, advanced cooling with Peltier devices, and real-time communication tools. These sensors, strategically placed within the emulsification apparatus, continuously record and analyze data using sophisticated algorithms to detect anomalies and trigger alerts for prompt intervention. The system also ensures temperature regulation and provides operators with real-time dashboards and historical data analytics to enhance monitoring and support process improvements. By reducing parameter fluctuations and improving efficiency, the proposed system raises the consistency and quality of margarine production while contributing insights to global IoT applications.

2.3 Proposed Solution

An IoT-based system was proposed to address challenges in SAVONOR's margarine production and broader IoT-related technical issues. The system integrates pH, temperature, and color sensors within the emulsification apparatus to monitor critical parameters in real time, supported by a Peltier cooling system for precise temperature regulation. It also triggers a buzzer to alert Plant Managers once margarine reaches the final stage or if there is any abnormality detected. Advanced algorithms analyze data instantly, detecting anomalies and triggering alerts via GSM-based SMS and email notifications to ensure reliable communication in areas with unstable internet connections. A user-friendly dashboard allows operators to monitor parameters in real time and access historical data for analysis and optimization. By leveraging local data storage and GSM technology, the system ensures uninterrupted monitoring and control during network interruptions, enhancing reliability and scalability. This solution aligns with SAVONOR's needs and addresses global IoT concerns, improving production quality and efficiency while demonstrating robust and scalable industrial IoT applications.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This study focuses on SAVONOR in Burundi, one of the largest manufacturers of laundry soap, toilet soap, multi-purpose liquid detergent, dishwashing liquid, palm oil, sunflower oil, margarine, and mayonnaise. The research especially focused on SAVONOR's margarine production division because it was experiencing serious issues that needed to be addressed. SAVONOR's operational region and geographical environment are shown in Fig. 1, while the acceptance letter for conducting the research is included in Appendix 1.

3.2 Target Population

The target population for this study included workers from the margarine production department (plant managers), maintenance personnel, and laboratory personnel. To include participants from various roles within these divisions, a simple random sampling technique was used. Details of the sample size and selection process have been provided. To effectively fulfil the needs of the department, the design and execution of the suggested monitoring system were led by the insights provided by these important stakeholders.

Figure 1: SAVONOR's localisation

3.3 Research Methodology

The project employed qualitative research methodology to investigate the effectiveness and quality of implementing an IoT-based system for real-time monitoring of margarine production processes at SAVONOR in Burundi. Drawing from the exploratory nature of qualitative research, the study utilized various methods, including interviews with key stakeholders, structured observations, and focused group discussions. These methods were chosen to gather rich, in-depth insights into the challenges, opportunities, and potential solutions for adopting IoT technology in food production. The qualitative approach allowed for flexibility and adaptability during data collection, enabling the research team to capture nuanced perspectives and experiences relevant to the study objectives.

3.4 Sampling Techniques and Sample Size

This project employed a purposive sampling method, a type of non-probability sampling technique. Purposive sampling was chosen because it aligns with qualitative research methodologies, focusing on selecting participants with the most relevant expertise and experience related to margarine production. According to Tutz (2023), this strategy ensures systematic participant involvement by combining conversational and interview methodologies. The study included 20 participants, comprising 10 workers from the Margarine production department, eight workers from the laboratory, and two maintenance personnel. The sample size was selected for data saturation and practical reasons, guaranteeing diverse perspectives and manageable group sizes for interviews and focus groups while balancing the roles of important stakeholders for comprehensive understanding.

3.5 System Requirements

3.5.1 Data Collection Methods

Data collection is essential for acquiring information to develop an IoT-based system for real-time monitoring of margarine production processes at SAVONOR in Burundi. This includes being aware of stakeholders' requirements and preferences. Primary and secondary data collection techniques were used to achieve this. While primary methods include stakeholder observations, focus groups, and interviews, data sources include already published literature.

(i) Interviews

The interviews were used to collect data from key personnel from the SAVONOR company in Burundi, A total of 20 interviews were conducted with key personnel, including 10 plant managers, eight laboratory personnel, and two maintenance personnel. These were semi-structured interviews designed to gather detailed insights while allowing flexibility for participants to elaborate on their responses. The interview guide with open-ended questions used during the interviews is shown in Appendix 2.

(ii) Observations

The SAVONOR facility's margarine production process was observed. This involved monitoring protocols, keeping tabs on equipment usage, and following the workflow of margarine manufacture. The guide for the observation checklist can be found in Appendix 3. A month-long observation session was used to understand the current procedures and operating difficulties thoroughly.

(iii) Focus Group Discussions

Three focus group discussions were held at the SAVONOR facility, the focus group included 10 plant managers, eight laboratory personnel, and two maintenance personnel, with each group consisting of participants from the same professional role. The guide for these discussions can be found in Appendix 4. The findings from these focus group discussions were used to develop the requirements for the IoT-based real-time margarine monitoring system.

A comprehensive review of existing literature, including academic journals, books, and online resources, aimed at understanding monitoring systems' functionality. This approach sought to gather insights, suggestions, and answers proposed by academic researchers across various fields. Specifically, an extensive literature review on IoT monitoring processes, including studies on cocoa and wine fermentation and the application of IoT technologies in monitoring alcohol production, fermentation processes, and related areas, was sought.

3.5.2 Data Analysis

Microsoft Excel was essential for arranging the qualitative data gathered for the study. It was employed to methodically document the questions and responses from interviews and focus groups. Furthermore, Excel made data organization easier by making it simple to sort, filter, and categorize responses. Thematic analysis was used to analyze qualitative data, following the six-step framework: Data familiarization, coding, theme searching, reviewing, defining, and reporting (Braun, 2006).

The interviews and focus group discussions underwent manual transcription by listening to audio recordings and noting the transcripts. During the coding process, codes that were similar to one another were allocated. Patterns or themes were identified across various interviews and focus group discussions.

Microsoft Excel was selected as the main tool for qualitative data analysis because it is easy to access, simple to use, and flexible in handling qualitative datasets. Excel allowed for organizing data, coding efficiently, and visualizing the representation of emerging themes without requiring specialized software. Sticky notes helped with organizing ideas visually, making it easy to rearrange and improve the themes that were found. Themes were reviewed and refined, and interview excerpts were thoroughly examined within each topic to ensure consistency. Themes were reassessed and improved, and to guarantee coherence, interview snippets were carefully scrutinized for every subject.

Once common patterns in the data related to margarine production monitoring were found, similar themes were grouped for clarity, and inconsistent themes were segregated to convey the nuances of the information properly. Additional themes were incorporated or removed iteratively until it was decided that the topics accurately reflected the insights gathered from the monitoring process.

3.6 System Development Approach

This project used an agile methodology, which is renowned for its strategy of breaking projects into incremental phases (Ekström & Pettersson, 2016). Extreme Programming (XP), depicted in Fig. 2, was specifically utilized as the system development approach. The XP was adopted because it excels at effectively managing change, adapting to changing requirements, and facilitating ongoing improvements throughout the development cycle to provide a useful end product that meets stakeholder needs.

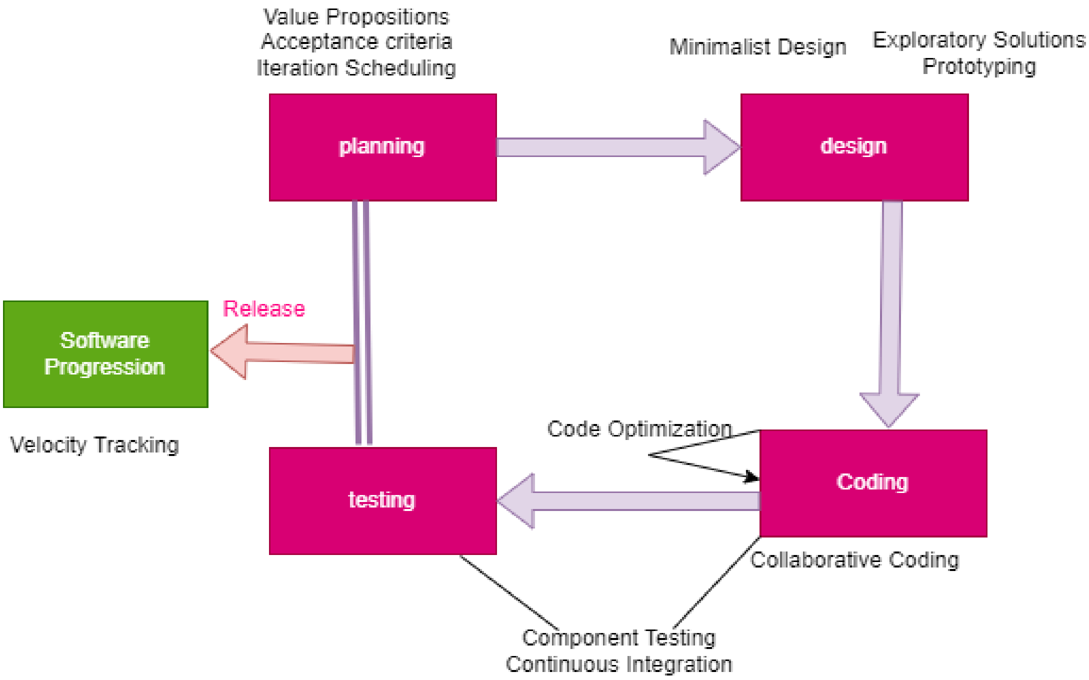

Figure 2: The XP development methodology

3.7 System Development

3.7.1 Software Requirements and Tools

This party describes the many tools and programming languages that were utilized to complete this system's development. The functions of software development tools are identical to those of an application or program. Developers can use it for creating, maintaining, testing, building, debugging, fixing, and providing support for software applications or products. Users use it to automate and simplify many software development operations. Several software tools have been employed in this research.

Software was created using a programming language as a command instruction and additional syntax. Programmers can create high-level code in this language, and it can be compiled into a low-level language that computer software can understand.

(i) Sublime Text Editor

A text editor that is frequently used by developers to create programs or applications is called a sublime text editor. It has several features that make working with the code base easier, like syntax highlight auto-indentation, file recognition, sidebar, plugin, and package.

Multiple sections, multiple windows, split windows, and over seventy different file types are supported by Sublime Text. We can alter the color scheme, text font, global key bindings, tab stop, file-specific snippets, and even the syntax highlighting rule using a sublime text editor.

You may get Sublime Text from the official website. The most recent version of Sublime Text is now version four (sublimetext4), which works with Linux, Windows, OS X, and Windows 64-bit.

The developed system was coded using Sublime for the user interface, data insertion, database data displays, and sensor-to-database connection.

(ii) XAMPP

Many servers and languages, including the Apache HTTP server, MariaDB, and scripting languages like PHP and Perl, use the free and open-source XAMPP web server. It may be accessed on Linux, macOS, and Windows computers. You can use tar, exe, and compressing files to download and launch XAMPP. When utilizing Windows OS, you must install the Microsoft Visual C++2017 redistributable. The XAMPP comes with a variety of modules, including OpenSSL, phpMyAdmin, MediaWiki, Joomla, WordPress, and more.

Developers can write and test their programs on a local web server with XAMPP. It supports a variety of operating systems and languages, including X64 packages for macOS and Linux and IA 32 packages for Windows. For data storing in data phpMyAdmin, Xampp was utilized.

(iii) Hypertext Preprocessor (PHP)

Hypertext Preprocessor (PHP) is one common language for server-side scripting applications. It enables programmers to create web applications that are browser-based. The PHP comes with several extensions that let it communicate with databases, get information for online displays, and store data there. The PHP is known for its features, which include high running efficiency, multiplatform compatibility, safety performance, and freeness. A mobile application or web-based application can be made dynamic with PHP. It permits data entry into the database, data visualization from the database, data posting on the web server for database insertion, and email performance actions through PHP mail files.

(iv) Hypertext Markup Language (HTML)

The HTML language allows data to be displayed in a web browser. The HTML is the language used to make websites. The HTML files are terminated by the .htm or .html extension, and an HTML element consists of several tags and attributes. At the beginning and end of each element, a tag is shown to the browser. An element is composed of three main parts:

(a) The open tag indicates the beginning of the tag;

(b) The output element to be displayed within the context;

(c) Closing tag to end the tag.

The HTML uses a variety of tags, including heading tags, which range from h1 to h6. These tags contain the content that will be shown; they range in size from h1 to h6. Additionally, there is the paragraph tag, which begins with <p>... The material to be displayed...</p> and is used to arrange items within a paragraph.

Many tags are available in HTML that you can use to organize the design you want to make on HTML pages. User interfaces that communicate with the system are built using HTML. Simple structures are provided by HTML and can be expanded in size and style using CSS and other languages. The main uses of JavaScript are in design and styling. Because HTML is simple to use and can be connected with other languages, it was chosen for this system. The HTML was used to create the system's images, tables, and user interfaces, including those for user registration and authentication.

(v) Cascading Style Sheets (CSS)

The language used to define styles on websites, such as layouts, colors, and fonts to improve how our pages look, is called CSS. It is not dependent on HTML and may be used with markup languages based on XML.

Style definitions for web pages are typically stored in external files that may be accessed through the <link rel="stylesheet" href="filename.css"> link. Web pages are styled using CSS. Stylesheets, also known as external CSS files, are used to change only the HTML file and the overall appearance of the website. Forms were created using HTML tags, and CSS was utilized to design them.

