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THE DEVELOPMENT OF IoT BASED ROBOTIC SYSTEM FOR SERVING TEA IN ACADEMIC INSTITUTIONS. CASE STUDY: INES-Ruhengeri.

A dissertation submitted in partial fulfillment of requirements for the award of a Bachelor's Degree of Science with honors in Computer Science, Option of Industrial IT.

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DECLARATION

I do hereby declare that the work presented in this dissertation is my own contribution to the best of my knowledge. The same work has never been submitted to any other University or institution. I, therefore, declare that this work is my own for the partial fulfillment of the award of a Bachelor's degree of science with honors in Computer Science, honors in industrial information Technology at INES-Ruhengeri.

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APPROVAL

This is to certify that this dissertation work entitled "The development of IoT based robotic system for serving tea in academic institutions" is an original study conducted by NSANZIMANA Elie under my supervisor's guidance.

Supervisor's name: Eng. NIYOMUGABA Alexandre

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Submission date: ....

DEDICATION

- To Almighty God
- To my Grandmother
- To my family
- To my supervisors
- To my lecturers
- To my classmates
- To my friends

ACKNOWLEDGEMENT

I would like to extend my sincere gratitude and appreciation to all those who assisted and supported me in making this research a successful output. First and foremost, I thank God almighty for his mercies, unfailing love, and providence and for giving me strength and seeing me through my studies. The completion of this research project would have not been possible without those all above mentioned guidance, and support from my supervisors Eng. NIYOMUGABA Alexandre and Mrs.SHIMIRWA Aline Valerie to whom I am highly grateful in countless ways. You have supported me throughout my project from the conception of the research idea to the final stage with advice and patience that enabled me to design and implement this research project.

ABSTRACT

The advancement of automation and smart technologies has opened new possibilities for enhancing service delivery in academic environments. This project presents the design and implementation of an IoT-based robotic system for serving tea in academic institutions, with focus on convenience, efficiency, and affordability. The system combines hardware and software components like an ESP32 microcontroller, RFID cards, LCD displays, water pump as tea dispenser, Keypad for commanding to create a semi-autonomous tea-dispensing robot that responds on user command and payment confirmation. The users interface the system through a graphical user interface (GUI), facilitating them to register, login, select the amount of tea they desire, and make payments through RFID credit cards. The system also includes a recharge interface for crediting and top-ups of credits as well as transactional monitoring to ensure transparency and accountability. The use of IoT ensures that there is real-time communication among hardware modules and the server, which facilitates live data processing, reporting, and control of the system. Besides this, integration of AMRs (Autonomous Mobile Robots) or AGVs (Automated Guided Vehicles) is also intended in future development, which can make the robot deliver the tea to the office or class consumers straightaway. Prototype testing and verification were successful in being able to work with user registration, processing payments, delivering the correct amount of tea, and processing live transactions. The system prevents a lot of human intervention, especially during off-peak service periods while maintaining cleanliness and minimizing operating Setbacks. Constraints including the reliance on stable internet networks and user compliance with RFID technology were discovered. Overall, the system created is a robust and scalable solution that meets the requirements of academic institutions today, enabling smarter, more automated campus life. It facilitates movement towards digitalization of service sectors in academic settings and provides the foundation for further IoT based campus robotic research in the future.

Keywords: Internet of Things (IoT)**,** Robotic System**,** Espressif Modules (ESP)**,** RFID**,** Keypad**,** Water pump, Relay Module**,** Liquid Crystal Display (LCD)**,** Battery

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AGV: Automated Guided Vehicle

AMR: Autonomous Mobile Robot

Cobot: Collaborative Robot

DB: Database

ESP32: Espressif Systems 32-bit Microcontroller

GUI: Graphical User Interface

HMI: Human-Machine Interface

HTTP: Hypertext Transfer Protocol

IoT: Internet of Things

LCD: Liquid Crystal Display

LED: Light Emitting Diode

MCU: Microcontroller Unit

PWM: Pulse Width Modulation

RAM: Random Access Memory

RFID: Radio Frequency Identification

ROM: Read-Only Memory

UI: User Interface

UX: User Experience

VDC: Volts Direct Current

Wi-Fi: Wireless Fidelity

LIST OF APPENDICES

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background of the study

The fourth industrial revolution increases usage of robotics, embedded system, and internet of things (IoT) system at an extraordinary speed globally. The most sectors had went ahead with this new world because of the use of robotics and IoT in service automation, such as a sector in beverage supplying machines; (Yigitcanlar et al., 2021). The development of an IoT-based robotic system that provides tea in academic institutions has described a tea that was served with much efficiency by an IoT-based robotic system for the simple reason that the technologies were cheap, reliable, and easily compatible into automated serving applications This was influenced by the use of ineffective traditional methods of tea serving adopted by most academic institutions.

In East Africa, IoT-based robot systems are being used to increase efficiency and automation. Around 30% of Rwanda's and Kenya's smart agriculture projects use IoT sensors to track the crops in real-time. In healthcare, around 25% of hospitals in urban areas use IoT devices for patient tracking and equipment management. In education, adoption of IoT-based technology like service robots is growing by 12% annually and enhancing learning and resource management. These systems use sensors, cloud computing, and automation to facilitate improved decision-making and service delivery (Reid-miller, 2020).

In Rwanda, although the government supports digitalization, network stability in rural areas is a concern Costly importation of IoT hardware and electricity instability could require backup power sources). Data protection regulations must be followed to ensure business-critical data is secure Low awareness and high installation costs are barriers to IoT adoption, requiring government subsidy and sector promotion. (Yigitcanlar et al., 2021).

Based on those technologies, robotics, embedded system and an IOT system the development an IoT based robotic system for serving tea in academic institutions, specifically focusing on INES Ruhengeri as one of Rwanda's academic institutions known as Digital Campus and, by focusing on teaching engineering, sciences, and technology programs, the system has been implemented. Its primary objective was to facilitate the harmonious service of tea serving in real time to efficient service provision.

Thus the system efficiently enabled quick service, eliminated long queues waiting for service and boosted working hours.

To develop this system the ESP32 Microcontroller for managing system operations, connectivity, and IoT communication, Relay Module for controlling the tea dispensing mechanism keypad for tea quantity to be dispensed selection, water Pump for ensuring liquid flow , 12V DC Power Adapter for supplying power to the microcontroller and other components, Voltage Regulator for maintaining stable power supply to different modules, RFID Reader for cashless payment and user authentication, Frames for robotic system housing, Storage Tank for holding the tea before dispensing.

The method of manual distribution led to long queues, high operation costs, inefficiency and delays within the process of service provision Thus, using IoT-based automation in institutional food service automation was hopeful way and increased the rate of service to users, with reduced human operations and more convenient services. It also investigated the suitability of using IoT-based automation in institutional food and beverage service, hence contributing to smart service solution trends. Despite these solutions, while the system came with several advantages, it had its limitations too. Amongst the major concerns were the correctness of payment identification and malfunctions in the robotic dispenser. Moreover, maintenance and reliability under real environmental conditions remained a concern that had to be tested with more improvements.

Based on the validation results, the developed system effectively served the tea at INES Ruhengeri, in real time. It increased the rate of service to users, eliminated long queues, high operation costs, inefficiency and delays of service with reduced human operations and more convenient services.

1.2. Problem Statement

Most academic institutions including INES-Ruhengeri always consider tea to be part of meals. The old way of distributing the tea used to be done by queuing up for very long hours, delayed serving, improper sharing, and heightened cost of operation since it is handled manually .These issues further caused a reduction in convenience and had negative impacts on the punctuality and productivity of students, especially in the morning hours when time is short and most of the existing supplying machines and automated tea dispensers had been highly expensive, difficult to operate, and often not adaptable to academic environments.

To address these issues, the IoT based robotic system for serving tea in academic institutions was developed. This system reduced queuing up for very long hours, delayed serving, improper sharing, and heightened cost of operation by allowing one-time tea serving, with dispensing tea after receiving the money inserted and smart payment approach, thus providing fairness in portioning and this reduces delays, minimizes time, enhances efficiency, affordability, accuracy of dispensing and ease of use and the system is cost-efficient and adaptable to academic environments.

1.3 Research Objectives

1.3.1 General Objective

The general objective of this project is to develop and implement an IoT robotic system for serving tea in academic institutions, with a case study at INES-Ruhengeri.

1.3.2 Specific Objectives

i) **To collect data:** By use of questionnaires, interviews, and observations in INES-Ruhengeri for the system development.

ii) **To analyze**: the data collected analysis for the system requirements (functional and non-functional) and hence details for design specifications.

iii) **Design and develop**: designing and developing an integrated system for IoT based robotic with an ESP32 microcontroller and RFID for cashless-based payment and automated serving tea with precision and speed.

iv) **test and validate:** Testing and validation of a system performance in a real-world environment to ensure it meets the specified requirements and objectives.

1.4 Research questions

This study explored how a robots simplify the tasks

- ❖ What are the technologies used to collect data?
- ❖ What are the functional and non-functional requirements of the system?
- ❖ How the system should be integrated?
- ❖ How is the system going to be secured?
- ❖ How is the system able to dispense tea?

- ❖ How the system impact the waiting time and work efficiency advancement for users?
- ❖ Where the system should be located?

1.5. Choice of the Study

This study is motivated by the need to boost efficiency in serving tea within the academic environment, especially at INES-Ruhengeri as one of Rwanda's academic institutions. Then selection of INES-Ruhengeri as a test-bed provided a real-world context for the application and testing of the proposed system, ensuring both academic benefits and practical value in similar institutional environments. The old ways of serving tea were characterized by long queues, poor service, and human labor force and had proved time-wasting and highly inconveniencing for both students and staff. This research, therefore, reduce operational inefficiencies, and provide a user-friendly experience. In the background of rapid advancement of automation across the service sectors worldwide.

1.6 Significances of the study

1.6.1. Personal Interest

This research helped the researcher to acquire knowledge in robotics, IoT, and embedded systems and also solved the real-world problem, academically as a student who deals with Industrial Information technology, developing an IoT-based robotic system brought technical skills in automation, programming, and system integration. This was a contribution to academics and practical experience which proved valuable future opportunities in the smart technologies field.

1.6.2. Public Interest

The automatic tea-serving system contributed to a much-improved delivery of service, through efficiency and reduced waiting times for both students and employees. Therefore, this project enhanced convenience by eliminating problems that were generally associated with long queues and irregular portions within an academic setup. Due to this, the study contributed to the development of IoT-based automation management in food and beverage -service businesses and possibly encouraged further innovations across various institutions.

1.6.3. Community Interest

The system was developed with the aim of integrating smart solution applications in daily life as part of greater technological developments in local institutions. Additionally, it provided job opportunities in maintaining and managing automated service provision systems. Successful implementation of such innovation seeped into other sectors, including hotels, motor, restaurants and cafeterias, hence contributing to economic development and technology advancement within the community.

1.7 Research Hypotheses

The hypotheses for the development of an IoT-based robotic system for serving tea in academic institutions were as follows:

- ❖ It is suggested that this system will automate the tea-serving process, reducing human intervention and improving service efficiency.
- ❖ It is anticipated that this system will enhance user convenience by integrating RFID-based payment for seamless transactions.
- ❖ It is assumed that the system will utilize sensors to regulate tea portion sizes, ensuring quality and consistency.
- ❖ It is thought that this robotic system will significantly reduce wait times.
- ❖ It is expected that the system will operate reliably in high-demand environments, maintaining continuous service during peak hours.
- ❖ It is proposed that this IoT-based robotic system will contribute to resource optimization by minimizing tea wastage and energy consumption.

1.8 Study of the delimitation

This research focused on developing and deploying an IoT-based robotic system for serving tea at INES-Ruhengeri. The system automatically dispensed tea and made payments, targeting students, workers, and visitors. It was tested and evaluated within the institution but did not involve tea preparation, ingredient sourcing, or off-campus delivery. Testing was restricted to a single academic period due to time constraints. The absence of vital parts like a vibro motor sensor, load cell, solenoid valve, and stainless steel nozzle affected efficiency, reliability, and maintenance.

1.9 Research methodology

The research used, both qualitative and quantitative. Primary and secondary data sources in the collection of data. Primary data was obtained through questionnaires, interviews, and observations at INES-Ruhengeri to understand the challenges faced in the traditional methods of serving tea. Secondary data was obtained through literature review regarding IoT-based automation, robotics, and similar supplying systems. The collected data were analyzed using Google Form and this gives a structured framework that provides the full procedures needed for the development and achievability assessment of the IoT-based robotic tea-serving system for an academic institution. For system design and development, the Agile XP methodology was employed, utilizing hardware materials such as RFID Reader, water pump, LCD, Relay module, battery, database for data storage and ESP32 with Arduino IDE software for programming while IoT technology allowed for remote monitoring and automation. The system was tested and validated by use of testbed to ensure functionality, reliability, and security, aligning with required standards before implementation.

1.10 Organization of the study

This study is organized into five chapters. The first chapter presents the general introduction, which describes the background, problem statement, objectives of the project, research questions, and significance of the study, research hypothesis, and methodology. The second chapter covers the literature review. It describes definitions of key terms used in this study and related works of other researchers. The third chapter describes the research materials and methods. It includes the software development methodology used, the techniques for gathering and analyzing data, the functional requirements of the project and non-function requirements hardware and software requirements. The fourth chapter presents results obtained and discussions on the implementation of prototype. It includes the physical architecture, use case diagram, interface and flowchart of the system. The fifth chapter presents a conclusion and recommendations in different fields

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discussed the definition of the key terms used in this study and related works in the field. It examined previous research and technology in IoT applications, particularly for academic institution's tea serving.

2.2 Key Terms Definitions

This section is designed to ensure a common understanding of key concepts used in the study.

2.2.1 Internet of Things (IoT)

The Internet of Things (IoT) refers to the connection of interrelated devices such as sensors, actuators, microcontrollers, and the cloud for communicating and exchanging data via the Internet. IoT connects different devices (things) and other technologies over a communication network to make real-time monitoring systems. (Berte, 2018)

Figure 1: IoT System (Berte, 2018)

The Internet of Things (IoT) facilitates the collection and sharing of information or data between devices, such as sensors, actuators, and microcontrollers, as well as software and cloud servers, via an internet connection without human intervention. Its primary goal is to create self-reporting devices that can communicate with each other in real-time, enhancing automation and efficiency across various systems (Yigitcanlar et al., 2021).

2.2.1.1 Characteristics of IoT

The Internet of Things (IoT) is based on a series of fundamental building blocks that allow connectivity, data collection, processing, monitoring and automation. One of the key aspects is monitoring, which allows IoT systems to continuously monitor environmental conditions, equipment condition, and user behavior with sensors. Automation follows by having devices perform actions on their own with minimal human intervention, such as smart thermostats controlling heat or manufacturing equipment that optimizes production. Data analysis, however, plays a vital role in IoT through the execution of huge amounts of real-time data and deriving valuable meaning to drive efficiency, determine patterns, and make precise decisions. Connectivity ensures unplugged connectivity between devices utilizing protocols like Wi-Fi, Bluetooth, 5G, and LPWAN to enable real-time data transfer. Security is paramount in the protection of IoT systems from cyber threats, upholding data integrity, and deterring it from unauthorized users. Lastly, integration with cloud computing and AI enhances IoT to enable intelligent automation, predictive maintenance, and mass data storage and access (Bailey et al., 2013).

2.2.1.2. Applications of IoT

IoT has revolutionized a number of sectors in the economy through the provision of smart, data-driven solutions. In intelligent homes, IoT enables smart devices like voice assistants, smart locks, and security cameras to increase convenience and security. Industrial IoT enhances production and supply chain management through predictive maintenance, autonomous production lines, and real-time inventory tracking. In medicine, IoT is used in patient remote monitoring, wearable health sensors, and smart medical devices that transmit vital data to doctors. In agriculture, IoT is utilized in smart irrigation systems, sensors for monitoring the soil, and automated livestock tracking, making it more efficient and reducing wastage of resources. Smart cities utilize IoT in traffic management, waste collection, public safety, and energy-efficient street lighting. In transportation and logistics, IoT simplifies fleet management through GPS tracking, real-time monitoring of shipments, and automated toll collection. Applications of IoT continue to expand, transforming industries and enhancing daily life through data-driven insights and automation (Saha et al., 2022).

2.2.1.3 Monitoring

Monitoring in the real world involves paying close attention and continuously observing changes in a specific environment, object, or individual. This process often requires the use of recording devices to accurately capture and log every change, ensuring that detailed information is available for review and analysis. In the context of IoT technology, monitoring is the systematic and continuous collection and analysis of data from various connected devices within a network. This data-driven approach ensures that users are well-informed about the status and performance of IoT systems, enabling timely information and decision-making. IoT monitoring can be applied in financial monitoring to track economic aspects, process monitoring to oversee operational workflows, and impact monitoring to evaluate the effects and outcomes of IoT interventions on overall system efficiency (Saha *et al*., 2022).

2.2.2 Robotic Systems

Robotics is a branch of computer engineering that involves the conception, design, manufacture and operations of robots. The objective of the robotics field is to create intelligent or a computed machines that can assist humans in a variety of ways (Robotics, 2007). And robotic systems can be defined as systems that provide intelligent services and information by interacting with their environment, including human beings, via the use of various sensors, actuators and human interfaces (Hughes & Drury, 2019). The robotic systems can be categorized into several types based on their functionality and application. Industrial robots are widely used in manufacturing for tasks such as assembly, welding, and packaging, improving precision and efficiency. Service robots assist in non-industrial environments, including healthcare, hospitality, and domestic tasks, such as robotic waiters and automated cleaning systems.

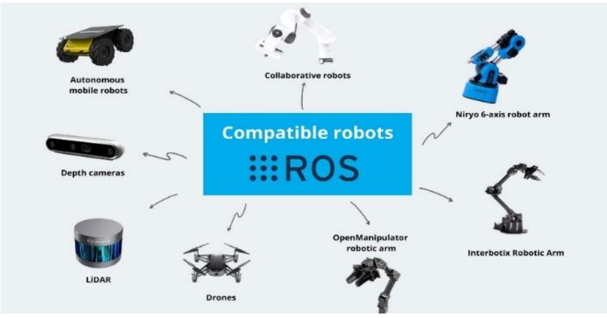

Figure 2: Robotic systems (Hughes & Drury, 2019).

Autonomous mobile robots (AMRs) navigate dynamic environments using sensors and AI, commonly seen in warehouses and delivery services. Humanoid robots mimic human actions and interactions, often used in research and customer service (Bennewitz et al., 2005).

2.2.2.2 Types of robots

i) Autonomous mobile robots (AMRs)

An autonomous mobile robot is a type of robot that can understand and move through its environment independently. Examples are: Humanoid robots, Entertainment pets, Drones, Underwater robots. Autonomous Mobile Robots (AMRs) are advanced robotic machines capable of moving and performing tasks independently without any direct human intervention. Unlike Automated Guided Vehicles (AGVs), which move with predetermined tracks or routes, AMRs use sensors, cameras, and artificial intelligence-driven algorithms to dynamically navigate in their environment.

Figure 3: AMRs (Fraune *et al.*, 2015*).*

AMRs have applications across multiple industries such as logistics, healthcare, and food service, where they transport material, deliver food, and aid other automation tasks. For the scenario of an IoT-based robotic system for the service of tea in schools, AMRs can be implemented to dispense tea to students automatically, reducing the level of human intervention and improving service efficiency (Fraune et al., 2015).

ii) Automated guided vehicles (AGVs)

An automated guided vehicle (AGV) is a mobile robot that differ from an autonomous mobile robot (AMR). AGV robot follows along marked long lines or wires on the floor, or uses radio waves, vision cameras, magnets, or lasers for navigation Automated Guided Vehicles (AGVs) are robotic devices that move and transport material independently in various industries. The robots employ sensors, cameras, and mapping technologies to drive products along pre-defined routes efficiently without human intervention.

Figure 4: AGVs (Mehami *et al*., 2018).

In the case of an IoT-based robotic system for serving tea in educational institutions, AGVs may be employed to carry tea from the preparation zone to various distribution points, providing timely and uniform service. Their integration with RFID technology and IoT sensors would provide real-time tracking, automated route optimization, and smooth interaction with users (Mehami et al., 2018).

iii) Articulated robots/ Axis Robot

An articulated robot or Axis Robot are robot with rotary joints (e.g. a legged robot). Articulated robots can range from simple two-jointed structures to systems with 10 or more interacting joints (axis) and materials. Mostly they are powered by multiple electrical motors. Axis 1 Rotates robot at the base of the robot, Axis 2 Forward-back extension of robot's lower arm.

Figure 5: Axis Robots (Humbe *et al*., 2014).

Axis 3 Raises lowers robot's upper arm etc. Most industrial robots utilize Six-axes, which give them the ability to perform a wide variety of industrial tasks compared to robots with fewer axes (Humbe et al., 2014).

iv) Cobots / collaborative robot

A collaborative robot, also known as a cobot, is an industrial robot that can safely operate alongside humans in a shared workspace. A cobot, or collaborative robot, is a robot intended for direct human-robot interaction within a shared space, or where humans and robots are in close.

Figure 6: Collaborative robot (Knudsen, 2020).

Cobots or collaborative robots are specifically engineered robots meant to work alongside humans in shared environments. Unlike typical industrial robots, which operate in isolation, cobots have advanced sensors, artificial intelligence-based control systems, and safety mechanisms to enable effective and secure human-robot collaboration. For an IoT-based robotic system for serving tea in schools, cobots can be used to assist with dispensing and serving tea and taking commands from users. The robots can make the process more efficient by reducing waiting times, offering individualized service based on RFID card information, and ensuring hygiene through automated processes (Knudsen, 2020).

v) Cartesian Robot

Cartesian Robot is one of the most commonly used robot types for industrial applications and are often used for CNC machines and 3D printing.

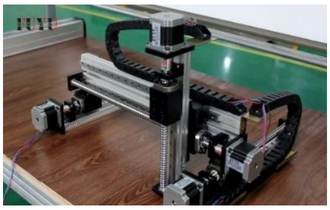

Figure 7: Cartesian Robot (Knudsen, 2020).

The primary advantage of Cartesians is that they are capable of moving in multiple linear directions. In addition, Cartesians are able to do straight-line insertions into furnaces and are easy to program (Sánchez-sánchez & Reyes-cortés, 2014).

Vi) Delta Robots

Delta Robot is a type of parallel robot that consists of three arms connected to universal joints at the base. The key design feature is the use of parallelograms in the arms, which maintains the orientation of the end effector. Delta robots are known for their high speed and high accelerations. Their design is what makes them speedier than other types of industrial robots most industrial robots have motors located in the robot arm making them conducive for heavier payload applications.

Figure 8: Delta robot (Berners-lee, 2020).

Delta Robot consists of a fixed base, a travelling plate and three kinematic chains that connect the fixed base to the travelling plate, which is the robot's end-effector. Delta robots are mainly used in applications where the robot is picking products in groups and placing them in a container or in an assembly pattern (Liu, 2004).

2.2.3 Espressif Modules (ESP)

Espressif Modules (ESP) are a series of small and versatile microcontroller modules created by Espressif Systems. They are very popular in the world of embedded systems because they can built-in wireless connectivity, are affordable, and easy to use. The most known ESP are the ESP8266 and ESP32, which help developers to connect devices in easy way. Whether it's for IoT solutions, wearable technology, or smart home automation, ESP modules help developers create new connected devices and benefit from a lively and supportive community. With their performance, ease of use, and widespread use, ESP modules are continuously reshaping the world of embedded systems and driving progress in connected technology (Chilcott & Kjærgaard, 2021).

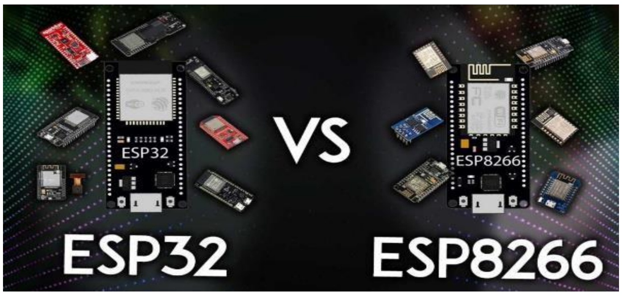

Figure 9: Espressif Modules (EM) *(*Of *et al.*, 2010*).*

The ESP32 and ESP8266 are both cheap Wi-Fi modules suitable for projects in IoT and home automation. The ESP32 features a dual-core processor, faster Wi-Fi, more GPIOs, and Bluetooth support, making it more powerful and versatile than the ESP8266, it supports analog measurements on multiple channels, while the ESP8266 has fewer GPIOs and lacks Bluetooth capability. Although the ESP32 is more expensive, its enhanced features and functionalities make it a preferred choice for many IoT projects, while the ESP8266 remains a cost-effective option for simpler applications with fewer requirements (Of *et al*., 2010).

2.2.4. RFID reader.

RFID technology relies on radio waves to send and receive information between a tag and a reader. At its simplest level, an RFID reader sends a signal out to an RFID card and the card sends back an information-carrying signal (Hutchison & Mitchell, 2007).

Figure 10*:* RFID Reader (Baumbauer *et al.*, 2020).

2.2.4.1 Types of RFID Readers

Fixed RFID readers are stationary devices designed for uninterrupted RFID tag reading in warehouses, stores, production lines, and logistics centers. Fixed RFID readers scan tags as they pass over a defined scan zone automatically, in contrast with handheld readers that must be hand-operated. Fixed RFID readers optimize efficiency through automation of inventory tracking, reduced errors, and enhanced real-time visibility.

Fixed RFID readers may be classified depending on antenna topology, connectivity method, and purpose (Hutchison & Mitchell, 2007).

I . Based on Antenna Configuration

(a) **Single-Port Fixed RFID Readers**

Single-port fixed RFID readers have one antenna port, i.e., they can accommodate one RFID antenna at a time. They are suitable for applications with limited coverage and are utilized in controlled access points where a limited area needs to be scanned. They are applicable for doorway checkpoints, library book tracking, and access control systems.

Figure 11: Single-Port Fixed RFID Readers *(*Marrocco *et al.,* 2008*).*

Since they are simpler and cheaper than multi-port readers, they are used extensively in cases where there is just one specific entry or exit point that needs to be tracked. They are not ideal for big warehouse operations where multiple RFID antennas are needed to cover a bigger area (Marrocco *et al*., 2008).

(b) Multi-Port Fixed RFID Readers

Fixed multi-port RFID readers contain over a single antenna port (i.e., 2, 4, or 8) and are capable of communicating with multiple RFID antennas at a time. They are thus ideal for application where wide-area scanning and the offer of multiple-item tracking from various angles is necessitated. Fixed readers are utilized in warehouse inventory management, factories, and logistics operations where it is important to monitor large numbers of RFID-tagged assets. Having increased read accuracy and larger coverage, multi-port readers give fewer missed tags, consequently reducing errors within inventory control. They are mainly installed in distribution centers, conveyor lines, and manufacturing environments in order to render smooth automated reads.

Figure 12: RFID reader (Miles *et al*., 2008).

Fixed readers identify objects as they move through specific checkpoints. The Fixed RFID Reader operates based on the principles of radio frequency identification (RFID) technology. It emits radio waves through its built-in antenna to communicate with RFID tags within its range. These radio waves activate the RFID tags, which then respond by transmitting their stored information back to the reader. One key feature that sets the Fixed Android RFID Reader apart is its compatibility with external antennas. This allows users to customize the reader's antenna configuration based on their specific needs and application requirements (Miles et al., 2008).

***Ii* . Ranked based on Connectivity & Data Processing**

(a) **Network-Connected Fixed RFID Readers**

Networked RFID readers are designed to connect to local or cloud systems via various communication technologies such as Ethernet, Wi-Fi, 5G, or Bluetooth. These readers play a significant role in real-time data transfer, and they are a key component of smart warehouses, logistics, and supply chain automation. With connectivity to cloud platforms, these RFID readers enable remote monitoring and centralized data management, and businesses can track inventory across locations.

Figure 13: Network-Connected Fixed RFID Readers *(*Delgado & Pavon-Marino, 2013*)*.

For example, in huge e-commerce fulfillment centers (Amazon and Walmart), networked RFID readers update data automatically to stock management systems, offering real-time inventory levels and reducing human mistake. The readers are also future-proof since they can be integrated with AI analytics for better decision-making (Victoria Bueno-Delgado & Pavon-Marino, 2013).