(vi) Bootstrap

A free and open-source CSS framework called Bootstrap makes front-end web development mobile-first. It has JavaScript and CSS that are based on templates for the button navigation topology and other user interface elements.

Bootstrap is a library that incorporates HTML, CSS, and JavaScript, primarily aimed at streamlining the creation of informative web pages. When incorporated into a web project, its main goal is to apply Bootstrap's color, size, font, and layout choices to that project. The built system may be accessed through web-based and mobile applications with a uniform interface thanks to the usage of the Bootstrap framework, which guarantees a consistent user interface.

(vii) MySQL

The MySQL is a tool employed for establishing a database that serves the purposes of storage, manipulation, and the definition of individual tables. Situated on the foundation of structured query language (SQL), it has established itself as the industry standard for relational database management. It gives users the ability to utilize SQL statements to access data.

(viii) Arduino Integrated Development Environment (IDE)

This is what the Arduino IDE looked like when it was first launched. Upon initiation, it displays an empty sketch, providing a canvas for immediate programming as shown in Fig. 3. After writing a sketch on the Arduino board in the manner demonstrated in Appendix 5, the sketches are checked for defects before being uploaded to the board. To enable code uploading, the board and port configurations must first be configured (Fezari & Al-Dahoud, 2018). Simply connect your Arduino board to the computer using the USB cable.

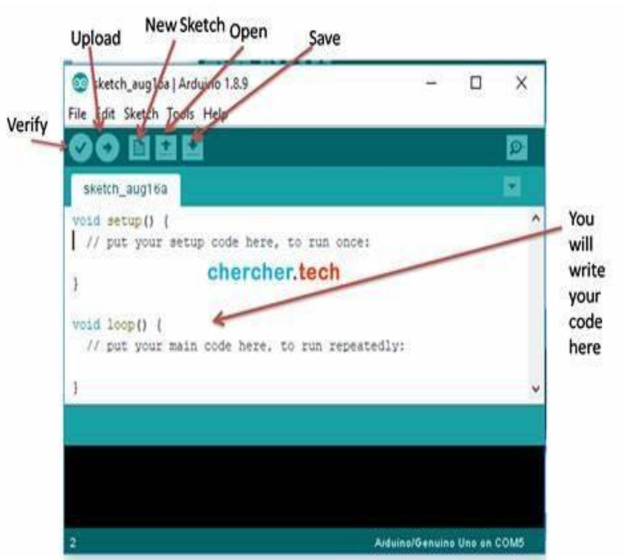

Figure 3: Arduino ide interface (Fezari & Al-Dahoud, 2018)

(ix) ThinkSpeak

ThingSpeak serves as a robust application platform tailored for IoT system development as shown in Fig. 4. It facilitates the creation of applications that leverage data gathered from sensors. ThingSpeak is an excellent entryway to the IoT since it is an open data platform for IoT application development that connects effortlessly with current enterprise systems. Its versatility extends to the integration of data with various third-party platforms, systems, and cutting-edge IoT platforms, such as ioBridge and Arduino (Nakhuva & Champaneria, 2015).

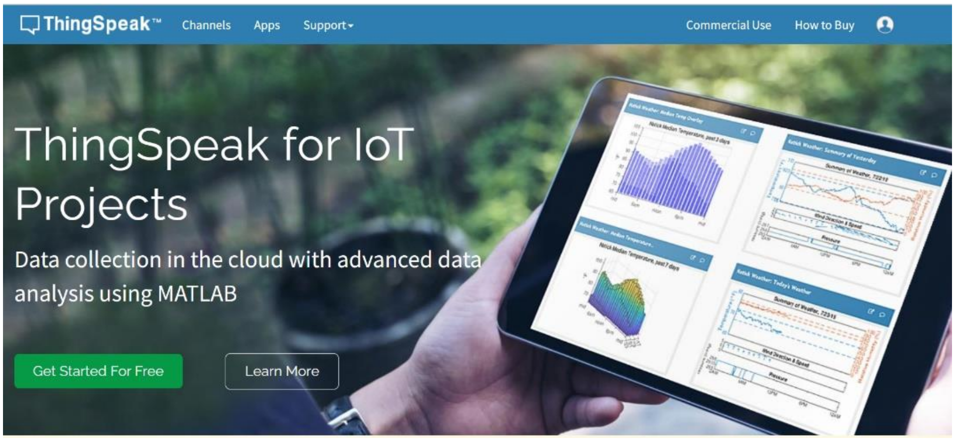

Figure 4: Screenshot of ThingSpeak IoT cloud

3.7.2 Hardware Requirements and Tools

The margarine production monitoring system was developed using a variety of physical devices as hardware tools. As shown in Table 1, these comprised computer devices, mobile devices, sensors, actuators, and other parts that were chosen to guarantee that the prototype integrated effectively with the business's needs for maximum functionality in the production of margarine.

Table 1: Proposed hardware components of the system

S/N	Hardware Component	Specifications
1.	Microcontroller	ESP32-WROOM-32D
2.	GSM module	GSM SIM800L
3.	pH Sensor	Module
4.	Temperature Sensor	DHT22
5.	Jumper wires	A few
6.	Color Sensor	TCS3472
7.	Light Dependent Resistor	Module
8.	Relay	Relay Channel 2
9.	Buzzer	Passive buzzer
10.	Heatsink Thermoelectric Cooler	12 V TEC1-12706
11.	Screw Countersunk	4 mm
12.	Aluminum Heatsink Cooling	40x40x11mm LED Power Memory Chip IC Transistor
13.	Mini Brushless Computer Fan PC	5 V DC
14.	Pipes	Water
15.	Aluminum Water Cooling	40x10x12 mm

(i) Microcontroller

The ESP32 as shown in Fig. 5, was used in this project. An open-source software and hardware development environment. The ESP32 is a low-cost, low-power system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. Antenna switches, power amplifiers, low-noise receiver amplifiers, filters, and power management modules are all built into the ESP32. The ESP32 is designed for mobile devices, wearable electronics, and IoT applications, and it consumes very little power thanks to a variety of power-saving features, such as fine-resolution clock gating, multiple power modes, and dynamic power scaling. A comparison of the ESP32 with other popular microcontrollers, including the ESP8266 and Raspberry Pi, is shown in Table 2, highlighting the factors behind selecting the ESP32 for this project.

Figure 5: The ESP32 Pinout (Cameron, 2021)

Table 2: Comparison table between ESP32, ESP8266 and Raspberry Pi

S/N	Feature	ESP32	ESP8266	Raspberry Pi
1.	Microcontroller	Dual-core Xtensa 32-bit LX6	Sine-core Tensilica 32-bit	Broadcom ARM Cortex-A53
2.	Clock Speed	Up to 240 MHz	Up to 160 MHz	1.2 GHz (Raspberry Pi 3B+)
3.	Wi-fi	Integrated Wi-Fi 802.11 b/g/n	Integrated Wi-Fi 802.11 b/g/n	Requires USB Wi-Fi dongle
4.	Bluetooth	Integrated Bluetooth 4.2 (ESP32)	No Bluetooth support (ESP8266)	Requires USB Bluetooth dongle
5.	GPIO Pins	36	17	26/40 (depending on model)
6.	Analog Pins	18 (12-bit ADC)	1 (10-bit ADC)	0
7.	I2C/SPI/UART	Yes / Yes / Yes	Yes / Yes / Yes	Yes / Yes / Yes
8.	Memory	Up to 520 KB RAM, 16 MB Flash	160 KB RAM, 4 MB Flash	1 GB (Raspberry Pi 4B)
9.	Operating Voltage	3.3 V	3.3 V	5 V
10.	Usage	IoT applications, wearables	IoT applications, Wi-Fi devices	General-purpose computing
11.	Cost	Moderate	Inexpensive	Moderate to High

(ii) The 20x4 liquid crystal display (LCD)

The LCD with a resolution of 20x4 as shown in Fig. 6 was used in this project. In computing, a liquid-crystal display (LCD), also known as a flat-panel display, electronic visual display, or video display, is a display device that makes use of the light-modulating properties of liquid crystals. Twenty-four characters can be displayed in each of the four rows of the 20x4 LCD, for a total of eighty characters that can be displayed at any one time on the LCD.

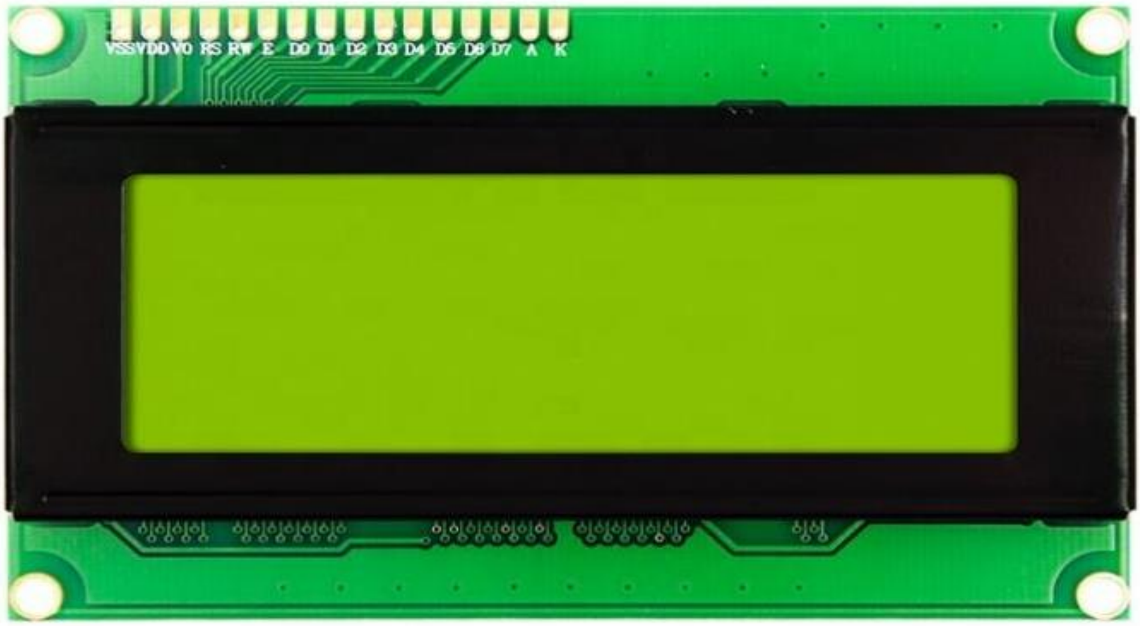

Figure 6: The 20x4 LCD (Cameron, 2021)

(iii) Global system for mobile communication (GSM) SIM800L module

In particular, this project will make use of the GSM module. Because of its versatility, the GSM SIM800L is a compact GSM module with a modem that may be used in a range of IoT applications shown in Fig. 7. With the same module, it can make and receive calls from outside the system, send and receive text messages, and connect to the internet via TCP/IP and GPRS. Additionally, it can make it easier to send and receive data in real time over large distances, including text and voice.

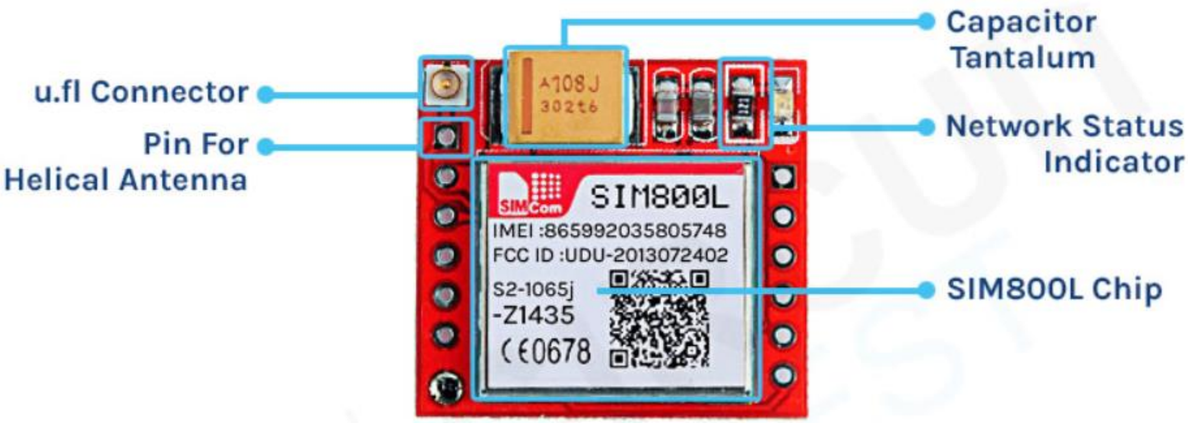

Figure 7: The GSM SIM800L module (E-gizmo, 2017)

(iv) Buzzer

A buzzer (Fig. 8), is a sound-generating device that uses electricity to produce sounds. Piezo buzzers and magnetic buzzers are two types of buzzers that are typically powered by direct current. If you want to use them in a different way than you usually do, they come in a variety of designs and can make a lot of different sounds. It will help in my proposed project because the system will require sending notifications using sounds.

Figure 8: Buzzer (Bansal, 2020)

(v) Push Button

A pushbutton as shown in Fig. 9, is a simple switch mechanism to control some aspect of a machine or a process, such as a push-button (also spelled pushbutton). When it comes to buttons, you're more likely to find them made of plastic or metal. This proposed project will be used to switch on the prototype when it comes to time margarine production and switch off after finishing the production.