(b) Standalone (Edge Computing) RFID Readers

Edge computing RFID readers, or independent RFID readers, contain processing capability built in that allows the reader to read RFID data locally without the assistance of an outside server or cloud connection. The readers are employed when low latency is required and network connectivity is poor or costly. In industries like total industrial automation and auto manufacturing, the readers can directly read, process, and respond to RFID information in real-time, reducing dependency on cloud computing.

Figure 14: Standalone (Edge Computing) RFID Readers (Nd, 2020).

Standalone readers are beneficial for security and access control purposes, where processing RFID information at the local end is required in order to take rapid decisions (e.g., toll plazas and access-controlled areas). They help promote operational efficiency through reduced data communication time and increasing data security with local encryption of sensitive information (Nd, 2020).

2.2.5 Keypad

A keypad is an input device used to enter numerical and text data. In this project, the keypad allows customers or restaurant staff to manually input orders or interact with the robot when necessary. Also keypad is a basic input device that consists of a set of buttons or keys which facilitate the input of data, commands, or control of electronic systems.

Figure 15: Keypad *(*Choi *et al*., 2021*).*

Keypads have widespread use in security systems, ATMs, mobile phones, industrial automation, and robotic systems. They offer an efficient means by which users can interact with machines, enabling the input of particular data like passwords, numerical data, and operation commands. In an IoT-based robotic system for the dispensing of tea in schools, a keypad is employed as a user interface for authentication, drink selection, and system configuration for ease of use and security. The inclusion of a keypad in robotic tea dispensers increases accessibility and maximizes user experience, especially in high-traffic environments like university cafeterias, where speed and accuracy of input are critical (Choi *et al.*, 2021).

2.2.5 .1 Types of Keypads

I .**Touch Keypad**

A capacitive touch keypad operates on electrical signals rather than physical buttons. These keypads detect input through the capacitance of human touch, just like a smartphone screen. They are modern, sleek, and very durable because they do not have any moving parts and so are resistant to wear and tear. Capacitive keypads are widely used in home automation, medical equipment, and modern appliances as they are low maintenance and aesthetically pleasing.

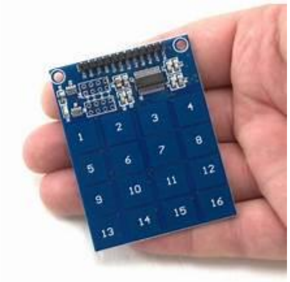

Figure 16: Touch keypad (Colle & Hiszem, 2007).

In an IoT-enabled robot tea dispenser, a capacitive touch keypad would help significantly to boost user interaction in terms of a natural and smooth interface so that students could conveniently select their choice of tea options. In addition, because the use of such keypads does not require physical pressure, they reduce component stress and ensure longevity and can thus be made to support use around the clock in schools (Chilcott & Kjærgaard, 2021).

II. **Numeric Keypad**

A numeric keypad consists of only numbers (0-9) and a few function keys such as Enter, Clear, or Cancel. Such keypads are utilized in calculators, ATMs, security panels, and point-of-sale terminals. They are highly efficient and easy to operate and therefore are appropriate for applications requiring quick numerical input.

Figure 17: Numeric keypad (Colle & Hiszem, 2007).

In a robot tea-dispensing system based on IoT, a numeric keypad can be used for user authentication, whereby students or employees can enter a customized PIN code to collect their tea orders. This offers limited access to the machine and prevents unauthorized use, promoting efficiency in self-service tea machines at school. Numeric keypads also reduce decision time, which makes them the suitable choice for high-velocity environments (Colle & Hiszem, 2007).

III. **Alphanumeric Keypad**

An alphanumeric keypad has numbers and letters, similar to a mobile phone keypad or computer keyboard. These keypads enable users to input not only numerical values but also text-based instructions or labels, making them ideal for applications where accurate data entry is required, such as security authentication systems, industrial machines, and smart vending machines.

Figure 18: Alphanumeric keypad (Williams, *n.d.*, 2021).

In an IoT-based robotic tea dispenser, an alphanumeric keypad can enable students to input customized orders, include their names, or modify the drink preferences. It provides a higher degree of personalization, thus students get tea based on their preference, such as extra sugar, lemon, or other milk. Besides, alphanumeric keypads can be connected with RFID card readers or user databases to capture the user's own preference for future orders, hence enhancing convenience and customer satisfaction (Williams, *n.d.*, 2021).

IV. Wireless Keypad

A wireless keypad communicates with electronic systems via Bluetooth, Wi-Fi, or radio frequency (RF) signals, eliminating the need for actual wiring. Wireless keypads are widely used in industrial control panels, security panels, and home automation applications so that users can operate machines remotely.

Figure 19: Wireless keypad (Burnstein, 2001).

In an IoT-based robotic tea dispenser system, a wireless keypad can be employed to allow students to order tea at a distance with the help of their mobile phone or other devices, reducing waiting time and providing hassle-free operation. This feature is especially useful in busy educational institutions where students often have hectic timetables and would welcome a quick, automated ordering mechanism. Additionally, wireless keypads ensure hygiene by reducing bodily contact, hence being an ideal solution for modern food service automation (Burnstein, 2001).

2.2.6. Water Pump

A water pump is a mechanical or electromechanical device for transferring water from one location to another based on pressure generated through motors or mechanical forces. In embedded systems, especially in IoT and automation projects, small DC water pumps are commonly used for dispensing liquids under regulated conditions — such as in tea dispensers, irrigation systems, or automatic plant watering systems. They are powered with DC voltage (usually 3V–12V) and may be controlled by microcontrollers (like Arduino or ESP32) with the help of a relay module, MOSFET, or motor driver.

Figure 20 : High Water Pump *(*Chen *et al.*, 2014*).*

In this research, the water pump is a vital component since it serves as the primary dispensing device for pumping the tea from the storage tank to the cup of the user. Once an original RFID card is scanned and the system verifies that the user has enough balance in the database, the microcontroller (ESP32) sends a signal to activate the DC water pump. The pump presses tea through a pipe into the user's cup (Chen et al., 2014).

2.2.7. Relay Module

The relay module serves as a significant interface between low-voltage ESP32 microcontroller and high-power devices like the water pump or solenoid valve used to release tea. It allows the system of IoT-Based Robotic System for Serving tea in Educational Institutions to serves as a significant interface between low-voltage ESP32 microcontroller and high-power water pump to release tea.

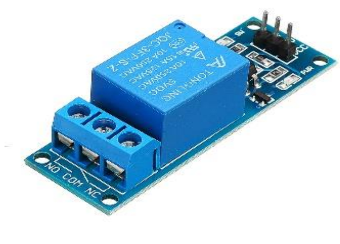

Figure 21 : Relay Module (Ji *et al.*, 2023).

It allows the system to control these device safely by acting as an electronic switch, toggling pump on or off based on authorized RFID card scans, user input through the keypad, and real-time sensor inputs such as tea level from the sensors or inventory level. The relay ensures that tea is released only after all the requirements are met, correct balance, user authorization, and sufficient tea, while protecting the microcontroller from electrical damage by isolating it from high currents. This renders the relay module essential to automation and secure handling of the tea-dispensing capability in our IoT solution (Ji et al., 2023).

2.2.8. Liquid crystal display (LCD)

A liquid crystal display, commonly known as an LCD, derives its name from the unique combination of solid and liquid states of matter it utilizes. By harnessing the properties of liquid crystals, LCDs generate visible images on super-thin display screens. These advanced technology screens are prevalent in various devices such as laptop computers, televisions, smartphones, and portable gaming consoles. The innovative design of LCD technology enables displays to achieve remarkable thinness compared to traditional cathode ray tube (CRT) displays (Tamang, 2020).

Figure 22: Liquid Crystal Display (Del Campo *et al*., 2021).

The key advantage of LCDs is their ability to precisely manage pixel brightness by varying the voltage applied to the liquid crystal cells. This enables them to achieve precise control over color and intensity. LCDs come in a variety of configurations, including character displays like the 2x16 LCD, which are well-suited for compact text-based information with parallel interfaces, making them popular choices for various projects. Beyond character displays, LCDs also include larger and more advanced types, such as 16x2, 20x4, 8x2, and 40x4 configurations, each with its own unique applications and size requirements (Del Campo et al., 2021).

2.2.8. 1. Types of Liquid Crystal Display (LCD)

A Liquid Crystal Display (LCD) is a flat-panel display technology that utilizes liquid crystals for image display. LCDs find applications in TVs, computer monitors, smartphones, industrial control panels, and embedded systems due to their low power consumption, high-resolution output, and small form factor. In IoT-based robotic tea serving systems in academic institutions, LCDs can be utilized as the user interface to display menus such as tea type, payment status, and order status. The choice of LCD depends on factors such as resolution, power consumption, response time, and application (M. S. Kim et al., 2016).

i) In-Plane Switching (IPS) LCD

IPS LCDs were developed to overcome the limitations of TN technology. In IPS displays, liquid crystals move in the same plane, which improves viewing angles and color accuracy. This makes IPS displays suitable for smartphones, tablets, high-end monitors, and medical devices where accurate color representation is necessary.

Figure 23: IPS LCDs (Takeda *et al*., 1998).

While IPS LCDs do offer superior image quality and stable colors, they are power-hungrier and slightly slower in response time compared to TN displays. In an IoT-based robotic tea-serving system, an IPS LCD can enhance the user interface experience by presenting clear, crisp, and readable text or graphics, making it easy for students and staff to use the system and place orders according to their preference (Takeda et al., 1998).

ii) Vertical Alignment (VA) LCD

Vertical Alignment (VA) LCDs provide a balance between TN and IPS technology. In VA panels, liquid crystal molecules are aligned vertically when no voltage is applied, resulting in deeper blacks, higher contrast ratios, and better viewing angles compared to TN panels. VA LCDs are therefore suitable for use in applications such as TVs, industrial control, and professional monitors.

Figure 24: VA LCDs (Chen *et al*., 2014).

Yet, VA panels have a slower response time compared to TN panels and are thus less suitable for fast-moving content. In a robotic tea dispenser enabled by IoT, VA LCDs can be used to display colorful, high-contrast order information, making the system easier to use in a variety of lighting conditions, for example, poorly lit cafeteria settings (Chen et al., 2014).

2.2.9 Arduino Integrated Development Environment (IDE)

The Arduino Integrated Development Environment (IDE) is a powerful and user-friendly software platform that has revolutionized the world of electronics and embedded systems. The Arduino IDE is open-source software that enables users to write, compile, and upload code to a wide range of Arduino modules, including the popular Arduino Uno, Arduino Mega, Arduino Leonardo, and Arduino Micro. One of the key advantages of the Arduino IDE is its accessibility – even individuals with no prior technical knowledge can easily get started with the learning process. The Arduino IDE supports a variety of operating systems, including Windows, macOS, and Linux, ensuring a diverse user base and widespread compatibility. Additionally, The IDE environment mainly contains two basic parts: Editor and Compiler, where the former is used for writing the required code and later is used for compiling and uploading the code into the given Arduino Module, which allows the code to be executed and the desired functionality to be achieved (Fezari & Al Zaytoona, 2018).

2.2.10 Battery

Batteries were utilized by drones to power their electronics and motors. Because these batteries are rechargeable, it could be used them repeatedly, where Li-ion and Li-polymer (Lipo) batteries are the two most popular battery types found in drones. The lightweight and large capacity of these batteries is crucial for ensuring that the drone can fly and take off from the ground a respectable duration (Li, Matthew, *et al.*, (2018):).

Figure 25: Lithium Ion battery (Zaatari, 2019)

In this case, considering the balance between performance, safety, and cost-effectiveness, would recommended Lithium Polymer (Lipo) batteries. It offered a high power-to-weight ratio, making them suitable for drone applications where weight is a critical factor.

Figure 26: Lithium polymer battery (Zaatari, 2019)

Additionally, Lithium Polymer batteries provide high energy density and can deliver the required power output for pesticide-spraying drones efficiently. However, it's essential to handle and charge them with care to avoid safety hazards. (Long, Lizhen, *et al.* , (2016):).

2.3 Related works

A number of research studies have examined the convergence of IoT and robotics to automate tea service for improved efficiency and decreased human interaction. Robotics in the food and beverage sector has improved dramatically with robotic waiters and automated dispensing units gaining acceptance in restaurants and cafeterias. For instance, a study by Kim et al. (2021) points out the way robotic systems with AI and IoT sensors can effectively handle tea service operations, minimizing waiting times and enhancing customer satisfaction. Likewise, Zhang et al. (2020) illustrated the use of robotic food dispensers in self-service restaurants, establishing their reliability and precision in food portioning (Zaatari, 2019).

IoT integration in robot food service systems has played an important role in real-time stock level monitoring, remote control, and data collection. According to research by Patel and Shah (2019), IoT-enabled vending machines and automatic food dispensers optimize operational effectiveness through remote tracking of transactions and stock levels. This is a concept related to the proposed system, in which IoT technology is utilized to track transactions, manage ingredient usage, and dispense tea automatically within schools. Additionally, Li et al. (2022) point out in their study the benefit of IoT connectivity for automating foodservice, showing how cloud-based systems enhance decision-making and predictive maintenance for dispensers. However, this study lacked a focus on cost-effective solutions for academic institutions, which our project aims to address (Saha et al., 2022).

Various robotic geometries have been explored for dispensing food and drink, highlighting their autonomous function. Kumar et al. (2018) provides an examination of the deployment of robotic arms for serving drinks, where robotic actuators are precision-controlled for making and serving drinks. This is consistent with the proposed system, which will deploy robotic arms or actuators to achieve precision serving of tea. In addition, Liu et al. (2020) explain the use of conveyor belt systems and robotic arms in automated kitchens, pointing out their ability to improve hygiene and reduce human involvement. Despite their success, these studies did not emphasize affordability and adaptability for smaller academic institutions, a gap our project intends to fill (Fraune et al., 2015).

Automation of payment is another critical component of robotic food service systems. Payment and ordering systems based on RFID have been widely researched due to their efficiency and convenience. Garcia et al. (2017) talk about RFID-based transactions being used in cafeterias for seamless cashless payment. The projected IoT-based robot for serving tea will apply RFID technology in facilitating students to make payments in a streamlined way, providing a contactless and smooth transaction process. Wang and Chen (2021) also affirm the same by demonstrating how RFID-based automation in foodservice industries eliminates human mistakes and enhances security. Nonetheless, these solutions primarily targeted large-scale food industries rather than small institutions with limited budgets, which our project seeks to address by creating a more cost-effective solution (Fraune *et al*., 2015).

The use of LCDs and keypads in robotic food dispensers is also another area encompassed under related research. A study by Sharma and Das (2019) indicates that user interfaces, such as touchscreen panels and keypads, are essential in ensuring maximum interaction between users and robotic vending systems. The proposed system will incorporate an LCD screen and a keypad for the purpose of selection to ensure it is user-friendly and accessible. Hernandez et al. (2021) research also confirms that an intuitive interface significantly improves customer experience and the effectiveness of operations in automated food services. However, the study did not incorporate user authentication and payment integration, which our project will implement to enhance security and usability (Chen *et al*., 2014).

The economic impacts of robot food service systems have also been examined in recent studies. It was found, as suggested by a study done by Wilson and Clark (2023), that automation in the food and drink service leads to reduced operating costs and enhanced profitability. The study also observed that IoT-enabled robot systems provide returns on investment over the long term by reducing human operator errors and optimizing resources. Similarly, Gonzalez et al. (2022) demonstrated in their research that robotic food dispensers contribute to sustainability by reducing food wastage and improving portion control. However, there remains a gap in research on cost-effective, scalable solutions specifically designed for academic environments, necessitating further study in this area (Xie, 2010).

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter focuses on different research materials and methods applied in the development and implementation of the IoT-based robotic system for serving tea in academic institutions. It discusses the scope of the case study, the techniques used for data collection, data analysis methods, system requirements, system development methodology, software requirements, and the hardware requirements for the project.

3.2 Case Study

The focus of the study within this research is on the development and implementation of the IoT-based robotic system for serving tea in academic institutions specifically for INES Ruhengeri Mary Gandhi Restaurant to address the challenges faced by traditional manual methods of tea serving and provide an efficient and innovative solution to enhance real time service and monitoring and operational efficiency.

Figure 45: People waiting to be served

3.3 System Development Methodology

3.3.1 Introduction

System development Methodologies are the processes used in a system development for guidance on how to plan, organize and develop projects effectively. In designing different systems, various types of system development methodologies are used, and by considering the actual requirements of the system, the developer can choose the best methodology appropriate to the system. To choose the methodology for a given system, the developer can consider some factors like cost, timeline, quality, and the ability to adapt to changing requirements (Blake, 2021). System development process includes the activities like understanding, collecting data, analyzing, planning, designing, implementation and maintenance of systems. System development approaches have undergone reforms as per the changes in software development technology. A following is one of system development methodology.

3.3.2 Agile Methodology

Agile is the system development methodology management that break down the system into several stage or dynamic phase each of which allow for consistent collaboration with stakeholders to promote steady improvement stage (Tutorials Point (I) Pvt. Ltd., 2015).

Extreme Programming (XP) is an agile software development framework that aims to produce higher quality software, and higher quality of life for the development team. XP is the most specific of the agile frameworks regarding appropriate engineering practices for software development.

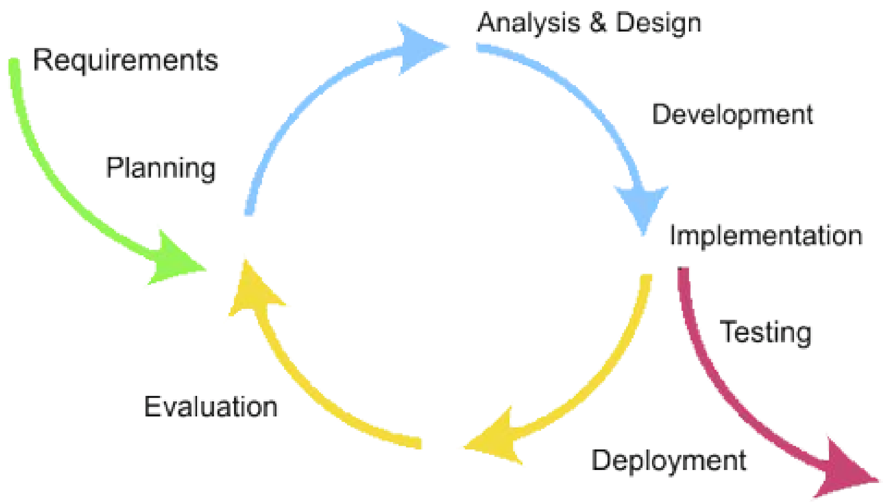

Figure 27*:* Agile model *(* (Erickson, 16.4 (2005).)

- **Requirement Gathering:** You must define the criteria at this step. You should describe the prioritized based on the needs of the users and the goal of the factory and estimate the time and effort required to complete it.

- **Planning:** teams are formed, appropriates funding is designed, and initial requirement are discussed and formulated. There are only initial requirements, which are likely to change as the process evolves.

- **Design:** development teams work to deliver software-based on requirement and feedback. Multiple teams are involved in the interaction of the development and communicate the progress of each evolves.
- **Develop/implementation:** The work begins once the team has defined the requirements. Designers and developers begin work on their projects, with the goal of releasing a functional product.
- **Test:** This phase basically involves the testing team i.e., the Quality Assurance team checks the product's performance and seeking for the bug during this phase.
- **Deployment:** The team creates a product for the user's work environment in this phase. Customer notification and migration are considered, along with end-of-life activities.

3.4. Data Collection

Data collection refers to the process of gathering and measuring relevant and Observable information or measurements from various sources in a structured manner. It is a core step in the scientific method, as it provides the foundation for analysis, interpretation, and decision-making. During data collection, the data types, the sources of data, and the methods used must be identified. The collected data allows researchers to draw conclusions and make evidence-based claims about the phenomena under investigation since it serves as the foundation for scientific analysis, interpretation, and inference in decision-making (Xie, 2010).

3.4.1 Techniques used for Data Collection Methods

Both quantitative and qualitative techniques are employed for data collection. Quantitative data is gathered through surveys and structured interviews, while qualitative data is collected through observations, documentation analysis, and semi structured interviews with stakeholders, including students, staff, and restaurant servants .

- **Sampling Techniques**

To efficiently gather data, a purposive sampling method was utilized by select participants who have direct involvement and experience with the existing manual Tea serving service at INES Ruhengeri. The sample includes students who used to wait or the queue of tea taking, faculty members which affected by the inefficient of using manual tea serving, which caused students to be late in the class, and including those who refused to take tea due to the long wait and service delay.

- **Sample size**

The sample of the current study was selected by referring to Allain Bouchard probabilistic method about determination of the sample (Sabiti, 2004). His formula is this: $n_c = \frac{n}{1+\frac{n}{N}}$

In this formula, (‘’n’’ stands for sample size for definite population,’’ **N**’’ stands for the population size, where by ‘’$\mathbf{n_c}$’’ stands for the corrected sample. Bouchard table (see appendix) highlights that when the population size is about 1000, holding the error margin of +_10% and accuracy of 95%, 100 elements represent the sample size for the universe or definite population. With this perspective, with the target population (including students, university staff and restaurant servers) of 5849 at Ines Ruhengeri. In this study **n** stands for 374 respondents were used as the sample size.

So, the corrected sample for the total sample size of the study was calculated as follows: $n_c = \frac{n}{1+\frac{n}{N}} = \frac{n \times N}{n+N} = \frac{374 \times 5849}{374+5849} = \frac{2187526}{6220} =$ 351.7~352. Therefore, the sample was 352 respondents.

Table 1: Population, sample size. Sampling techniques and research tools

Category of population		**Number**	**Sample**	**Sampling**	**Research tools**
Head Staff	Vice chancellor	1	1	Purposive	Questionnaire
	Deans	4	4	Purposive	Questionnaire
Heads of department(HoDs)		13	13	Purposive	Questionnaire
Lecturers		100	26	Random	Questionnaire
Students	Local	5573	250	Purposive	Questionnaire
	International	1,150	50	Purposive	Questionnaire

Mary Gandy restaurant	Manager	1	1	Purposive	Questionnaire
	Tea servers	7	7	Purposive	interview
Total		**5849**	**352**		

Source: Primary Data, 2025

Observations

Direct observation technique was employed to actively participate in institution services for cross-analysis of the current tea processes at INES Ruhengeri. The service of tea serving using manual challenges were documented. This showed clearly the tea service and some inefficient manual monitoring system there. By engaging in the observation of tea, a comprehension of limitations in the manual tea service monitoring system was attained. This observation constituted the foundation for recognizing methods to enhance the system and shaping the blueprint of an IoT-based robotic system for tea serving in academic institutions which utilized ESP32, RFID, ultrasonic sensor and MYSQL.

Interview

Stakeholders involved in or affected by the traditional tea serving system in academic institutions are engaged in interviews to gather valuable insights into their experiences, perspectives, challenges, and expectations regarding the manual tea serving system. By engaging with stakeholders directly, the qualitative data were gathered that complements the information obtained from technics.

Questionnaire

To systematically collect quantitative data from audience, a structured questionnaire was designed and distributed among students, and staff at INES -Ruhengeri. The questionnaire aimed to capture detailed information on the effectiveness, efficiency, and challenges of the existing manual breakfast tea serving system.

Data Analysis

The data collected from both techniques were transferred to Google Forms for analysis. This analysis involved identifying common themes, patterns, and trends by reviewing response summaries, charts, and graphs generated by Google Forms.

3.5 System requirement

3.5.1 Function Requirement

Functional requirements outline the specific functionalities and features the IoT based robotic system for tea serving in academic institutions must possess to meet its intended purpose. These are derived from stakeholder needs and expectations regarding what the system should do and how it should behave (TechTarget, May 2018). Based on the collected data, the functional requirements for this system are:

- ❖ The system must accept the cashless payment money to avoid manual payment
- ❖ The system must validate the inserted amount and display the current balance on LCD
- ❖ The system must calculate and show the available tea portion based on the payment
- ❖ If the money is insufficient, the system should reject the transaction or request additional funds
- ❖ The system should save power for long standalone operation
- ❖ The system should be compatible with remote control system, providing flexibility in deployment.
- ❖ The system should dispense tea in real time

3.5.2 Non-function requirements

Non-functional requirements define system characteristics that describe the operations and constraints of the system. They are basically the requirements that outline the system performance standards, security protocols, and usability criteria to ensure the effectiveness and reliability of the system. (altexsoft, 30 Dec, 2023). Based on the collected data, the non-functional requirements for this IoT-based robotic system for tea serving in academic institutions are:

- **Performance:** the system should dispense tea within 10 seconds upon payment confirmation and stop when requested quantity is over.
- **Reliability and Availability:** the system should run 24 hours in 7 days with no or minimal down time.
- **Usability:** The system user interface should be easy to use.
- **Security:** The system should protect transactions.
- **Scalability:** the system should enable serving various tea options.
- **Maintainability:** system maintenance should be easy, with easily replaceable tea cups and should require minimal maintenance, reducing the need for frequent repairs.
- **Portability:** If intended for portable use, the system should be lightweight and easy to be moved.
- **Remote Monitoring:** The system should support remote monitoring capabilities where it allowing operator to track its status, and performance in real-time from a distance when it is serving tea.
- **Low Noise:** The system should be able to produce less noise during its operation to avoiding disturbing people or animals.

3.6 Hardware requirements

Hardware requirements are the physical and visible components and devices needed for the system to operate efficiently (Pappalardo, 2021). Based on collected data, the hardware requirements for the efficient operation of an IoT-based robotic system for tea serving in academic institution included a microcontroller ESP32 DEVKIT DOIT V1 board, LCD display, RFID, Water pump, Relay module, Keypad, and power supply.

3.6.1 Microcontroller ESP32 DEVKIT DOIT V1 board

The Microcontroller ESP32 DEVKIT DOIT V1 board is a series of chip microcontrollers developed by Espressif; it is essential for IoT systems as it can easily connect to a Wi-Fi network to connect to the internet, is not highly expensive, and consumes very little power compared to other microcontrollers. It comes with voltage regular and USB input for power and upload code, particularly with 36 pins exposed used to connect peripherals, 18 pins for each side with variable numbers of GPIOs depending on the board model. It has a micro USB interface that is used to connect the board to the computer to upload code or apply power (Of et al., 2010).

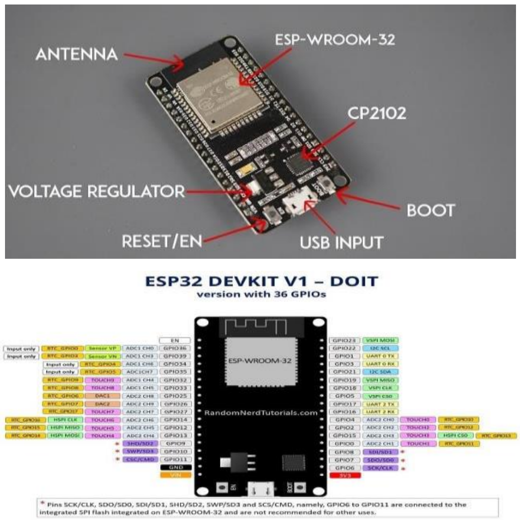

Figure 28: The ESP32 DEVKIT DOIT (Del Campo *et al*., 2021)

It also uses the CP2102 chip (USB to UART) to communicate with the computer via a COM port using a serial interface. This board comes with a RESET button, likely labeled EN, to restart the board and a boot button to put the board in flashing mode (available to receive code). It built-in blue LED that is internally connected to GPIO .This LED is useful for debugging to give some sort of visual physical output. There's also a red LED that lights up when power is provided to the board (Del Campo *et al*., 2021).