Figure 9: Push-button (Chen & Y., 2022)

(vi) The DHT22 sensor

The DHT22 as shown in Fig. 10, is a more accurate and effective temperature sensor that can measure temperatures between -40 and 80°C and offers a humidity reading of 0–100% with a 2–5% accuracy. It is the best temperature sensor for this project in terms of characteristics and accuracy.

Figure 10: The DHT22 sensor (Azhari *et al.,* 2023)

(vii) The pH Sensor

The pH sensor is one of the most crucial instruments for measuring pH and monitoring water quality. With this kind of sensor as shown in Fig. 11, alkalinity and acidity in water and other liquids can be measured. When used correctly, pH sensors can guarantee the security and quality of goods and processes that occur in wastewater treatment or industrial facilities.

Figure 11: The pH sensor (Habekost, 2020)

(viii) The TCS3472 Sensor

The TCS3472 sensor as shown in Fig. 12, developed by AMS (ams AG), is a color light-to-digital converter designed to measure RGB (Red, Green and Blue) values, providing precise data on hue, saturation, and light intensity. Applications needing precise color recognition, color consistency, and ambient light measurement need this sensor. Real-time color sensing and data integration for a range of industrial and consumer electronics applications are made possible by its smooth interface with IoT systems and platforms like Arduino.

Figure 12: The TCS3472 sensor (Valke *et al.,* 2022)

(ix) The 5 V DC Mini Brushless Computer Cooler Cooling Fan PC

If the computer's CPU cooling fan has burned out or become noisy, this fan as shown in Fig. 13, is a great replacement. The CPU PC Cooling Fan on your computer maintains a comfortable temperature increased airflow.

Figure 13: The 5 V DC mini brushless computer cooler cooling fan PC (Kim *et al.,* 2015)

(x) Thermoelectric cooler

A thermoelectric cooler, also called a Peltier cooler, is a semiconductor-based apparatus that can heat or cool when an electric current is supplied. It transfers heat from one side of the gadget to the other via the Peltier effect (Fig. 14).

Figure 14: Thermoelectric cooler (Okorie *et al.,* 2024)

(xi) Screws

The word "screws" refers to a general category of fasteners that have cylinder-wrapped helical ridges called threads, was used in this project on the actuator part. Screws as shown in Fig. 15, are frequently used to apply pressure and connect items. They are made for specialized purposes and are available in a variety of shapes and sizes.

Figure 15: Screws (Gong *et al.,* 2022)

(xii) Aluminum heatsinks cooling

The aluminum heatsinks (Fig. 16), play a crucial role in reducing the board's temperature and ensuring its safe operation. The chance of overheating-related hardware failure can be decreased with the installation of an aluminum heatsink. will, when used with a fan, cool more LEDs.

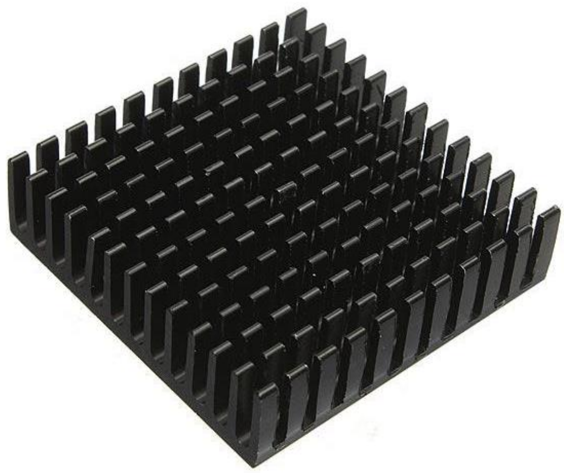

Figure 16: Aluminum heatsink cooling (Attar *et al.,* 2020)

(xiii) Brushless DC pump

A brushless DC pump, as depicted in Fig. 17, is a miniature BLDC motor-driven DC water pump that operates on 12 or 24 V. It uses magnetic force to rotate its impeller, pressurizing and moving water for fluid lifting, circulation, and booster systems.

Figure 17: Brushless DC pump (Gujjar & Kumar, 2017)

(xiv) Water pipe

A water pipe as shown in Fig. 18, is generally referred to as a conduit or tube intended for the conveyance of water. These pipes are frequently utilized in plumbing systems for domestic, commercial, and industrial applications. Their materials, sizes, and purposes might vary.

Figure 18: Water pipe

(xv) Aluminum water cooling cooler

Compact and specialized, the aluminum water-cooling cooler heatsink for CPU LED, depicted in Fig. 19, is made to effectively dissipate heat produced by electronic equipment, particularly central processing units (CPUs) and light-emitting diodes (LEDs).

Figure 19: Aluminum water-cooling cooler (Liu & Yu, 2022)

(xvi) Relay

Relays (Fig. 20) are electrical switches that work using an electrical signal and is used also to open electromechanically and close circuits automatically. By opening and shutting the contacts of one electrical circuit, these devices regulate the conductivity of another, and vice versa. Relays generally operate in two states: Normally Open (NO) when the circuit's contact is open and closed when the relay is de-energized. Relay contacts marked as "Normally Closed" (NC) remain closed even when powered on, making it possible to automate the control of aviation obstacle lights by remote access via a computer or mobile device that accesses a web-based program.

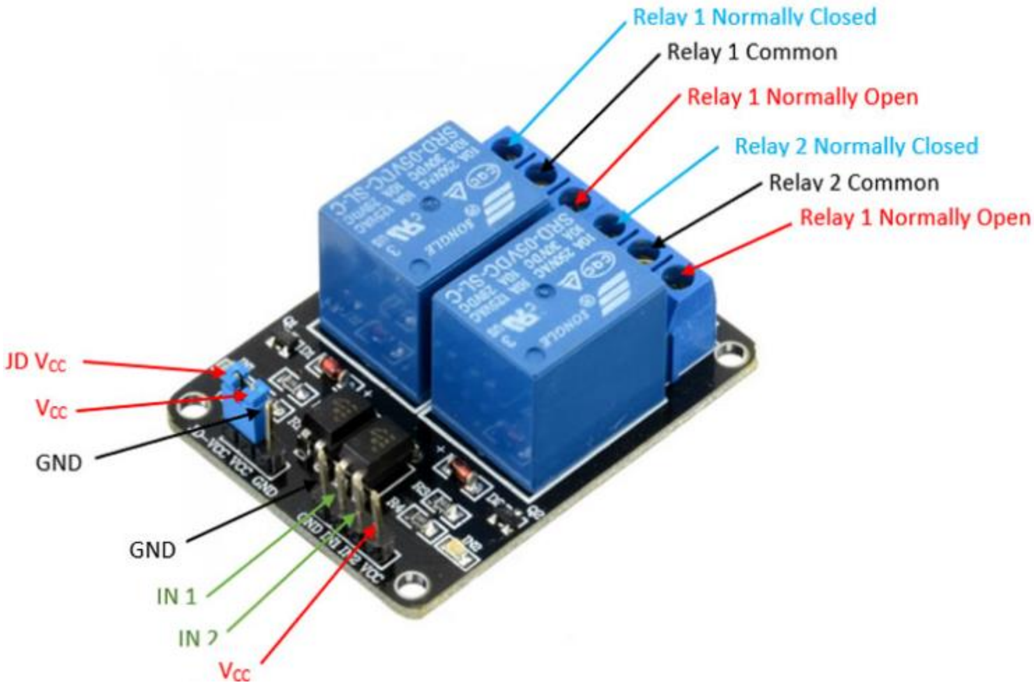

Figure 20: Relays (Zabala, 2017)

(xvii) Voltage regulator

An integrated circuit (IC) for voltage regulation, the L7805CV shown in Fig. 21, has a set output voltage of +5 V. It is frequently used in electronic circuits to control voltage levels and guarantee that linked components receive a steady power supply. The L7805CV IC may have a particular version or variation denoted by the "V3" designation.

Figure 21: The L7805CV voltage regulator (Srivastava *et al.*, 2021)

3.8 System Design

3.8.1 System Architectural Design

System Architectural Design (SAD) refers to the process of defining the structure and behavior of a system's components and their interactions (Bussemaker *et al.,* 2021). It entails drawing out a blueprint that describes the architecture of the system, including its data flows, interfaces, and modules. This section contains the system architectural diagram, which gives an overview of the parts, connections, and interactions of the monitoring system we have designed. The system's general design is depicted in Fig. 22, along with the interconnectedness of its many components.

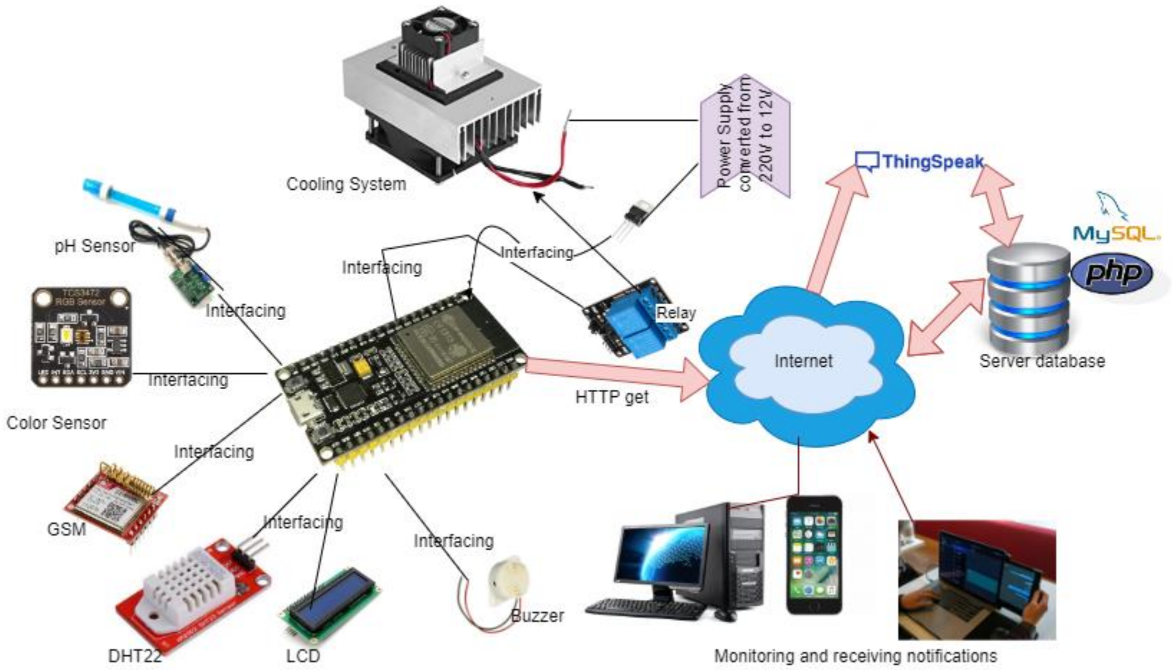

Figure 22: System architectural design

3.8.2 Block Diagram

The suggested block diagram shown in Fig. 23, lists the essential elements of the margarine production monitoring system. The structure and relationships between the many components covered in the previous sections are illustrated clearly in Fig. 23.

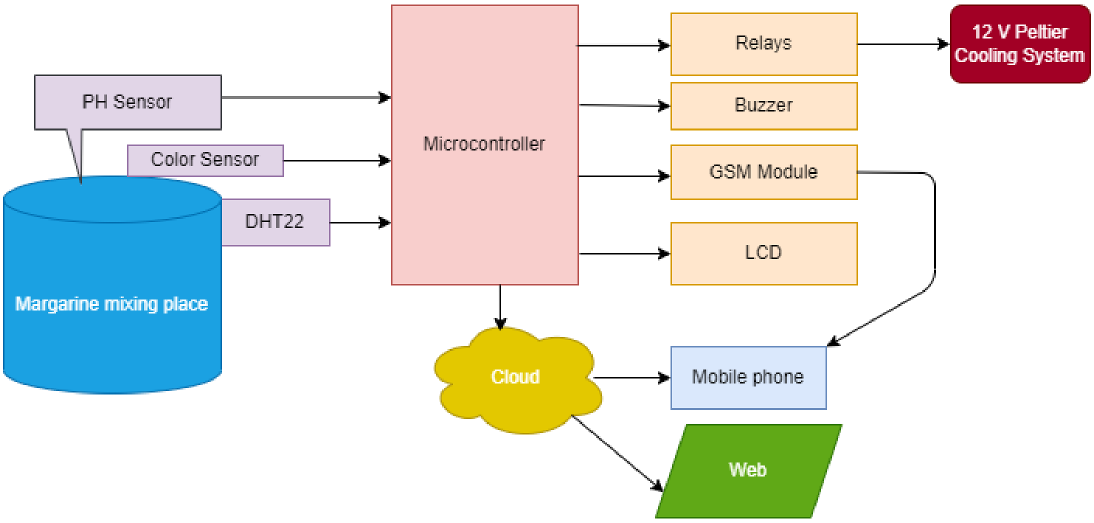

Figure 23: System block diagram

3.8.3 Schematic Diagram

The schematic diagram of the proposed IoT-based real-time margarine production monitoring system comprises an ESP32-WROOM-32D microcontroller board, various sensors, and actuators. The TCS3472 Color Sensor is connected to pins 21 (SCL) and 22 (SDA), sharing the I2C bus with the LCD. The pH Sensor is connected to pin 32, the DHT22 Temperature and Humidity Sensor to pin 12, the Buzzer to pin 19, and the Relay Module (2 Channels) to pins 26 and 27. The GSM SIM800L Module's transmitter (Tx) is connected to pin 33, and the receiver (Rx) is connected to pin 25. All sensors are powered by the 5 V and 3.3 V outputs from the ESP32-WROOM-32D microcontroller, ensuring seamless integration and efficient power management as illustrated in Fig. 24.