3.6.2 20x4 Liquid Crystal Display (LCD)

A 20×4 LCD display is a liquid crystal display with two rows that can display 20 characters in each row, providing a total of 40 characters of information. It works by controlling the liquid crystals to block or allow light, creating characters and symbols on the screen. The display has 16 pins for power, data communication, and control signals, and the contrast can be adjusted to improve readability. 20x4 LCD displays are versatile and can be used to display a wide range of information, including text, numbers, symbols, and basic graphics, and they often include support for custom character generation. These displays are widely used in various applications, from digital clocks to industrial automation (Del Campo *et al*., 2021)

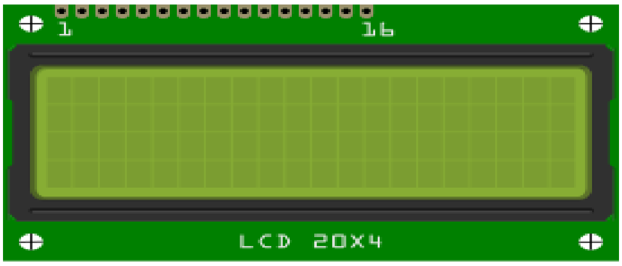

Figure 29: 20x4 Liquid Crystal Display (LCD) (Del Campo *et al*., 2021)

i. The working principle of a 20x4 LCD

The fundamental working principle of a 20x4 LCD display is based on the ability to control the orientation of liquid crystal molecules using electrical signals. The display is constructed with two polarized glass or plastic panels, with the liquid crystal material sandwiched in between. A reflective mirror is placed at the back of the assembly. When no electrical current is applied, the liquid crystal molecules are aligned in a specific orientation that allows light to pass through the panels, reflect off the mirror, and come back out, making that area of the display appear bright. However, when an electrical current is applied to a specific region of the LCD, the liquid crystal molecules in that area start to realign or untwist (Chen et al., 2014).

This change in molecular orientation causes the polarization of the light to shift, preventing it from passing back out through the front polarizing panel. As a result, that particular area of the display appears dark, creating the desired character or symbol. The LCD controller, a dedicated integrated circuit, manages the operation of the 20x4 LCD. It receives character data and control commands from an external device, such as a microcontroller. The controller then retrieves the corresponding character bitmaps from its internal character generator ROM and stores the data in its display RAM

Based on the data in the display RAM, the LCD controller applies the appropriate electrical signals to the liquid crystal panel, selectively activating the desired regions to block or allow light, effectively displaying the characters and symbols on the 20x4 grid. Additionally, the contrast of the display can be adjusted by manipulating the voltage across the liquid crystals, and a backlight, if present, can be controlled to optimize the visibility of the information in different lighting conditions. Through this combination of liquid crystal behavior, display memory management, and electrical signal control, the 20x4 LCD can provide a compact, cost-effective, and versatile means of presenting alphanumeric data in a wide range of electronic applications (Chen et al., 2014)

ii. 20X4 LCD Display Pinout

The following are the main pin on 20X4 LCD:

Table 2: Table for pin specification of 20X4 LCD

Specifications	**Details**
Contrast:	for adjusting the contrast
8 Data pins	pins used to transmit the data to be displayed on the LCD
Background display pin	Backlight control of the LCD
power supply	LCD requires a 5V power supply
K=GND	ground connection for the LCD display

iii. Connection and Power Supply of 20X4 LCD Display

The 5V pin on the ESP32 must be connected to the VCC pin of the LCD display, providing the necessary 5V power supply to the LCD. The GND pin on the ESP32 must be connected to the GND pin of the LCD display, ensuring a common ground reference. The GPIO 21 pin on the ESP32 must be connected to the SDA (Serial Data) pin of the LCD display. This pin is used for data communication between the ESP32 and the LCD.

The GPIO 22 pin on the ESP32 is connected to the SCL (Serial Clock) pin of the LCD display. This pin is used for the clock signal during data communication. These control pins (SDA and SCL) allow the ESP32 to send commands and data to the LCD display, enabling it to display the desired information. By using the specified GPIO pins and power connections, the LCD display can easily integrate into the ESP32based project and start displaying information on the LCD (Chen et al., 2014).

Table 3: I2C LCD and ESP32

I2C LCD	ESP32
GND	GND
VCC	VIN
SDA	GPIO 4 (D2)
SCL	GPIO 5 (D1)

3.6.3 Fix RC522 RFID

Fixed multi-port RFID readers contain over a single antenna port (i.e., 2, 4, or 8) and are capable of communicating with multiple RFID antennas at a time. They are thus ideal for application where wide-area scanning and the offer of multiple-item tracking from various angles is necessitated. Fixed readers are utilized in warehouse inventory management, factories, and logistics operations where it is important to monitor large numbers of RFID-tagged assets. Having increased read accuracy and larger coverage, multi-port readers give fewer missed tags, consequently reducing errors within inventory control. They are mainly installed in distribution centers, conveyor lines, and manufacturing environments in order to render smooth automated reads.

Figure 30: RFID reader (Miles *et al.*, 2008).

Fixed readers identify objects as they move through specific checkpoints. The Fixed RFID Reader operates based on the principles of radio frequency identification (RFID) technology. It emits radio waves through its built-in antenna to communicate with RFID tags within its range. These radio waves activate the RFID tags, which then respond by transmitting their stored information back to the reader. One key feature that sets the Fixed Android RFID Reader apart is its compatibility with external antennas. This allows users to customize the reader’s antenna configuration based on their specific needs and application requirements (Miles et al., 2008).

Working Principle of Fix RC522 RFID and Its Pin Connections

RFID (Radio Frequency Identification) works on the principle of using radio waves for the wireless identification and tracking of objects. The two most important parts of an RFID system are the RFID reader (or module) and the RFID tag. The reader transmits a radio frequency signal through its antenna. When an RFID tag is within range, it receives this signal and will reply with the information on the tag (usually an ID number). Passive tags (tags without their own power source) utilize the energy from the reader's signal to reply, while active tags possess their own battery for longer range and stronger signals. The reader then decodes the received data and sends it to a computer or microcontroller for identification or tracking (Miles et al., 2008).

Pin Connections of a Fix RC522 RFID.

Table 3: Table for pin specification of Fix RC522 RFID

Specifications	**Details**
VCC	**3.3V** power supply **(not 5V, which will destroy the module).**
GND	Ground pin.
RST (Reset*)*	Digital pin to Reset the module.
SDA (Serial Data/SS)	Used for SPI communication
SCK (Serial Clock)	Provides clock signal for SPI; connects to the SCK pin of the microcontroller.
MOSI (Master Out Slave In)	Pin that Sends data from microcontroller to RFID module.
ISO (Master In Slave Out)	Pin that Sends data from RFID module to microcontroller.

These pins allow the RFID module to be communicated with by microcontrollers like Arduino or ESP32 using the SPI (Serial Peripheral Interface) protocol, where the system reads tag data and performs actions based on identification (Miles et al., 2008).

3.6.4 Water Pump

A water pump is a mechanical or electromechanical device for transferring water from one location to another based on pressure generated through motors or mechanical forces. In embedded systems, especially in IoT and automation projects, small DC water pumps are commonly used for dispensing liquids under regulated conditions — such as in tea dispensers, irrigation systems, or automatic plant watering systems. They are powered with DC voltage (usually 3V–12V) and may be controlled by microcontrollers (like Arduino or ESP32) with the help of a relay module, MOSFET, or motor driver.

Figure 31 : High Water Pump (Miles *et al*., 2008).

In this research, the water pump is a vital component since it serves as the primary dispensing device for pumping the tea from the storage tank to the cup of the user. Once an original RFID card is scanned and the system verifies that the user has enough balance in the database, the microcontroller (ESP32) sends a signal to activate the DC water pump. The pump presses tea through a pipe into the user's cup (Chen *et al*., 2014).

3.6.5 Relay Module

The relay module serves as a significant interface between low-voltage ESP32 microcontroller and high-power devices like the water pump or solenoid valve used to release tea. It allows the system of IoT-Based Robotic System for serving tea in Educational Institutions to serves as a significant interface between low-voltage ESP32 microcontroller and high-power water pump to release tea.

Figure 32: Relay Module (Ji *et al*., 2023).

It allows the system to control these devices safely by acting as an electronic switch, toggling pump on or off based on authorized RFID card scans, user input through the keypad, and real-time sensor inputs such as tea level from the sensors or inventory level. The relay ensures that tea is released only after all the requirements are met, correct balance, user authorization, and sufficient tea, while protecting the microcontroller from electrical damage by isolating it from high currents. This renders the relay module essential to automation and secure handling of the tea-dispensing capability in our IoT solution (Ji *et al*., 2023).

3.7 Software requirements

This includes all software components and specifications needed to develop the system.

3.7.1 Hypertext-preprocessor) (PHP) and My structured query language (MYSQL)

PHP (Hypertext Pre-processor) and MySQL are two popular technologies mostly used in web development. PHP is a server-side scripting language, while MySQL is a used relational database management system (DBMS) (Languages & Applications, 2024).

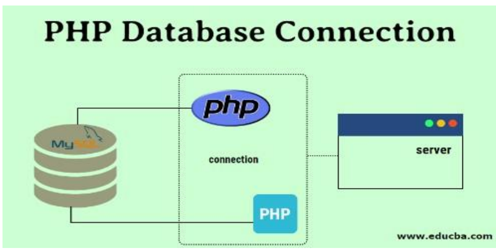

Figure 33: Dynamic web page interaction with a web server (Ji *et al.*, 2023).

i. Hypertext-preprocessor (PHP)

PHP is primarily utilized for server-side scripting, which means the PHP code is executed on the server before being sent to the client's web browser. This allows for the dynamic generation of web content and the ability to interact with databases, handle forms, process user input, and perform various server-side tasks. PHP is a powerful language for web development. It has a wide range of features and built-in functions that simplify tasks such as generating HTML, managing cookies and sessions, working with files and directories, and interacting with databases. PHP can be embedded directly within HTML code or used to create standalone scripts and command-line applications (Brackett, 1990).

ii. MySQL

MYSQL stands for My Structured Query Language. It is a popular open-source relational database management system (RDBMS) that is used for storing and managing data. MySQL's speed, reliability, and ease of use make it a popular choice for web applications, online stores, and other applications that require a database. It works by storing data in tables, which are organized into rows and columns. Each table in a MySQL database represents a specific entity, such as a user or a product, and the columns in the table represent the attributes or properties of that entity.

To access and manipulate data in a MySQL database, you can use Structured Query Language (SQL), which is a standard programming language for working with databases. You can use SQL to create tables, insert data into tables, update data in tables, delete data from tables, and retrieve data from tables (Mysql, 2013).

a. Relational Database Management System

RDBMS is a type of database management system (DBMS) that stores data in a row-based table structure that connects related data elements. An RDBMS includes functions that maintain the security, accuracy, integrity, and consistency of the data. A relational database management system is a collection of programs and capabilities that enable IT to create, update, administer, and otherwise interact with a relational database. RDBMS stores data in the form of tables, with most commercial relational database management systems using Structured Query Language (SQL) to access the database (Brackett, 2020).

3.7.2 Arduino IDE

The Arduino Integrated Development Environment - or Arduino Software (IDE) is an open-source software platform used for writing and uploading code to Arduino boards and other compatible microcontroller-based devices. It provides a user-friendly interface that simplifies the process of programming and interacting with Arduino hardware. It includes a text editor, a compiler, and an upload tool, allowing developers to write, compile, and upload code to their Arduino boards or other microcontroller boards easily (Zait Anat, 2018).

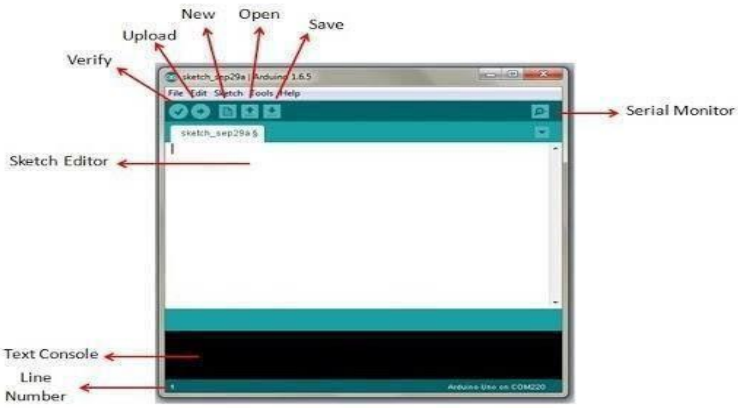

Figure 34: Arduino IDE (Ji *et al*., 2023).

The Arduino IDE supports a variety of operating systems, including Windows, macOS, and Linux, ensuring a diverse user base and widespread compatibility. Additionally, The IDE environment mainly contains two basic parts: Editor and Compiler, where the former is used for writing the required code and later is used for compiling and uploading the code into the given Arduino Module, which allows the code to be executed and the desired functionality to be achieved (Fezari & Al Zaytoona, 2018).

i. Working system of Arduino IDE

At its core, the Arduino IDE offers a user-friendly text editor for writing and editing code, commonly referred to as "sketches." The IDE then compiles the sketches, converting the high-level code into machine-readable instructions that can be uploaded directly to the target Arduino board through a serial communication protocol. The Arduino IDE also features a built-in serial monitor, allowing developers to view output, debug information, and interact with the board during the development and testing phases. Additionally, the IDE provides a library manager, enabling users to easily install, manage, and utilize a wide range of external libraries and dependencies, further enhancing the functionality and versatility of the platform (Brackett, 1990).

3.7.3 Testbed

Testbed software is a virtual or managed system that is utilized to test, measure, and validate the performance and conduct of systems such as IoT-based projects before mass deployment. For this research of robotic tea-serving system based on IoT, testbed software plays a critical role in emulating hardware component operation like RFID reader, LCD display, relay module, water pump, and keypad, along with ensuring smooth integration with cloud databases or local server. It allows developers to debug, monitor, and graphically visualize how these pieces work together in real time as conditions shift, helping to identify system weaknesses and optimize performance. Some of the most popular ones for this purpose are Proteus to simulate at the circuit level, Tinkercad Circuits for low-level Arduino and sensor simulation, Node-RED to visually see data flow, and XAMPP to simulate locally the backend environment (PHP and MySQL). It also allows performance analysis, data logging, and user interface testing on boards like Blynk or Firebase Emulator. Use of testbed software saves the cost of hardware in prototyping, minimizes the risk of component damage, enables quick development through debugging, and provides a safe environment to test user input and system output like RFID authentication, balance checking, and automated dispensing of tea. Short, testbed software is an integral part of IoT development that provides a stable means to emulatetest, and iterate on systems such as yours prior to implementation.

CHAPTER 4: DESIGN AND IMPLEMENTATION

4.1 Introduction

In this chapter, the meaning of integrating an IoT-based robot system to serv tea in learning contexts is discussed. The discussion investigates how the system can automatically serve tea, take payments, and communicate with the users via RFID and graphical user interfaces. Such observations are closely examined against the initial objectives and point out the advantages of the system like better speed of service and less manual intervention. Additionally, there are limitations and room for enhancement. This discussion provides valuable insights on how the system can be implemented to the fullest extent within campus settings, proving its capacity to streamline everyday services and optimize the automation of institutional processes.