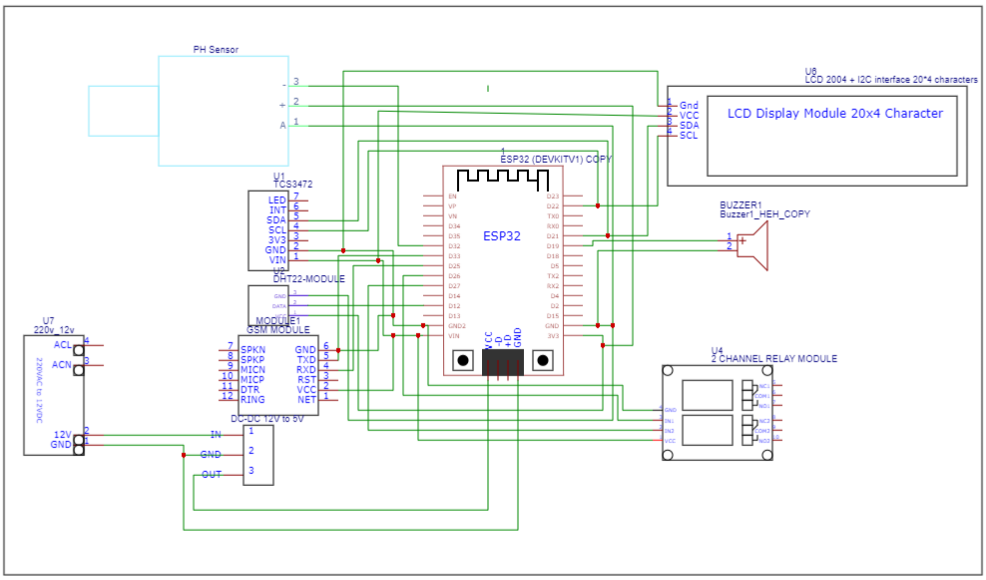

Figure 24: Schematic diagram of the system

3.8.4 Flowchart Diagram

The proposed flowchart diagram, which shows the step-by-step procedure of monitoring margarine production is shown in Fig. 25.

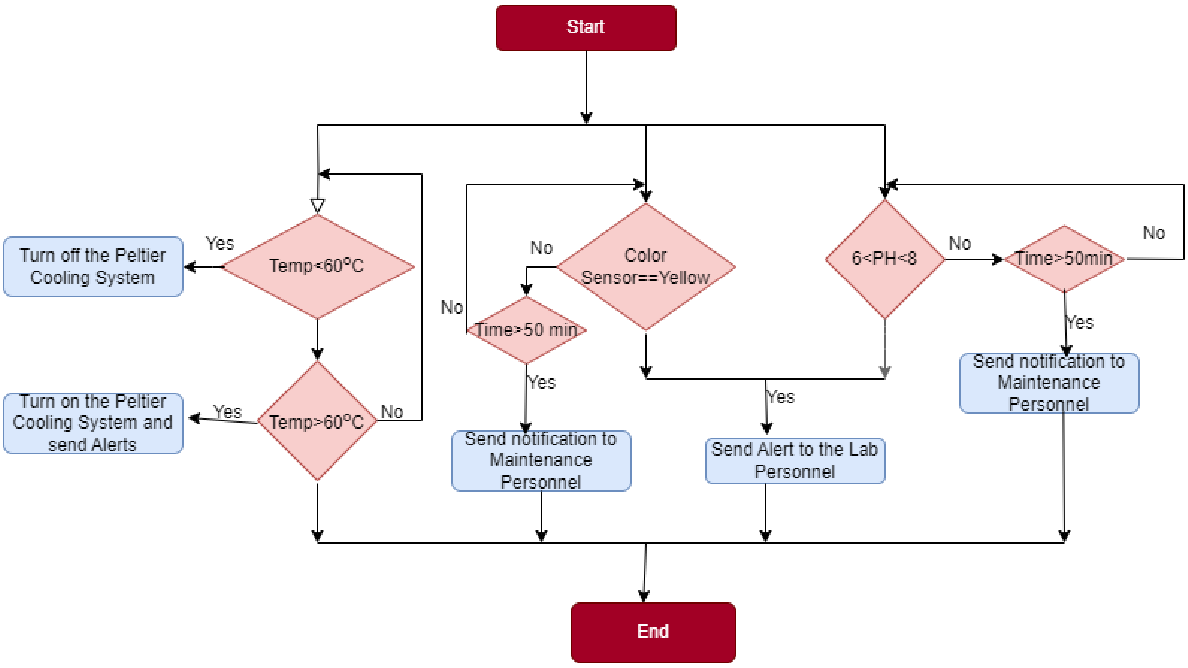

Figure 25: Flowchart diagram

3.8.5 Use Case Diagram

The use case diagram, which describes how users and the margarine production monitoring system interact is shown in Fig. 26.

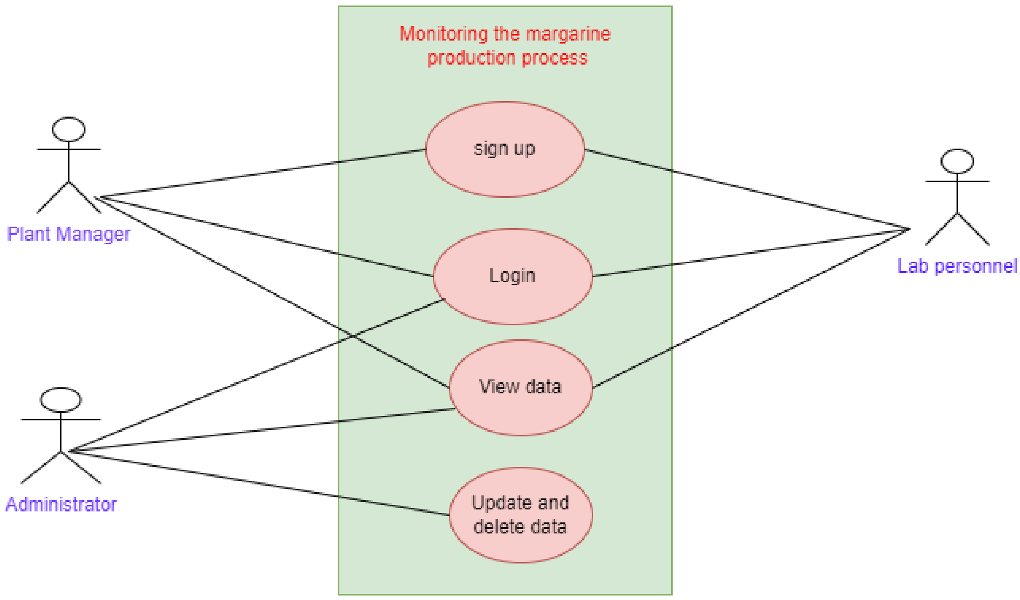

Figure 26: Use case diagram

3.9 System Testing

The V-Model shown in Fig. 27, presents the sequential testing phases that correspond with respective stages of development.

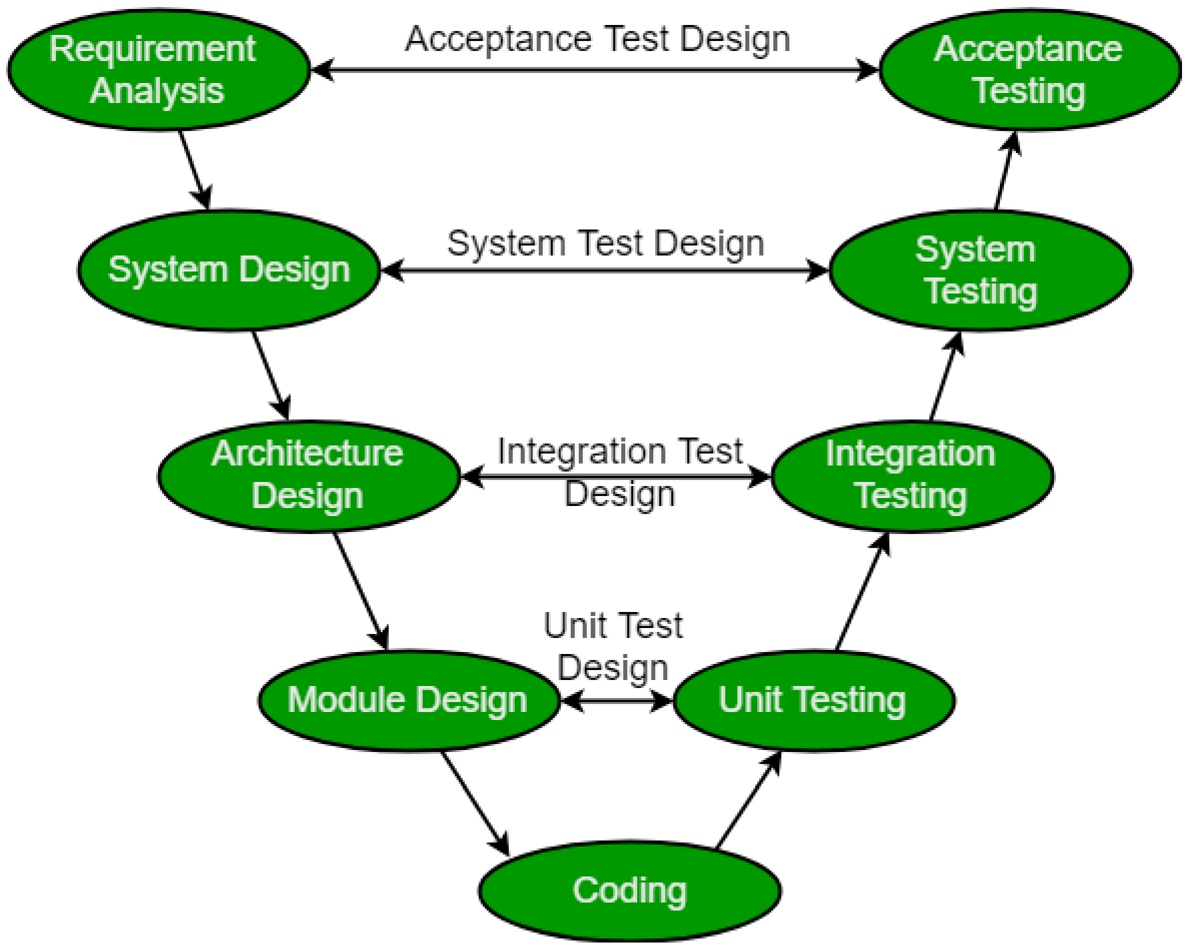

Figure 27: The V-Model (DOĞAN *et al.*, 2021)

3.10 Unit Testing

To ensure the functionality and quality of the software system in each phase of development, unit testing was used. This approach involved testing, compiling, loading, and running each unit or module of the software. The main objective was to isolate and test each component to determine whether it was performing as expected. Throughout the development phase, unit testing was conducted, which helped to identify any issues early on and facilitated more efficient debugging. By individually testing each module, as depicted in Fig. 28, defects or errors were promptly identified and worked on, ultimately enhancing the system's overall reliability.

Figure 28: Unit testing image

3.10.1 Integration Testing

Integration testing is a phase where different software modules are combined and tested together to ensure that they work correctly when integrated. It involves monitoring and testing the data flow between modules to detect any issues in their interaction. In this phase, the system was tested to make sure it met the integration requirements specified in the design phase. The testing was carried out to ensure that the different components of the system were working together seamlessly (Fig. 29).

Figure 29: Hardware integration testing image

3.10.2 Developed System Testing

A comprehensive testing phase was carried out within the margarine department following the successful development of the margarine production monitoring system. The main goal was to assess how well the system, which consists of several sensors and components, integrates and functions. Figure 30 shows the testing of the developed system done in SAVONOR Limited company.

Figure 30: Developed system testing

3.11 Ethical Considerations

Emphasizing the paramount importance of ethical considerations in the innovative margarine production monitoring system project, ethical standards have been upheld as a cornerstone throughout the work, with an unwavering commitment to maintaining the highest level of integrity. The developed system prioritized the respect and welfare of all parties affected by the technology. The ethical principles that guided the development of the margarine production monitoring system are detailed as follows.

(i) Project approval

Prioritizing ethical issues was crucial before starting the project. The appropriate SAVONOR authority granted formal approval for the project to be conducted on their property. This stage ensured the project complied with the institution's rules and ethical standards.

(ii) Voluntary participation

Participation in the initiative was completely voluntary. All participants, including laboratory staff, plant managers, and maintenance staff, received thorough explanations regarding the nature and goals of the study. They were allowed the freedom to choose whether or not to participate, and their choice had no bearing on how the group perceived them.

(iii) Data security and confidentiality

Several steps were taken to guarantee the participants' privacy and confidentiality:

(a) **Anonymity**: The project participants were not disclosed. To avoid identifying specific participants, all information gathered and shared for the project is given in an aggregated, anonymous manner.

(b) **Safe Data Storage**: The collected data, such as respondents' responses and interview transcripts, was stored on password-protected devices. Only authorized workers and the original researcher had access to the data.

(c) **Restricted Access**: The raw data was only available to those involved in the research process. To preserve participant confidentiality, data was disseminated in an aggregated and summarized format with a wider audience.

(d) **Informed Consent:** Every individual received an informed consent form outlining the study's goals, the methods used, and their rights as participants before they could begin the experiment. Before willingly giving their consent, participants could clarify doubts and ask questions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results from Data Collection

This data collection aimed to understand the challenges faced by the SAVONOR industry, specifically in the margarine production department. The evaluation of the margarine production process aimed to investigate the impact of the developed IoT-based system on real-time monitoring. The profile of respondents is as follows:

(i) Eight (8) laboratory personnel responsible for quality assessments,

(ii) Ten (10) plant managers overseeing production operations, and

(iii) Two (2) maintenance personnel responsible for ensuring the system's smooth functioning.

These respondents were important contributors to the comprehensive assessment of the IoT system's efficacy in enhancing margarine production at SAVONOR Company Limited.

4.1.1 Results from Interview with Plant Managers

An interview was conducted with 10 plant managers. The questions and answers asked to develop project are shown in Question 1.

Question 1: What are the reasons for the delay in margarine production?

Respondent	Response
Respondent 1	High temperatures, over 60 degrees Celsius, can cause delays.
Respondent 2	The lack of an automated cooling system contributes to delays in temperature regulation.
Respondent 3	The age of the machine is a significant factor in production delays.
Respondent 4	The absence of proper maintenance procedures can lead to machinery breakdowns and subsequent delays.

These results indicate that most respondents mentioned factors contributing to the delay in margarine manufacturing: High temperatures and the lack of an automatic cooling system, followed by the machine's age and maintenance problems.

Question 2: What techniques do plant managers use to inspect the margarine's readiness?

Respondent	Response
Respondent 1	We visually inspect the color changes of the margarine, specifically observing the yellow color.
Respondent 2	Visual inspection of the margarine's texture and consistency is our primary method.
Respondent 3	We rely on visual inspection to determine any irregularities or changes in the margarine's appearance."

According to these results, the majority mentioned Visual inspection, particularly observing the yellow color changes emerged as a common theme among plant managers.

Question 3: How do plant managers involve laboratory personnel in confirming the final stage of margarine production?

Respondent	Response
Respondent 1	We call the laboratory personnel to conduct tests to verify the quality and readiness of the margarine.
Respondent 2	Consulting laboratory personnel for tests is part of our protocol to confirm the final stage.
Respondent 3	Laboratory tests are conducted to ensure accuracy in determining the final stage of margarine production.

These results entail plant managers frequently communicate with laboratory personnel over the phone and conduct tests as part of the confirmation procedure for the final stage of margarine production.

4.1.2 Results from Interview with Laboratory Personnel

The interview involved eight laboratory personnel and their responses are discussed as follows:

Theme 1: Optimal Temperature for Margarine Production

The Laboratory personnel consistently agreed that maintaining a temperature of around 60°C is optimal for preserving margarine quality. Respondent 1 stated that temperatures around 60°C have been effective for maintaining margarine quality, but quality degradation is observed beyond this threshold. Respondent 2 found that temperatures above 60°C leads to undesirable changes in margarine's texture and flavor, and their team typically aims to keep temperatures within this range for optimal quality. Respondent 3 further emphasized that temperatures around 60°C are suitable for margarine production, with a noticeable decline in product quality, particularly affecting texture and shelf life, beyond this point.

Theme 2: Concerns about Temperature Exceeding 60°C

Respondents highlighted the risks associated with exceeding 60°C. Respondent 1 noted that temperatures beyond 60°C results in a noticeable degradation of the margarine's quality, especially in terms of texture and shelf life. Similarly, Respondent 2 and Respondent 3 also raised concerns about the negative effects on flavor and texture when temperatures exceed 60°C.

4.1.3 Results from Interview on Willingness to Adopt IoT-based System

An investigation was carried out to determine the employees' willingness to adopt an IoT-based system for real-time monitoring of the margarine production process. The employees included eight Laboratory personnel who were in charge of quality assessments, 10 plant managers who oversaw production operations, and two maintenance personnel.

Theme 3: Willingness to Adopt IoT-based System

A strong willingness to adopt an IoT-based system for real-time monitoring was expressed by most participants. Respondent 1 (Laboratory Personnel) strongly agreed that the implementation of such a system would be highly beneficial in keeping the team informed during production. Respondent 2 (Plant Manager) also agreed, stating that the IoT system would improve efficiency and productivity. Similarly, Respondent 3 (Maintenance Personnel) believed the system would help ensure the smooth functioning of the production process.

4.2 Results from Requirements Analysis

4.2.1 Functional and Non-functional Requirements

A variety of data was gathered through focus group discussions and interviews. The functional and non-functional requirements of the system were established through an analysis of collected data, shaping the system's design and development trajectory. The functional requirements are shown in Table 3, which lists the functions and tasks the system should perform to satisfy user demands. On the other hand, Table 4 lists the non-functional requirements, outlining limitations and possible performance, security, and usability aspects of the system. While non-functional criteria include more general factors influencing system functionality, functional requirements cover the fundamental tasks a system should accomplish.

Table 3: Functional requirements

S/N	Requirements
1.	The system shall continuously monitor the temperature, pH level, and color values of the margarine production process in real time
2.	The system shall automatically activate the Peltier cooling system if the temperature exceeds 60°C to maintain optimal production conditions
3.	The system shall send alerts to laboratory personnel when deviations in pH level and color value are in the required range.
4.	In cases where the pH value or color is outside the required range, the system shall alert maintenance personnel to check for production or equipment issues
5.	The system should have the capability to show the monitored parameters on an LCD screen
6.	The system shall allow for registration, login and logout of the system user. The user's name, email, role, contact, and password are required during registration.
7.	The system shall allow the administrator to edit or remove users' information, as well as review the monitored parameters.
8.	The system shall upload monitored parameters to both the database and ThingSpeak, enabling users to visualize, analyze, and review the data remotely.

Table 4: Non-functional requirements

S/N	Non-Functional requirements
1.	The system shall handle multiple tasks and operate continuously throughout the production process.
2.	Both the LCD display and the web application shall have a simple, easy-to-use interface.
3.	The web application shall be compatible with various devices, browsers, and operating system
4.	The system should be reliable by providing real-time data
5.	The system shall accommodate modifications and enhancements without disrupting functionality, ensuring scalability for future expansion.

4.3 System Development Results

This section discusses the developed system's findings. As the term "process" implies, the web application helps SAVONOR employees, specifically in the Margarine and Quality Control department, monitor the status of margarine during its manufacturing. It also enables remote monitoring of the margarine production process. Furthermore, notifications are sent to the maintenance and laboratory personnel via email and SMS, which they receive on their phones.

4.3.1 Achieving Outcomes: Hardware Integration Process and Performance

The hardware integration process reached important milestones as depicted in Fig. 31. The steps from beginning component assembly to the final results after the control PCB Circuit's etching and soldering are shown in this image. Notably, the system can autonomously regulate the Peltier cooler in response to temperature changes, activating or deactivating it when it exceeds sixty degrees Celsius. Moreover, a smooth interface with the ESP32 microcontroller makes real-time monitoring and operation updates possible. The integration process consists of the following crucial steps:

(i) Start the production: As illustrated in Fig. 31(1), this first stage is physically pushing the button to start working.

(ii) Internet Connectivity Check: Before showing any information, the second phase shown in Fig. 31(2), verifies internet connectivity.

(iii) Feedback Display: After determining internet connectivity, the system presents pertinent parameters for user feedback (Fig. 31(3)).

(iv) Cooling Activation: The last phase (Fig. 31(4)) shows how the cooling mechanism is activated in response to high temperatures within the system.

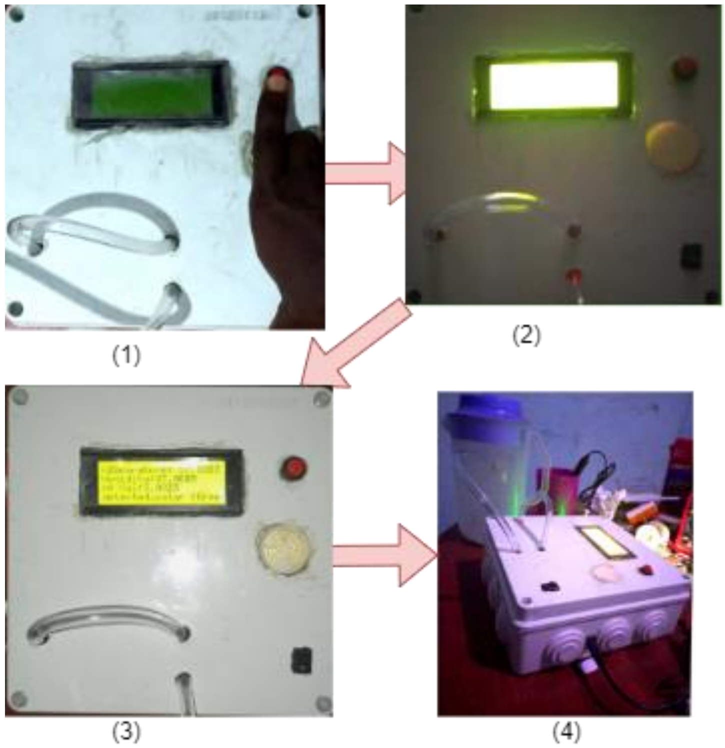

Figure 31: Achieving outcomes steps

4.3.2 Database Design Section

The results of the table database architecture are shown in Fig. 32, which includes tables for DHT22 data, pH level, color data, and users. The installation was successful using the MySQL Server, and PhpMyAdmin to visualize the results. This section outlines the approach taken to build an effective data management system that is essential for monitoring margarine production.

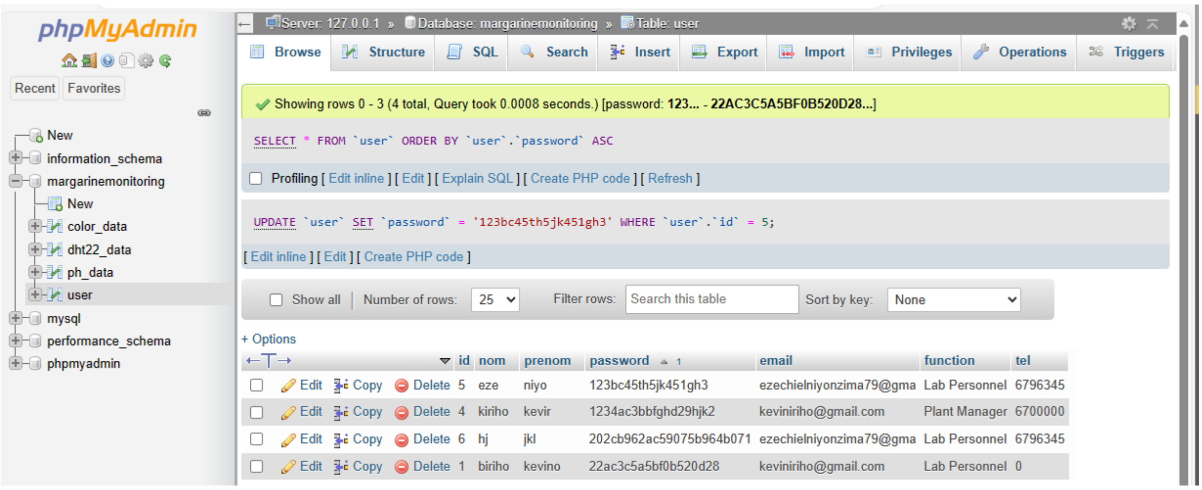

Figure 32: Database view in XAMPP tool

4.3.3 Web-Based and Mobile Application System Results

Integrating mobile and web applications, as the code used in Appendix 6, enhances user accessibility to sensor data, providing a seamless experience whether accessed from a smartphone, laptop, or desktop computer. The application and its corresponding database are securely hosted on a web server, ensuring data retrieval whenever an internet connection is available. Users benefit from various functionalities within this comprehensive system, including streamlined user registration and authentication processes, facilitating smooth navigation to different pages tailored to their needs.

(i) System's authentication page

The user authentication interface facilitates access to various functionalities within the system for subscribed users as shown in Fig. 33. The designed system allows users to authenticate themselves. Users should be enrolled in the IoT-based system for real-time monitoring of the margarine production process. Users must first register and remember their login information, which consists of a password and username that are necessary for the authentication procedure, to accomplish this.

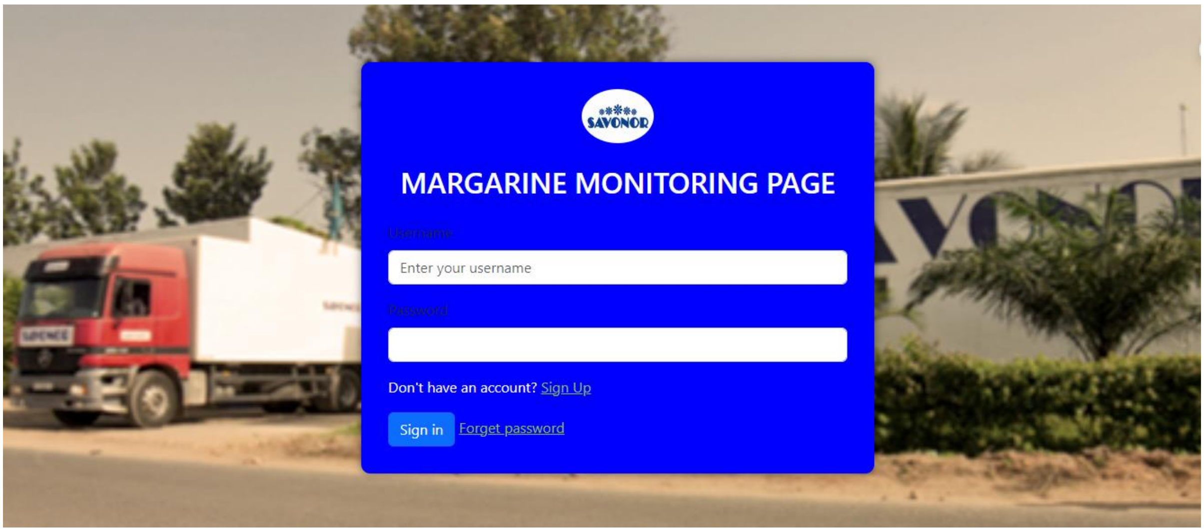

Figure 33: Authentication page

(ii) Registration page

The registration procedure is an essential part of the system that gives new users access to the platform's features. The registration interface, which leads users through the account creation process is shown in Fig. 34. This section lists the essential elements of the registration interface and describes the procedures for registering for system access.