4.2 The output results of the Analyzed data

After analyzing the data, it was evident that the traditional manual methods used to serve tea in academic institutions were not up to date. It was discovered that these methods were inefficient and prone to errors. During peak hours, around 69% of instances showed noticeable delays in tea distribution due to the manual process. Moreover, 41.4% of students faced issues like receiving incorrect tea portions or encountering problems with limited time between classes. In addition, concerns regarding hygiene and service consistency were raised in 27.6% of the cases. Another 37.9% of incidents highlighted the challenges in for long queues. Also about 17.2% of reported issues were associated with errors in record-keeping and the absence of real-time monitoring. These findings underscore the urgency of implementing an IoT-based robotic system to automate tea service in academic settings. Such a system would not only boost efficiency but also enhance hygiene standards and ensure precise, traceable, and user-friendly operations.

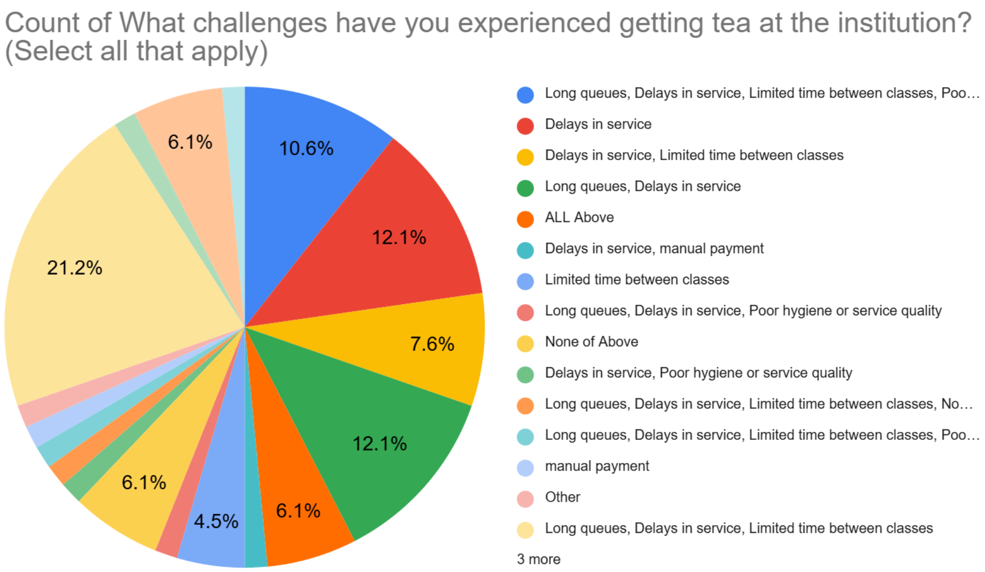

Figure 35: Pie chat

4.3 System Design Results

System design refers to the process of structuring and organizing the components, and interactions of a system to meet specific requirements and achieve desired functionalities. It involves creating a plan or blueprint for how the system will be structured and its different parts will work together where there physical architecture and logic architecture.

4.3.1 Physical Architecture

By using EasyEDA to design the physical architecture of robotic system, where each component is connected the circuit for all components as shown in the figure below;

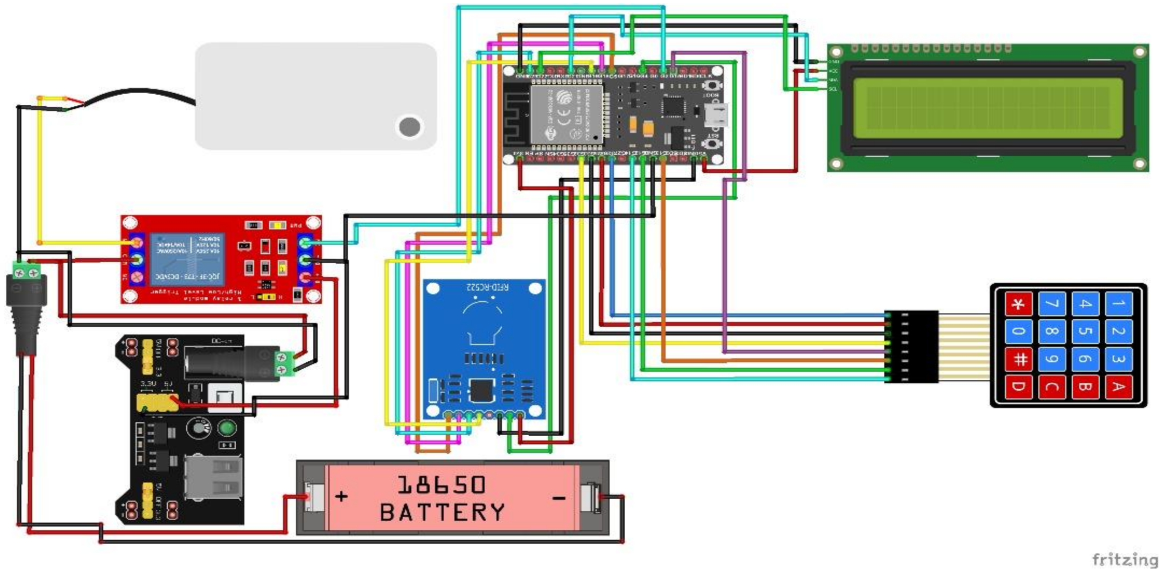

Figure 36: Physical Diagram

4.3.2 Use case diagram

Use case diagram illustrates the interaction of users with the IoT-based robotic tea-dispensing system. The primary actor is the student or staff member approaching the machine and initiating interaction by scanning his or her RFID card for identification. Once authenticated, the user is able to make use of the keypad to specify preferences such as the quantity of tea or sugar. Availability is verified by the use of sensors like load cells, and once all the conditions are verified, it triggers the robotic dispensing mechanism to dispense tea. Feedback is displayed on an LCD screen, and all user interactions are tracked in a connected database. In addition, an administrator can remotely interact with the system via an IoT interface to manage stock levels, reset system configuration, and review usage history. This encounter offers a secure, efficient, and personalized tea-serving experience

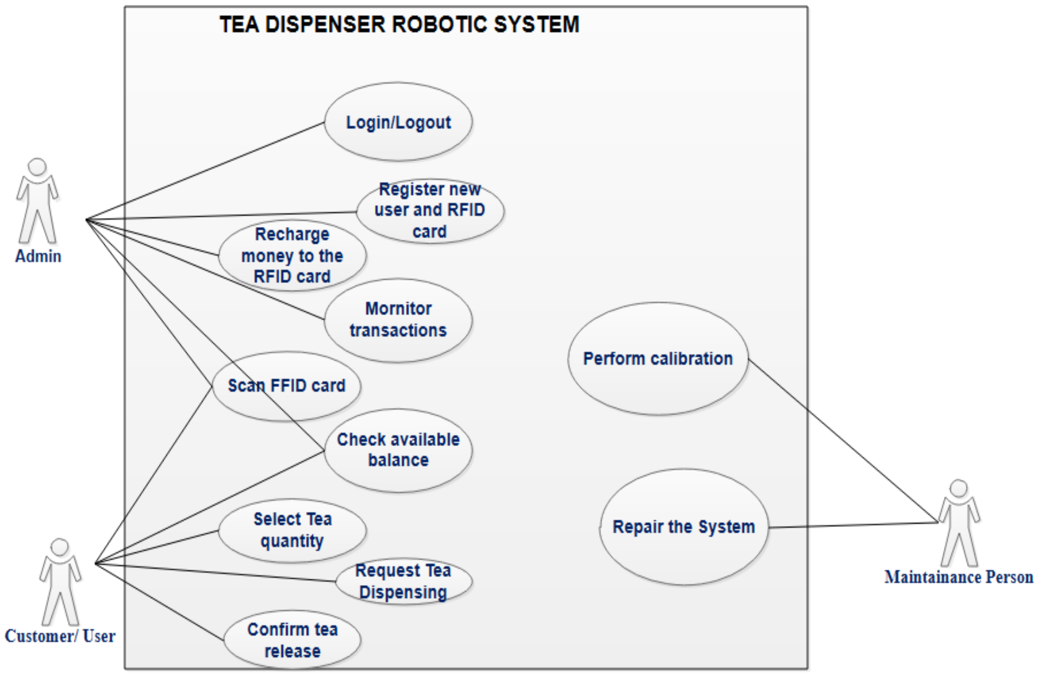

Figure 37: Use case Diagram

4.3.3 Flow chart diagram

This system is explained in a flowchart outlining how each step works step-by-step to autonomously serve the tea. The system commences when the system is activated, usually having a regulated DC power supply being connected to the ESP8266 microcontroller. The RFID reader is activated in order to confirm whether a registered RFID card had been scanned or not. If there is a valid card, the ESP8266 authenticates the user by cross-verifying stored data or querying a cloud database through Wi-Fi. Having identified the user, the system now keeps track of the tea content via a load cell sensor that detects the available weight of the tea tank. Provided the tea is adequate, the microcontroller proceeds to operate the DC pump or solenoid valve in dispensing the tea. A keypad can be incorporated to provide an interface by which the user may input the amount of tea or sugar to dispense and act accordingly. While dispensing, an LCD or OLED screen provides real-time feedback, for example, "Serving in Progress" or "Enjoy Your Tea." After the tea has been dispensed, the system adjusts the quantity of inventory and reports usage to the

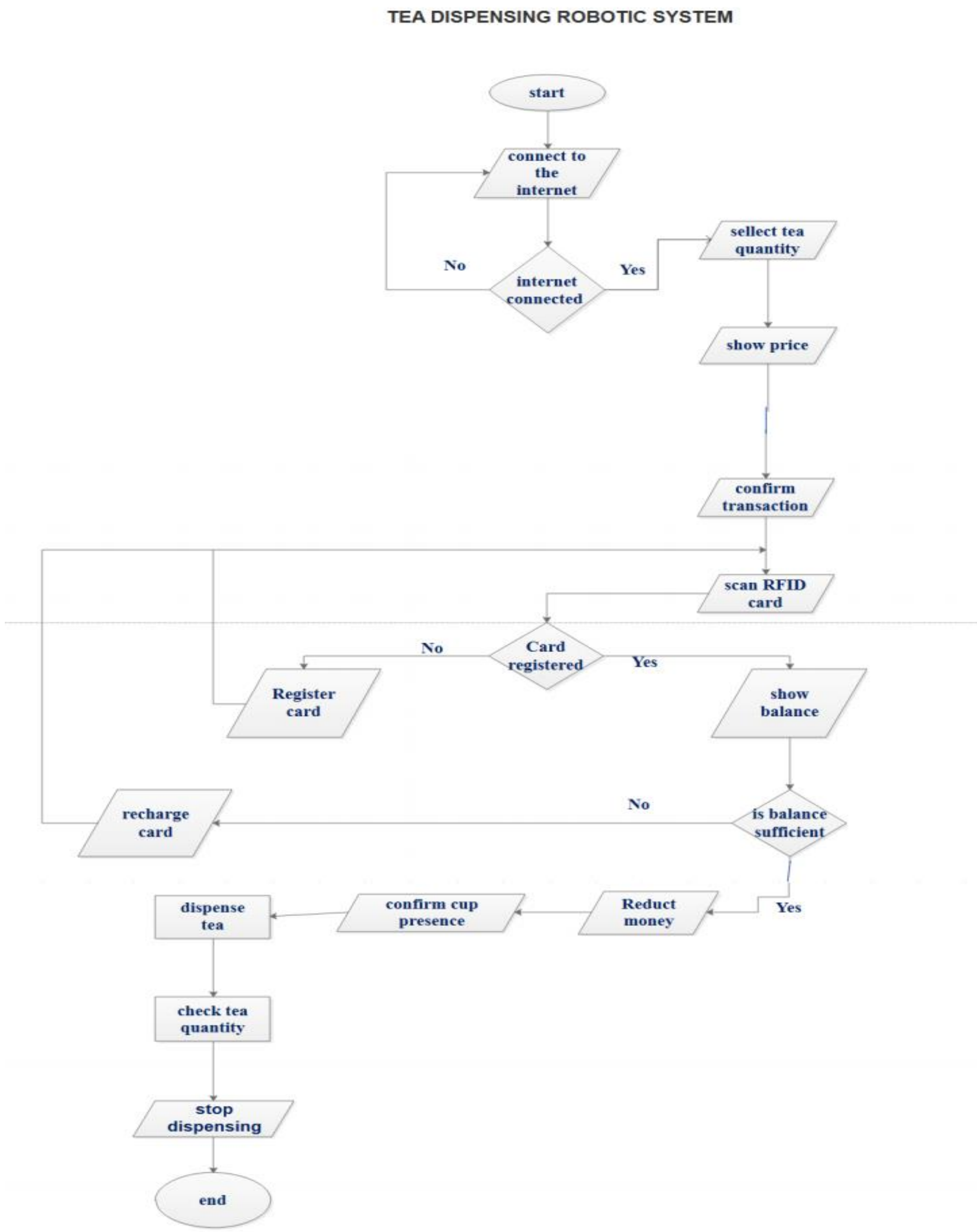

Figure 38: Flowchart Diagram

4.3.4 System architecture

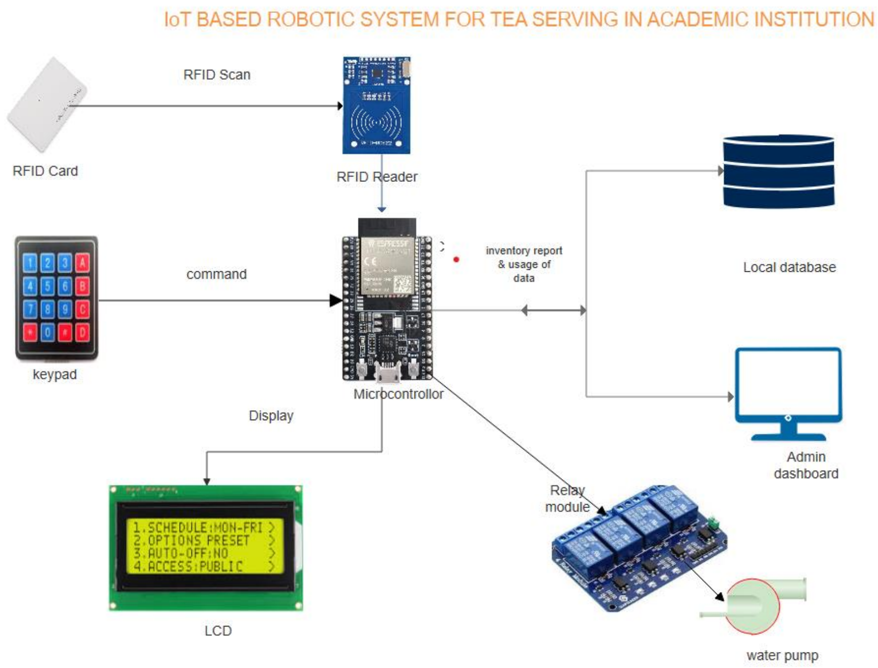

Figure 39: System architecture

4.4 User Graphical Interface

This section provides an overview of the software components developed for the prototype.

a. User graphical interface for login or register

The user graphical user interface is designed to provide a simple and easy-to-use experience for users of the tea-dispensing robot system. It includes particular login and registration pages where users can securely enter their details such as name, ID, and RFID card number. New users can register easily by filling in their details, while frequent users can log in to access the tea dispensing service. Clear signs and visual signals are made apparent on the screen by the LCD so that smooth interaction and guidance are possible during the process.