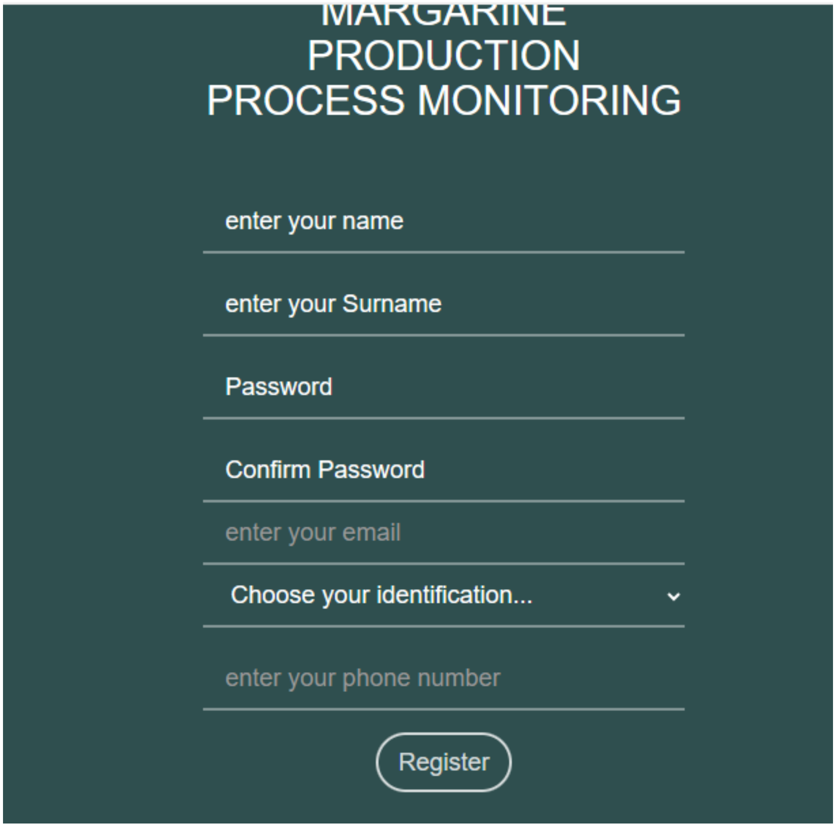

Figure 34: Users registration

(iii) System main page

An innovative real-time monitoring system built for the margarine production process has been introduced here. The system makes use of the IoT to incorporate necessary sensors and deliver real-time input on critical metrics. Together, the pH data, color sensor readings and DHT22 temperature and humidity values provide a thorough understanding of the manufacturing environment, as shown in Fig.35.

Figure 35: User registration

(iv) Admin interface

The administrative functionality of the developed IoT-based system for the real-time margarine production process allows for the seamless management of registered users. The admin interface as shown in Fig. 36, is equipped to perform essential tasks such as user deletion and information editing. This empowers administrators to efficiently update or remove user details as needed.

IOT BASED SYSTEM FOR REAL TIME MARGARINE PRODUCTION PROCESS

ID	Name	Surname	Password	Email	Function	Telephone	Update	DElete
1	biri	kevino	22ac3c5a5bf0b520d28	keviniriho@gmail.com	Lab Personnel	79979367	Edit	Delete
4	kiriho	kevir	1234ac3bbfghd29hjk2	keviniriho@gmail.com	Plant Manager	6700000	Edit	Delete
5	eze	niyo	123bc45th5jk451gh3	ezechielniyonzima79@gma	Lab Personnel	6796345	Edit	Delete
6	hj	jkl	202cb962ac59075b964b071	ezechielniyonzima79@gma	Lab Personnel	6796345	Edit	Delete
8	eze	niyo	123	jhhh@gmail.com	Lab Personnel	69796345	Edit	Delete
9	biriho	kevin	eze123	ezexercichielices241@gmail.com	Lab Personnel	79979367	Edit	Delete
10	abana	hello	ab123	ezechielniyonzima79@gmail.com	Lab Personnel	6789045	Edit	Delete
12	ezechiel	niyonzima	eze123	ezechielniyonzima79@gmail.com	Plant Manager	79979367	Edit	Delete

Back home home

@automation.com

Figure 36: Admin interface

(v) Real-time temperature monitoring

Temperature monitoring is one of the key project parameters; departures from the target could trigger the Peltier cooler to start cooling or shut off automatically. For this reason, one of the project's main objectives was to enable real-time monitoring of this parameter during the margarine production process. Figure 37 illustrates how the website or mobile application that was constructed was able to display the temperature and humidity data that had been successfully stored in the database.

IOT BASED SYSTEM FOR REAL TIME MARGARINE PRODUCTION PROCESS Accueil DHT22 Color Sensor PH Level

IOT BASED SYSTEM FOR REAL TIME MARGARINE PRODUCTION PROCESS

ID	Temperature	Humidity	Record Time
1	0.00	0.00	2023-09-27 17:36:00
2	0.00	0.00	2023-09-27 17:47:21
3	30.80	81.00	2024-05-07 20:03:18
4	30.90	80.90	2024-05-07 20:03:31
5	31.00	80.60	2024-05-07 20:03:43
6	30.50	80.30	2024-05-07 20:09:35
7	30.60	79.60	2024-05-07 20:10:19
8	30.60	79.80	2024-05-07 20:10:29
9	31.20	79.00	2024-05-07 23:10:12
10	31.40	79.60	2024-05-07 23:10:29

Figure 37: Temperature and humidity data

4.3.4 Notifications for Margarine Production Monitoring

The system included elements for tracking margarine readiness, such as pH levels and color indicators, to improve quality control. When the margarine reached the appropriate levels, when pH was greater than 60°C and the color sensor was showing yellow, automated alerts were issued to the Laboratory personnel. This proactive strategy reduced testing process delays and increased efficiency. Figure 38 shows the email notifications sent to Laboratory personnel and Maintenance personnel. Figure 39 shows the SMS notifications sent to Laboratory personnel and maintenance personnel.

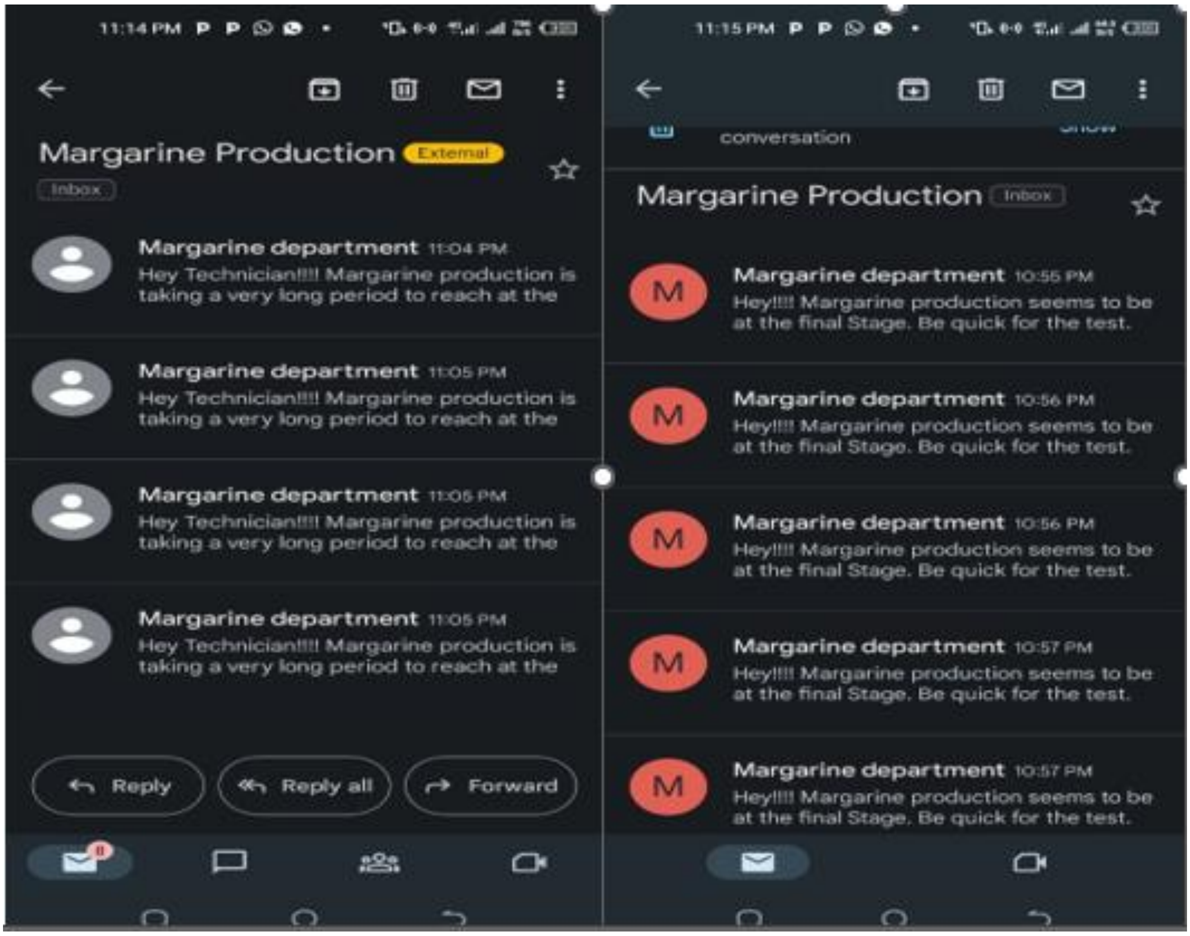

Figure 38: Email notifications sent to Laboratory personnel and Maintenance personnel

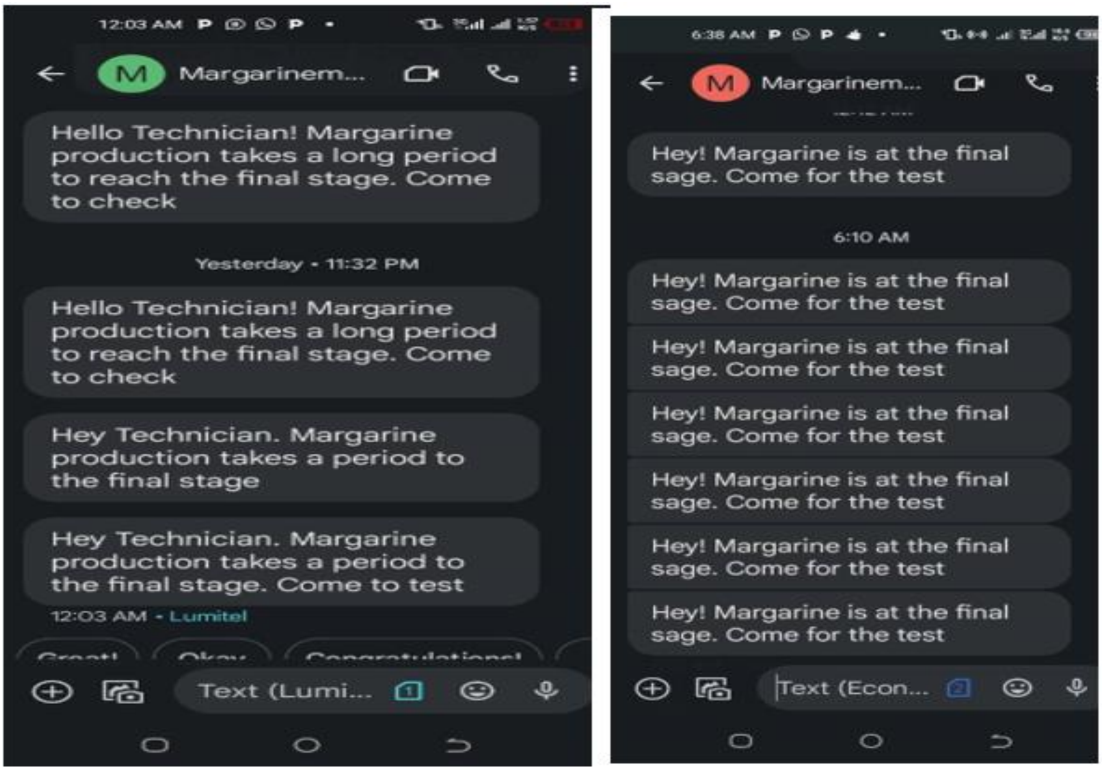

Figure 39: Technician and Laboratory personnel notifications

4.3.5 Data Visualization via ThingSpeak

Real-time monitoring of critical parameters in the margarine production process has been made possible by the integration of advanced sensors, such as the pH, color, and temperature sensors DHT22. The data collected is seamlessly transmitted to the ThingSpeak platform as shown in Figs. 40 and 41, a potent IoT hub tailored for effective and organized data and management.

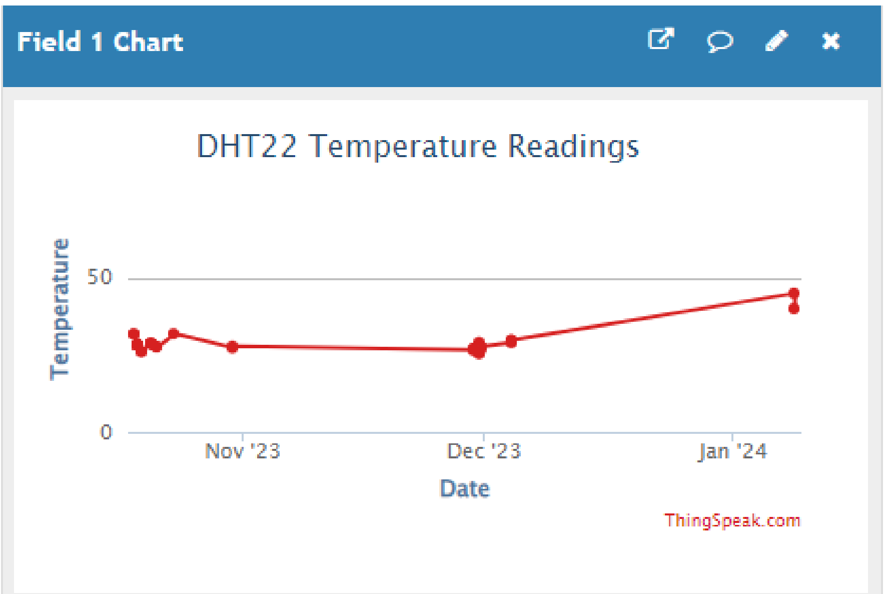

Figure 40: Temperature readings

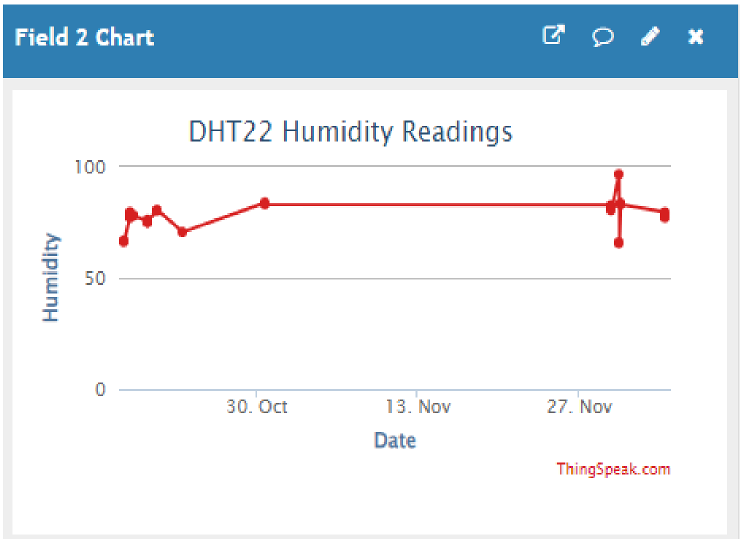

Figure 41: Humidity readings

4.4 System Testing Results

System testing was done to ensure that the produced system was suitable for its intended use and would work flawlessly in practical applications. This stage included a thorough analysis of the specifications of every component, done before the evaluation of the complete integrated system. Before conducting User Acceptance Testing (UAT), the system underwent rigorous testing phases to ensure its functionality and reliability.

4.4.1 Unit Testing

To make sure every part worked as intended, every sensor (pH, DHT22, color), microcontroller (ESP32), and actuator (Peltier chiller) was tested separately.

4.4.2 Integration Testing

Tests were conducted on the individual parts to confirm how well the various parts work together and integrate into the margarine production process monitoring system. This stage verified that all of the system's parts functioned as a unit.

4.4.3 System Testing

To verify the system's functionality in real-world scenarios, a comprehensive testing protocol was implemented involving the sensors, microcontroller, and actuators. The system's ability to track and regulate the parameters of margarine manufacturing was confirmed during this testing phase.

4.4.4 Test Cases

Detailed test cases acted as a guide for testing operations and were created to verify the system's behavior under diverse inputs and conditions. They provided detailed instructions, anticipated results, and standards for judging success or failure. After completing these testing phases, the system proceeded to User Acceptance Testing (UAT) to assess its suitability for end-user deployment.

4.4.5 User Acceptance Testing

In the project's final phase, User Acceptance Testing (UAT) was conducted to ensure that the system aligns seamlessly with the requirements outlined in the project specifications. This testing phase involved using data to emulate real-world scenarios, confirming the system's readiness for deployment.

Throughout UAT, end-user testers expressed satisfaction with the system's performance. The 20 respondents included 10 plant managers, eight laboratory personnel, and two maintenance personnel. Plant managers were primarily responsible for overseeing production and ensuring operational efficiency. Laboratory personnel focused on testing the quality of the margarine product at the final stage. Maintenance personnel ensured that equipment and system components functioned correctly.

As shown in Table 5, the majority of respondents indicated strong approval of the system's performance. Google Forms was utilized to confirm that the system's requirements were approved, as shown in Appendix 7. Their feedback emphasized the system's possible influence on margarine manufacturing while confirming that it complies with requirements. Thematic analysis emphasized the system's efficacy and dependability, confirming that it is prepared for implementation.

Table 5: User acceptance results

Validation	Respondents				
	Strongly Agree (%)	**Agree (%)**	**Neutral (%)**	**Disagree (%)**	**Strongly Disagree (%)**
The Peltier cooling system operates effectively based on temperature conditions	90%	5%	5%	0%	0%
The accessibility of the system from various devices	85%	10%	0%	5%	0%
The system's ability to generate alerts	80%	15%	5%	0%	0%
System responds appropriately when pH levels fall within or outside the predefined range	75%	15%	5%	5%	0%
The LCD screen accurately displays real-time information about the system's status.	80%	20%	0%	0%	0%
The web-based application is user-friendly and an easy to navigate	80%	15%	0%	0%	5%

4.5 Discussion

The margarine production experiments effectively monitored temperature conditions, color, and pH levels without human intervention. The ESP32 microcontroller was effectively interfaced with the system's components, which include the Peltier cooling system, color sensors, DHT22 sensors, and pH sensors, and linked to the Printed Circuit Board (PCB), as shown in Fig. 31. The database (Fig. 32) contained data from the pH, DHT22, and color sensors, allowing for remote visualization and real-time monitoring via the web application (Figs. 33–37) and mobile application.

Real-time monitoring of DHT22 values was achieved, and notifications (email and SMS) to the plant managers and Laboratory personnel (Fig. 38) and SMS (Fig. 39) were successfully sent to the database. Data was automatically sent to the ThingSpeak cloud for storage and remote visualization (Figs. 40 & 41), aiding SAVONOR personnel in monitoring margarine production processes and analyzing data remotely. Table 5 shows positive responses from users to the system's primary features, the registration, main, and login pages.

The developed system significantly enhances existing machinery and employee operations within the food industry, offering interactive features and support. Compared to previous IoT-based monitoring systems, such as those developed by Buonocore *et al.* (2021) and Canete-Carmona *et al.* (2020), which primarily focused on temperature and CO_2 monitoring, the proposed system integrates multi-parameter tracking, including temperature, pH, and Color. Additionally, unlike Spagnuolo *et al.* (2023), which monitored industrial drying kilns without real-time alerts, this system provides automated control through the Peltier cooling system and real-time notifications via SMS and email. These features enhance production monitoring, making the system more adaptable to margarine production.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study set out to develop an IoT-based margarine production monitoring system specifically designed to meet the needs of SAVONOR's operations in Bujumbura, Burundi. The objective was to address particular operational challenges in the department responsible for producing margarine, such as the lack of an automatic actuator for temperature regulation, the need to manually contact laboratory personnel, uncertainty about the operating temperature of the machinery, and reliance on visual inspections for color assessment.

Building upon identified limitations in existing systems, the IoT-based system seamlessly incorporates a variety of sensors and actuators into the production environment to successfully handle important factors:

(i) **Real-time Monitoring and Control**: The system is equipped with a highly advanced network of sensors strategically placed throughout the production area. These sensors include color, DHT22, pH, and Peltier cooling systems. The Peltier cooling system is essential to ensure constant quality in the production of margarine. It automatically cools when temperatures rise over predetermined levels.

(ii) **Alerts and Notifications**: The system has proactive alerting features to notify maintenance workers and laboratory personnel of important events. Multiple channels, such as email and buzzer alerts, transmit alerts, guaranteeing prompt intervention and quality control procedures.

(iii) **User Interface and Interaction**: The 20*4 LCD screen and user-friendly buttons ensure an intuitive user interface, enhancing the overall user experience and contributing to the efficiency of the monitoring system.

(iv) **Thorough Testing and Validation**: Extensive testing was carried out to assess the functionality of every system component, including the sensors and actuators. This required confirming the precision and dependability of every part in carrying out its designated functions, such as monitoring pH levels, spotting color changes, and regulating humidity and temperature.

The data validation in Table 5 confirms that the constructed system satisfies the requirements, corroborating the study's findings. This positions the system as valuable in enhancing SAVONOR's margarine production processes. By utilizing cutting-edge IoT technology to solve particular operational issues, the solution raises the bar for quality assurance in the food production sector and increases efficiency. By promoting ongoing innovation and quality in food production, the deployment of this technology has the potential to transform margarine production methods in the future.

5.2 Recommendations

Based on the successful development and implementation of the IoT-based margarine production monitoring system at SAVONOR in Burundi, recommendations are provided for both policymakers and practitioners.

(i) For policymakers, it is recommended that they focus on increasing internet speed to ensure uninterrupted data transmission, which enhances real-time monitoring and avoids delays. Additionally, promoting collaborations between the public, commercial, and research sectors can facilitate knowledge exchange and drive progress in the field.

(ii) For practitioners, the recommendations include offering clear instructions for using and maintaining the monitoring system effectively. Furthermore, implementing IoT technologies into current procedures can help streamline operations and maximize efficiency. Additionally, exchanging recommended procedures for analyzing data in real time can enhance decision-making processes and optimize production outcomes.

5.3 Future Work

Future work will incorporate machine learning algorithms to automatically identify margarine ingredients that must be better mixed during refining. Moreover, plans exist to create a completely working machine from scratch rather than integrating new features into the current system.

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APPENDICES

Appendix 1: Acceptance Letter

SAVONOR
Beauty & Hygiene

Our Ref: 09/DIR/SAV/HR/2023

19th January, 2023

To
The CENIT@EA Industrial Liaison and outreach officers
The Nelson Mandela African Institution
Of Science and Technology
Arusha, TANZANIA

Dear Sirs,

Re: INTERNSHIP PLACEMENT FOR YOUR STUDENT EZECHIEL NIYONZIMA

We have well received your letter requesting to give your young professionals the opportunity to do their internship at our company.

We are pleased to inform you that we have accepted a six month's internship for your young professional Ezechiel NIYONZIMA, currently studying Master in Embedded and Mobile Systems and starting from 21st February to 22nd August 2023.

Yours Faithfully,

Gervais NIYONGABO
Human resource Director of SAVONOR

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Appendix 2: Interview Guide for Developing an IoT-Based System for Real-time Monitoring of the Margarine Production Process

Section A: Opening Questions

1. Would you mind if we can conduct this interview in your office, or do you have an idea of another place that is more comfortable?
2. Can I know a little about you and what tasks are performing in this company?
3. How long have you been working in this company?
4. Do you have any questions for me before we continue with our interview?

Section B: Introductory Questions

Laboratory Personnel

1. How is your experience of working in this company?
2. Currently, how are margarine quality checks and maintenance carried out throughout production?
3. Could you elaborate on the factors you take into account while measuring margarine's pH, particularly when it comes to changing temperatures?
4. What difficulties do you encounter in maintaining constant quality, particularly in the presence of temperature fluctuations?
5. Is there another way for you to keep an eye on the process of making margarine?

Plant Managers

1. How is your experience of working in this company?
2. Could you elaborate on the factors you take into account while measuring margarine's pH, particularly when it comes to changing temperatures?
3. What difficulties do you encounter in producing the high quantity of margarine?
4. Is there another way for you to keep an eye on the process of making margarine?

Section C: Key Questions

Laboratory Personnel

1. How do you communicate with the Laboratory personnel?

2. How are you aware that Margarine has reached the end?
3. Which particular equipment or testing apparatuses do you use to keep an eye on margarine quality?
4. In your opinion, what effects does temperature variation have on margarine's texture, and how is this factor controlled?
5. Could you describe the protocols used to check margarine's color at various stages of production and various temperatures?
6. What kind of adjustments or remedial actions are usually taken when temperature changes present a problem?
7. Are there particular temperature ranges that are thought to be ideal for various margarine quality parameters?