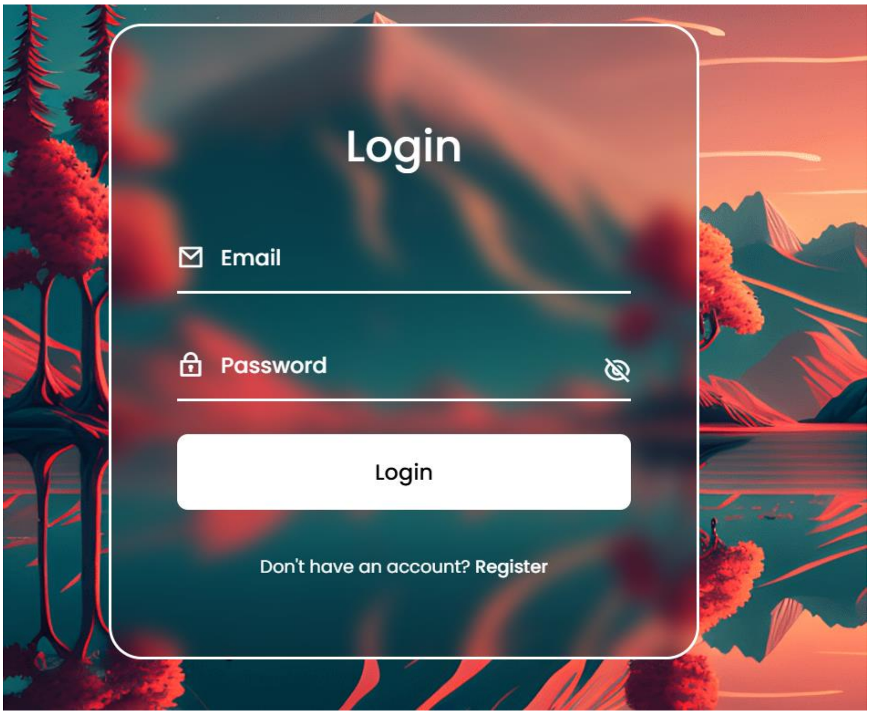

Figure 40: UGI for login/register

b. Dashboard

The recharging graphical user interface is user-friendly and simple, allowing users to replenish their RFID-based account. On selecting the recharge option, the system prompts the user to

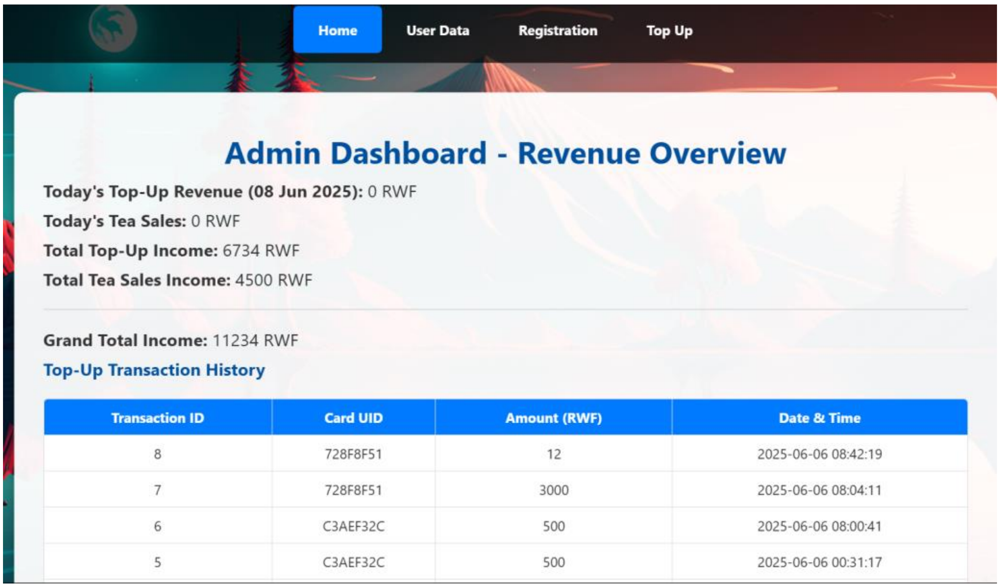

Figure 41: Dashboard

c. Database

The recharging graphical user interface is user-friendly and simple, allowing users to replenish their RFID-based account. On selecting the recharge option, the system prompts the user to

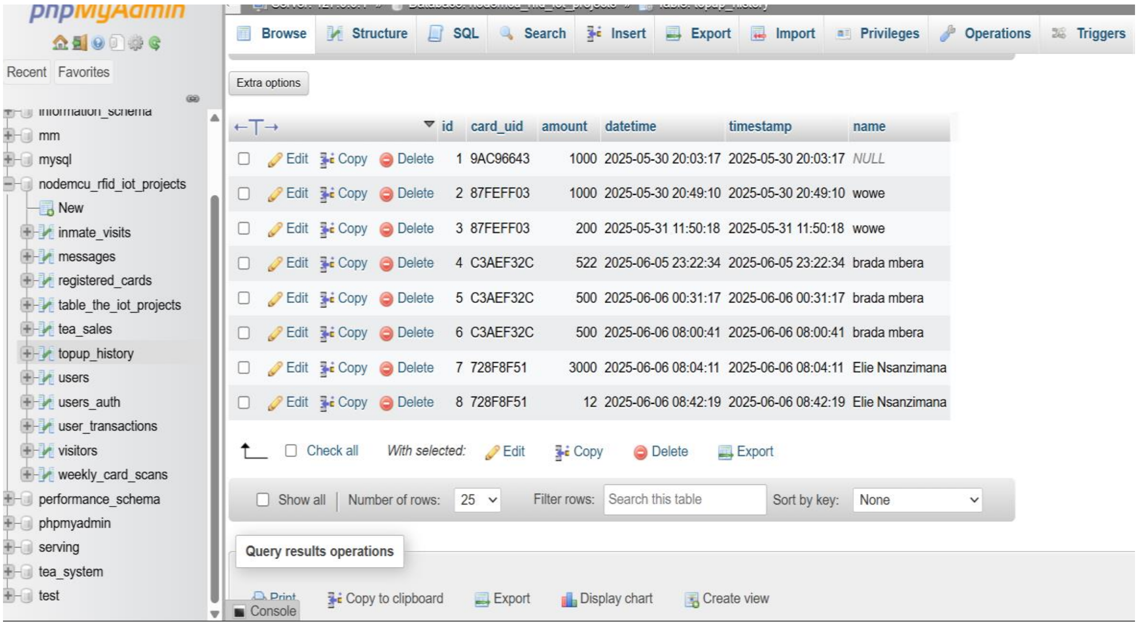

Figure 42: Database

4.5 Prototype

The developed system hardware comprises interconnected components that work together via an internet connection to ensure robust security and operational efficiency.

At the core of the IoT-based robots system for tea serving in academic institutions is the ESP32 microcontroller, which acts as the processor. It manages communication between various hardware modules and executes software commands to guide the process of serving tea. Integrated with an RFID module, the ESP32 reads user data from RFID cards to allow access to tea services. Additionally, the system also comprises an LCD display providing real-time visual feedback, such as user ID, remaining balance, amount of tea chosen, and transaction outcome.

For an extra layer of security and convenience, the system can support optional biometric or RFID-based authentication before conducting any transaction. The ESP32 communicates with an off-premise database via internet connectivity for credit balance updates, transaction history, and user data in real time. This allows for accurate and timely service delivery while enabling administrators to monitor operations remotely.

All the modules, including the ESP32 microcontroller, RFID reader, LCD, water pump, keypad, and relay module, are provided with a stable 5V power supply for smooth operation. Hardware and software integration through the ESP32 offers a smooth, automated, and user-friendly tea-serving solution for academic environments.

Figure 43: System Connectivity and Product

4.6 Discussion on the Results of the system

This section interprets the outcomes, explores their implications, and evaluates how they align with the initial objectives and hypotheses.

4.6.1 System Performance

During the testing and validation of the IoT-based robotic system for the delivery of tea in academic institutions, the system was found to successfully manage tea orders and payment through the use of RFID authentication. The system automated the ordering system, reducing delays and human intervention. The users were able to select their desired amount of tea through the interface, and payments were conveniently made through the use of RFID. The system provided smooth interactions, and the user interface presented up-to-date information on available tea, transactions, and account balances in real time. The ESP32 microcontroller, which was integrated with the payment system, processed multiple users at a time very efficiently without delay. While the system worked flawlessly when there was an internet connection, delays were experienced when the network connection was not good, demonstrating the need for a continuous and stable internet connection for the system to work at its optimum.

4.6.2 Security and Privacy Analysis

In this section, the security and privacy features that have been incorporated into the IoT-based robotic tea dispenser system are analyzed. Users must authenticate themselves using RFID cards to prevent unauthorized system access. If there is any mismatch RFID data, the system alerts users with a visual and audible warning for the security to intervene, thus preventing unauthorized tea dispensing. Personal information, including transaction records, is also securely stored in a central database and can be accessed by authorized individuals only. Strong data encryption and access controls ensure users' personal information is safe and can only be accessed by authorized administrators, upholding a high level of security and privacy throughout the system.

4.6.3 Robustness and Reliability

When subjected to real-world testing, the IoT-based robotic system functioned reliably, accurately logging transactions and tea dispensing times. The system accurately logged users' orders and provided trouble-free service processes. Nevertheless, performance degradation was noted when the system was subjected to poor or intermittent network connectivity. In such a scenario, there were delays in payment processing or quantity updates of tea, reflecting that the reliability of the system is greatly reliant on the availability of a stable internet connection. Amidst these problems, the system manifested flexibility in the sense that tea dispensing activities proceeded uninterruptedly during normal circumstances even under high-demand conditions.

4.6.4 System Flexibility

The IoT-based robotic tea dispenser system was designed with flexibility to allow administrators to update user profiles and transaction records with ease without having to go through a complete re-registration process. This capability renders the system adaptive to dynamic user information and service requirements, allowing for effortless changes when needed. The user interface is intuitive, with simple access to account

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The development and implementation of the IoT-based robot system to serve tea in academic institutions is a breakthrough towards improving campus services. By using Internet of Things (IoT) technology, the sophisticated system automates and streamlines ordering, serving, and paying for tea, reducing inefficiencies in the traditional manual method. The integration of RFID authentication for identification of users has significantly reduced waiting time, improved service speed, and minimized errors, enabling students and staff to enjoy a smooth tea experience without queuing.

Furthermore, the ability of the system to save transaction data in a centralized database ensures that all orders and payments are accurately documented, reducing the chances of errors and ensuring transparency. By eliminating manual tracing of tea orders and payments, the system improves operational efficiency and enables real-time tracking of tea distribution. The validation process confirmed the effectiveness of the system in providing a safe and efficient tea service while minimizing the application of human intervention and ensuring a secure and convenient experience. This tea serving system based on the Internet of Things is a template for similar applications in universities, paving the way for more campus services to be automated.

5.2. Recommendations

At the end of this study the Researcher want to give some recommendations to the followings:

5.2.1 Recommendation to Academic institutions and workplaces

Academic institutions and other workplaces should consider to accept and user this systems for their operations. By adopting this system, they can enhance the service of their clients' and their staff. The system is not exclusive, it is adaptable and can be effectively utilized in difference academic institutions and workplaces where tea serving is necessary.

5.2.2 Recommendation to INES Ruhengeri

I recommend that INES Ruhengeri officially accept and approve implementing this tea serving robotic system. By this means, the institution can significantly enhance the service of students’ staff and visitors. This system will replace the existing manual processes, thereby reducing human error, boosting Working hours, improving efficiency and data storage, increasing the institution's reputation as a leader in digital innovation and technological advancement among other educational institutions, and attracting prospective students to study in advanced technological and secure environments.

5.2.3 Recommendation to Students and Staff

It is recommended that students and staff at INES Ruhengeri embrace and familiarize themselves with using the IoT-based robotic tea-serving system. The users are encouraged to begin by registering their details, for example, RFID cards, through the system's user-friendly interface to enable convenient access to the tea service. Users are encouraged to secure their RFID cards and use them responsibly to purchase tea, inquire about their credit balance, and monitor transactions. To help ensure smooth operation of the system and timely tea service, the users are requested to follow carefully the instructions and report any fault in operation to us. Through this step, the students and staff members will be contributing towards making the environment more efficient, more organized, and more technologically advanced for a more satisfactory service experience in the institution.

5.3 System Limitations

In the case of the IoT-based robotic system for tea serving in academic institutions, the system also has some constraints that may affect its operation. The system's operating efficiency solely relies upon an unbreakable internet connection for real-time transaction handling, RFID verification, and credit updating. Any minor loss of connectivity could result in delayed services or unsuccessful operations at peak hours. Besides, proper use of the system will require users to be familiar with correct RFID card orientation and GUI use for tea amounts to be read and payments verified, potentially requiring training or briefing. The ambient conditions of low light or hardware sensitivity may affect sensor accuracy or card readability, causing inconvenience in service delivery

REFERENCES

Bailey, J., Oliveri, A., & Levin, E. (2013). NIH Public Access. *Bone*, *23*(1), 1–7. https://doi.org/10.1080/13645700600674179.Interventional

Baumbauer, C. L., Anderson, M. G., Ting, J., Sreekumar, A., Rabaey, J. M., Arias, A. C., & Thielens, A. (2020). Printed, flexible, compact UHF-RFID sensor tags enabled by hybrid electronics. *Scientific Reports*, *10*(1), 1–12. https://doi.org/10.1038/s41598-020-73471-9

Bennewitz, M., Burgard, W., Cielniak, G., & Thrun, S. (2005). Learning motion patterns of people for compliant robot motion. *International Journal of Robotics Research*, *24*(1), 31–48. https://doi.org/10.1177/0278364904048962

Berners-lee, T. (2020). *4 Queue*.