Plant Managers

1. How do you communicate with the Laboratory personnel?
2. How are you aware that Margarine has reached the end?
3. In your opinion, what effects does temperature variation have on margarine's texture, and how is this factor controlled?
4. Could you describe the strategies you usually use to check margarine's color at various stages of production?
5. What kind of adjustments or remedial actions are usually taken when temperature changes present a problem?
6. Are there particular temperature ranges that are thought to be ideal for various margarine quality parameters?
7. What strategies do you use to overcome these challenges?

Section D: Concluding Questions

1. How do you think an IoT-based system for real-time monitoring of the margarine production process could improve the current monitoring methods?
2. In your opinion, what benefits could be derived from implementing an IoT-based system in margarine production?
3. Are there any important information we missed in our discussion today?

Appendix 3: Observation Checklist

Date of Observation: 11st March to 12nd Avril 2023

Time: 1 Month

Observer Name: Ezechiel

Location: SAVONOR Margarine Production Department

1. Are the temperature, pH, and color values monitored during the margarine production process? (Yes/No)
    - If yes, how are these parameters monitored? (Manual/Automated)
    - Are there any delays or issues with monitoring parameters? (Yes/No)
2. What equipment is used for margarine production monitoring? (e.g., thermometers, pH meters, etc.)
    - Is the equipment functioning properly? (Yes/No)
    - Are any measurements taken manually? (Yes/No)
3. Are plant managers notified about any issues with the margarine production process? (Yes/No)
4. Are there any communication breakdowns between departments (lab, maintenance, production)? (Yes/No)
5. Are there any common issues observed in the margarine production process? (Yes/No)
6. Are temperature or pH levels consistently controlled? (Yes/No)
7. Do the workers face any challenges while monitoring production parameters? (Yes/No)

Appendix 4: Focus Group Discussions Guide

Section A: Introduction

Welcome and Introduction

- Introduce the purpose of the focus group discussions
- Explain the format and objectives of the discussions
- Ensure confidentiality and encourage open discussion

Section B: Opening Questions

1. Location Preference

- Ask participants if they have a preferred location for the discussions.
- Participant Introductions
- Allow each Participant to introduce themselves briefly and their roles within the company

2. Duration of Employment

Inquire about the length of time each participant has been working in their current role or with the company

3. Any Questions

Give participants the opportunity to ask questions before proceeding with the discussions

Section C: Discussions Topics

1. Margarine quality Checks and Maintenance

Discuss current practices and challenges related to margarine quality checks and maintenance

2. Factors Affecting Margarine Quality

Explore factors such as pH measurement, temperature variations, and their impact on margarine quality

3. Monitoring Process

Discuss existing methods for monitoring the margarine production process and potential improvements.

4. Challenges and Solutions

Identify challenges faced during margarine production and brainstorm possible solutions.

5. Ideal Monitoring System

Gather opinions on the potential benefits and features of an IoT-based monitoring system for margarine production.

Sections D: Conclusion

1. Perceived Benefits of IoT System

Discuss participants's opinions on how an IoT-based monitoring system could improve current monitoring methods.

2. Explore the potential benefits and advantages of implementing an IoT-based system in margarine production.

3. Any additional Information

Allow participants to share any additional insights or information they believe is relevant to the discussion.

Section E: Closing

Thank the participants for their valuable contributions

Provide information on the next steps in the project.

Appendix 5: Code used to Develop an IoT-Based System for Real-Time Monitoring of the Margarine Production Process in Arduino

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_TCS34725.h>
#include <Adafruit_I2CDevice.h>
#include <DHT.h>
#define DHTPIN 12     // DHT11 signal pin is connected to digital pin 2
#define DHTTYPE DHT22   // DHT22 sensor type
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <WiFi.h>
#include <Arduino.h>
#include <HTTPClient.h>
#include <WiFiServer.h>
#include <ThingSpeak.h>

LiquidCrystal_I2C lcd(0x27, 20, 4);
DHT dht(DHTPIN, DHTTYPE);

// Define your local Wi-Fi credentials
const char* ssid = "TECNO CAMON 18i";
const char* password = "eze1994@";

// Define the pins for the pH sensor connection
const int pHProbePin = 32;

#define SDA_TCS3472 4  // Use GPIO4 for SDA (TCS3472)
#define SCL_TCS3472 5  // for SCL (TCS3472)

#define THINGSPEAK_API_KEY "ANFY97UAMMWZVQ4C"
#define THINGSPEAK_CHANNEL_ID "2397660"

const int relayPin1 = 26; // GPIO 26
const int relayPin2 = 27; // GPIO 27

// Create an instance of the TCS34725 sensor
```

```
Adafruit_TCS34725 tcs =
Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_154MS,
TCS34725_GAIN_1X);
WiFiServer server(80);
WiFiClient client;

void setup() {
  // Set the relay pins as outputs
  pinMode(relayPin1, OUTPUT);
  pinMode(relayPin2, OUTPUT);

  // Initialize the relays to the OFF state (both channels OFF)
  digitalWrite(relayPin1, LOW);
  digitalWrite(relayPin2, LOW);
  Serial.begin(115200);
  lcd.init();
  lcd.begin(20, 4);
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("   Welcome to ");
  delay(2000);
  lcd.clear();
  ThingSpeak.begin(client);
  dht.begin();

  // Connect to Wi-Fi
  connectToWiFi();
  if (tcs.begin()) {
    Serial.println("Color sensor found");
  } else {
    Serial.println("No TCS34725 found ... check your connections");
  }
}

void loop() {
  if (WiFi.status() == WL_CONNECTED) {
    // Color sensor data collection
    uint16_t clear, red, green, blue;
```

```
tcs.getRawData(&red, &green, &blue, &clear);

float r_ratio = (float)red / (float)clear;
float g_ratio = (float)green / (float)clear;
float b_ratio = (float)blue / (float)clear;

String detected_color = "Unknown";
float highest_value = 0.0;

if (r_ratio > g_ratio && r_ratio > b_ratio) {
  detected_color = "Red";
  highest_value = r_ratio;
  delay(500);
} else if (g_ratio > r_ratio && g_ratio > b_ratio) {
  detected_color = "Green";
  highest_value = r_ratio;
  delay(500);
} else if (b_ratio > r_ratio && b_ratio > g_ratio) {
  detected_color = "Blue";
  highest_value = r_ratio;
  delay(500);
} else if (red > green && (red - green) > 50) {
  detected_color = "Yellow";
  highest_value = r_ratio;
}

// DHT sensor data collection
float temperature = dht.readTemperature();
float humidity = dht.readHumidity();

// pH sensor data collection
int pHValue = analogRead(pHProbePin);
float pH = map(pHValue, 0, 1023, 0, 14);

Serial.print("Temperature: ");
Serial.println(temperature);
Serial.print("Humidity: ");
Serial.println(humidity);
```

```
  Serial.print("detected_color: ");
  Serial.println(detected_color);
  Serial.print("pH_Value: ");
  Serial.println(pH);

  lcd.setCursor(0, 0);
  lcd.print("Temperature: ");
  lcd.println(temperature);
  lcd.setCursor(0, 1);
  lcd.print("Humidity:");
  lcd.println(humidity);

  lcd.setCursor(0, 2);
  lcd.print("pH Val:");
  lcd.println(pH);

  lcd.setCursor(0, 3);
  lcd.print("detected_color :");
  lcd.println(detected_color);
   if (temperature >= 25){
    digitalWrite(relayPin1, HIGH);
    digitalWrite(relayPin2, HIGH);
   }
   else { digitalWrite(relayPin1, LOW);
   delay(2000);
   digitalWrite(relayPin2, LOW);
   }

  delay(1000);

  // Send data to your local server
  String dht1Url =
"https://margarinetest.000webhostapp.com/Marigarinemonitor/dht1.php";
  String ph1Url =
"https://margarinetest.000webhostapp.com/Marigarinemonitor/ph1.php";
  String color1Url =
"https://margarinetest.000webhostapp.com/Marigarinemonitor/color1.php";
```

```
  HTTPClient http;
  http.begin(dht1Url);
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  String dht1Data = "value1=" + String(temperature) + "&value2=" +
String(humidity);
  int dht1ResponseCode = http.POST(dht1Data);
  http.end();

  http.begin(ph1Url);
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  String ph1Data = "value3=" + String(pH);
  int ph1ResponseCode = http.POST(ph1Data);
  http.end();

  http.begin(color1Url);
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  String color1Data = "value4=" + String(detected_color)+ "&value5=" +
String(highest_value);
  int color1ResponseCode = http.POST(color1Data);
  http.end();

  Serial.print("DHT1 Response Code: ");
  Serial.println(dht1ResponseCode);
  Serial.print("PH1 Response Code: ");
  Serial.println(ph1ResponseCode);
  Serial.print("Color1 Response Code: ");
  Serial.println(color1ResponseCode);

  if (dht1ResponseCode == 200 && ph1ResponseCode == 200 &&
color1ResponseCode == 200) {
    // All requests were successful
    Serial.println("All POST requests were successful");
  } else {
    Serial.println("Error on sending one or more POST requests");
  }

  // Send data to ThingSpeak
  ThingSpeak.setField(1, temperature);
```

```
    ThingSpeak.setField(2, humidity);
    ThingSpeak.setField(3, pHValue);
    int status = ThingSpeak.writeFields(atoi(THINGSPEAK_CHANNEL_ID),
THINGSPEAK_API_KEY);
    if (status == 200) {
      Serial.println("Data sent to ThingSpeak successfully!");
    } else {
      Serial.println("Failed to send data to ThingSpeak.");
    }

    // Print free heap memory
    Serial.print("Free Heap: ");
    Serial.println(ESP.getFreeHeap());

    delay(1000);
  } else {
    Serial.println("WiFi disconnected. Reconnecting...");
    connectToWiFi();
  }
}
void connectToWiFi() {
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP Address");
  Serial.println(WiFi.localIP());
}
```

Appendix 6: Code Used for Web Application

```
    <script src="https://www.google.com/recaptcha/api.js" async defer></script>
</head>

<body>
    <div class="container bootstrap snippets bootdey">
        <div class="row login-page">
            <div class="col-md-4 col-lg-4 col-md-offset-4 col-lg-offset-4">
                <img src="savonor logo.jpg" class="user-avatar img-thumbnail"><img src="
                Savonor-2 im1.jpg"
                    class="user-avatar img-thumbnail">
                <div class="col-md-4 col-lg-4 col-md-offset-4 col-lg-offset-4">
                    <h2>MARGARINE MONITORING PAGE</h2>
                    <form method="post" action="log.php">
                        <div class="form-content">
                            <div class="form-group">
                                <input type="text" name="name"
                                    class="form-control input-underline input-lg" placeholder="
                                    Enter your username"
                                    required>
                            </div>
                            <div class="form-group">
                                <input type="password" name="pass"
                                    class="form-control input-underline input-lg" placeholder="
                                    Enter your password"
                                    required>
                            </div>
                            <!-- Your form fields here -->
                            <div class="form-group">
                                <div class="g-recaptcha"
                                    data-sitekey="6LdHfkkpAAAAAJaA10D3NRGTmGj314LxxqggyFAh"></div
                                    >
                            </div>
```

```
<div class="alert-light text-primary text-center"></div>

<input type="password" name="pass2" class="form-control input-underline input-lg" placeholder="
Confirm Password" required>



<div class="alert-light text-primary text-center">


</div>
 <div class="form-group">

<div class="alert-light text-primary text-center"></div>
         <input type="email" name="email" class="form-control input-underline input-lg"
         placeholder="enter your email" required>
         <div class="alert-light text-primary text-center">
                    </div>


                     <div class="form-group">
                         <select  name="function" class="form-control input-underline input-lg"
                         required >
    <option selected>Choose your identification...</option>
    <option name="function">Lab Personnel</option>
    <option name="function">Plant Manager</option>

  </select>


</div>
```

```
</tr>
        <tr>
      <td>Temperature Value</td>
      <td><b>28.8</b></td>
    </tr>
    <tr>
      <td>Humidity value</td>
      <td><b>86.8</b></td>
    </tr>
    <tr>
      <td>Record Time </td>
      <td><b>2024-01-06 15:12:17</b></td>
    </tr>
    <tr>
      <td>Time elapsed</td>
      <td><b>2646 Minutes</b></td>
    </tr>
            <tr>
      <td>Temperature Value</td>
      <td><b>29.5</b></td>
    </tr>
    <tr>
      <td>Humidity value</td>
      <td><b>78.7</b></td>
    </tr>
    <tr>
      <td>Record Time </td>
      <td><b>2023-12-04 13:37:51</b></td>
    </tr>
    <tr>
      <td>Time elapsed</td>
      <td><b>50261 Minutes</b></td>
    </tr>
<!DOCTYPE html>
<html>
<head>
  <meta name="viewport" content="width=device-width, initial-scale=1.0">
  <style>
    table, th, td {
      border: 1px solid black;
    }
  </style>
</head>
<body>
  <table style="width:100%">
    <tr>
      <td colspan="2" style="text-align: center;"><b>IOT BASED SYSTEM FOR REAL TIME MARGARINE
      PRODUCTION PROCESS</b></td>
    </tr>
          <tr>
        <td>Color Value</td>
        <td><b>45</b></td>
      </tr>
      <tr>
        <td>Color Name</td>
        <td><b>Blue</b></td>
      </tr>
      <tr>
        <td>Record Time</td>
        <td><b>2023-12-05 16:54:11</b></td>
      </tr>
      <tr>
        <td>Time Elapsed</td>
        <td><b>48625 Minutes</b></td>
      </tr>
```

Appendix 7: Google Form's Screenshot used for UAT