Berte, D. (2018). *Defining the IoT Internet of Things versus the Smart Home*. https://doi.org/10.2478/picbe-2018-0013

Brackett, J. W. (1990). *Software Requirements (numeral assignment: mandatory/desirable/inessential)*. *January*.

Burnstein, R. A. (2001). *Using Wireless Keypads in Lecture Classes*. *39*(January), 8–11.

Chen, H., Peng, F., Luo, Z., Xu, D., Wu, S.-T., Li, M.-C., Lee, S.-L., & Tsai, W.-C. (2014). High performance liquid crystal displays with a low dielectric constant material. *Optical Materials Express*, *4*(11), 2262. https://doi.org/10.1364/ome.4.002262

Chilcott, M., & Kjærgaard, N. (2021). Low-cost wireless condition monitoring system for an ultracold atom machine. *Internet of Things (Netherlands)*, *13*. https://doi.org/10.1016/j.iot.2020.100345

Choi, M., Lee, S., Jo, M., & Shin, J. S. (2021). Keystroke dynamics-based authentication using unique keypad. *Sensors*, *21*(6), 1–19. https://doi.org/10.3390/s21062242

Colle, H. A., & Hiszem, K. J. (2007). *Standing at a kiosk : Effects of key size and spacing on touch screen numeric keypad performance and user preference*. *0139*. https://doi.org/10.1080/00140130410001724228

Del Campo, F. A., Villegas, O. O. V., Sanchez, V. G. C., De Jesus Ochoa Dominguez, H., & Nandayapa, M. (2021). Radial Basis Function Neural Network for the

Evaluation of Image Color Quality Shown on Liquid Crystal Displays. *IEEE Access*, *9*, 21694–21707. https://doi.org/10.1109/ACCESS.2021.3056050

Fezari, M., & Al Zaytoona, A. A. D. (2018). Integrated Development Environment "IDE" For Arduino Integrated Development Environment "IDE" For Arduino Introduction to Arduino IDE. *ResearchGate*, *October*.

Fraune, M. R., Sherrin, S., Selma, Š., & Smith, E. R. (2015). *Rabble of Robots Effects : Number and Type of Robots Modulates Attitudes , Rabble of Robots Effects : Number and Type of Robots Modulates Attitudes , Emotions , and Stereotypes*. *March*. https://doi.org/10.1145/2696454.2696472

Hughes, A., & Drury, B. (2019). Electric Motors and Drives: Fundamentals, Types and Applications. In *Electric Motors and Drives: Fundamentals, Types and Applications*. https://doi.org/10.1016/B978-0-08-102615-1.09989-X

Humbe, A. B., Deshmukh, P. A., & Kadam, M. S. (2014). *THE REVIEW OF ARTICULATED R12 ROBOT AND ITS INDUSTRIAL APPLICATIONS ARTICULATED R12 ROBOT AT JNEC , AURANGABAD*. *2*(2), 113–118.

Hutchison, D., & Mitchell, J. C. (2007). Financial Cryptography and Data Security: 11th International Conference, FC 2007, and 1st International Workshop on Usable Security, USEC 2007, Revised Selected Papers. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 4886 LNCS*.

Ji, X., Zhao, P., Wang, H., Yang, H., & Fu, M. (2023). Multiple-Receiver Inductive Power Transfer System Based on Multiple-Coil Power Relay Module. *IEEE Transactions on Circuits and Systems I: Regular Papers*, *70*(6), 2625–2634. https://doi.org/10.1109/TCSI.2023.3257827

Kim, M. S., Bos, P. J., Dong-woo, K., Yang, D., Lee, J. H., & Lee, S. H. (2016). Flexoelectric effect in an in-plane switching (IPS) liquid crystal cell for low-power consumption display devices. *Nature Publishing Group*, *October*, 1–10. https://doi.org/10.1038/srep35254

Kim, Y. (2016). *Tea and health*. *February*.

Knudsen, M. (2020). *Collaborative Robots : Frontiers of Current Literature*. *3*(2), 13–20. https://doi.org/10.38016/jista.682479

Leeuwen, A. Van. (n.d.). *Introduction to Monitoring and Evaluation in the CT and P / CVE field*.

Liu, X. (2004). *A New Approach to the Design of a DELTA Robot with a Desired Workspace*. 209–225.

Loo, D. D. F., Wright, E. M., & Zeuthen, T. (2002). Water pumps. *Journal of Physiology*, *542*(1), 53–60. https://doi.org/10.1113/jphysiol.2002.018713

Marrocco, G., Mattioni, L., & Calabrese, C. (2008). Multiport sensor RFIDs for wireless passive sensing of objects - Basic theory and early results. *IEEE Transactions on Antennas and Propagation*, *56*(8 II), 2691–2702. https://doi.org/10.1109/TAP.2008.927541

Mehami, J., Nawi, M., Zhong, R. Y., Mehami, J., Nawi, M., Zhong, R. Y., Santana, A., Afonso, P., Zanin, A., & Wernke, R. (2018). ScienceDirect ScienceDirect ScienceDirect Smart automated guided vehicles for manufacturing in the context Smart automated guided vehicles for manufacturing in the context Industry of Industry Costing models for of capacity between used capacity. *Procedia Manufacturing*, *26*, 1077–1086. https://doi.org/10.1016/j.promfg.2018.07.144

Miles, S. B., Sarma, S., & Williams, J. R. (2008). RFID technology and applications. *RFID Technology and Applications*, *9780521880*, 1–218. https://doi.org/10.1017/CBO9780511541155

Nd, C.-. (2020). *Designing Secure Lightweight Blockchain-Enabled RFID-Based Authentication Protocol for Supply Chains in 5G Mobile Edge Computing Environment Manuscript Type: SS on Blockchain and AI enabled 5G Mobile Edge Computing Designing Secure Lightweight Blockchain-*. http://creativecommons.org/licenses/by-nc-nd/4.0/Thedefinitivepublisherversionisavailableonlineat[https://www.sciencedirect.com/science/article/abs/pii/S1226086X20304883?via%3Dihub]

Of, F., Fundamental, A., Of, O., & Information, I. (2010). *IoT BASED SMART ATTENDANCE SYSTEM FOR STUDENTS IN EXAMINATION ROOM USING A BIOMETRIC CASE STUDY : INES EXAMINATION ' S ROOM*. *August 2023*.

Reid-miller, M. (2020). *Queues 15-121*.

Robotics, S. (2007). *Reading-2-Robotics Research*. *March*, 90–103.

Saha, S., Eidmum, M. Z. A., Hemal, M. M., Khan, M. A. H., & Muiz, B. (2022). Iot Based Smart Home Automation and Monitoring System. *Khulna University Studies*, 133–143. https://doi.org/10.53808/kus.2022.icstem4ir.0245-se

Sánchez-sánchez, P., & Reyes-cortés, F. (2014). *Cartesian Control for Robot*

Manipulators. *March 2010*. https://doi.org/10.5772/9186

Takeda, A., Kataoka, S., Sasaki, T., Chida, H., Tsuda, H., Ohmuro, K., Sasabayashi, T., Koike, Y., & Okamoto, K. (1998). *by New Rubbing-Less Technology LC molecule Protrusion*. *00*(c). https://doi.org/10.1889/1.1833672

Tamang, N. (2020). Jogamaya Devi College Interdisciplinary Volume 1, Issue 1, 2020. *Jogamaya Devi College Interdisciplinary Volume 1, Issue 1 (2020)*, *1*(1). https://jogamayadevicollege.ac.in/uploads/1593961706.pdf#page=80

Tutorials Point (I) Pvt. Ltd. (2015). Sdlc - Agile Model. *SDLC - Agile Model*, 1–2.

Victoria Bueno-Delgado, M., & Pavon-Marino, P. (2013). A centralized and aligned scheduler for passive RFID dense reader environments working under EPCglobal standard. *Simulation Modelling Practice and Theory*, *34*, 172–185. https://doi.org/10.1016/j.simpat.2012.07.006

Williams, J. R. (n.d.). *keypad3.pdf*.

Xie, H. (2010). *Development of a Flexible Robotic System for Multiscale Applications of Micro / Nanoscale Manipulation and Assembly*. 1–11.

Yigitcanlar, T., Corchado, J. M., Mehmood, R., Li, R. Y. M., Mossberger, K., & Desouza, K. (2021). Responsible urban innovation with local government artificial intelligence (Ai): A conceptual framework and research agenda. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 1–16. https://doi.org/10.3390/joitmc7010071

Zaatari, E. (2019). *Cobot Programming for Collaborative Industrial Tasks : An Overview Cobot Programming for Collaborative Industrial Tasks : An Overview*. https://doi.org/10.1016/j.robot.2019.03.003

APPENDICES

Appendix 1: Questionnaire used in research

Questionnaire for Evaluating the IoT-Based Robotic Tea Serving System

Dear respondent,
This questionnaire is designed to collect feedback and insights regarding the development and usefulness of the IoT-based robotic system for serving breakfast tea in academic institutions, specifically at INES-Ruhengeri. with just few minutes of Your responses will be confidential and used solely for academic research purposes. Thank you for your time and contribution.

ug2320244@ines.ac.rw Switch account

Not shared *

* Indicates required question

What is your Gender *

- Male
- Female

What is your Age Group *

What is your Age Group *

- 21–25
- 26–30
- Above 30

What is your Role at INES-Ruhengeri *

- Staff
- Student
- Other

Do you normally take breakfast tea at campus, MARY GHANDY RESTOURENT ? *

- Yes
- No

What challenges have you experienced of getting breakfast tea at the institution? *
(Select all that apply)

- [ ] Long queues
- [ ] Delays in service
- [ ] Limited time between classes
- [ ] Poor hygiene or service quality
- [ ] manual payment
- [ ] ALL Above
- [ ] None of Above
- [ ] Other

If yes, How much time do you usually spend in waiting to get your tea? *

- ○ Less than 5 minutes
- ○ 5–10 minutes
- ○ 10–15 minutes

Would you prefer a self-service system that uses an automated tea dispenser with cashless payment options (e.g., RFID or mobile money)? *

- ○ Yes
- ○ No
- ○ Maybe

Do you believe an automated tea-serving robot would improve the efficiency of tea service on campus? *

- ○ Strongly Agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly Disagree
- ○ Other: ____________

Are you comfortable using systems that involve RFID cards, or IoT System for transactions? *

- ○ Yes
- ○ No
- ○ Maybe

Which features would you like the robotic tea system to have? *

- ☐ Quantity selection (e.g., 1 cup, 2 cups)
- ☐ Payment using RFID or mobile money
- ☐ LCD display for instructions
- ☐ Automatic alerting if error occurs

Do you think a robotic system for tea service could reduce overcrowding and improve time management during break times? *

- ○ Yes
- ○ No
- ○ Not Sure

Any additional suggestions or feedback on how the tea service experience can be improved? *

Your answer

Submit

Clear form

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Appendex 2 : Arduino Code

```
#include <WiFi.h>
#include <HTTPClient.h>
#include <SPI.h>
#include <MFRC522.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Keypad.h>
```

```
// RFID setup
#define SS_PIN  5
#define RST_PIN 4
MFRC522 mfrc522(SS_PIN, RST_PIN);

// LCD setup
LiquidCrystal_I2C lcd(0x27, 20, 4);

// LED and Relay
#define RELAY_PIN  2

const char* ssid = "Mr.Elie.net";
const char* password = "me1234";

// Your required URLs
const char* serverURL =
"http://192.168.43.131/ElieProject/checkCardAndDeduct.php";
const char* getUID_URL = "http://192.168.43.131/ElieProject/getUID.php"; //
Newly added

// Prices
const int PRICE_SMALL = 500;
const int PRICE_MEDIUM = 1000;
const int PRICE_BIG = 1500;

String lastSentUID = "";
unsigned long lastSentTime = 0;
const unsigned long sendCooldown = 3000;  // milliseconds



// Keypad setup
const byte ROWS = 5;
```

```
const byte COLS = 4;
char keys[ROWS][COLS] = {
{'<', '0', '>', 'E'},
{'7', '8', '9', 'e'},
{'4', '5', '6', 'v'},
{'1', '2', '3', '^'},
{'F', 'f', '#', '*'}
};
byte rowPins[ROWS] = {26, 25, 33, 32, 15};
byte colPins[COLS] = {13, 12, 14, 27};
Keypad keypad = Keypad(makeKeymap(keys), rowPins, colPins, ROWS, COLS);

pinMode(RELAY_PIN, OUTPUT);
digitalWrite(RELAY_PIN, LOW);

lcd.begin();
lcd.backlight();
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Connecting WiFi");

WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED) {
delay(250);
Serial.print(".");
}

lcd.clear();
lcd.setCursor(0, 0);
lcd.print("WiFi Connected");
lcd.setCursor(0, 1);
lcd.print(WiFi.localIP());
delay(2000);
```

```
showMenu();
}

handleMenuInput();
break;
case CONFIRM_SELECTION:
handleConfirmation();
break;
case SCAN_CARD:
promptScanCard();
break;
case VERIFY_CARD:
verifyCardAndBalance();
break;
case ASK_PUT_MUG:
askPutMug();
break;
case PROCESS_PAYMENT:
processPayment();
break;
case FINISH:
finishTransaction();
break;
}
}
void handleMenuInput() {
char key = keypad.getKey();
if (key == '1' || key == '2' || key == '3') {
selected = key - '0';
price = (selected == 1) ? PRICE_SMALL : (selected == 2) ? PRICE_MEDIUM :
PRICE_BIG;
currentState = CONFIRM_SELECTION;
```

```
lcd.clear();
lcd.print(String(selected) + ". ");
if (selected == 1) lcd.print("Small Mug");
else if (selected == 2) lcd.print("Medium Mug");
else if (selected == 3) lcd.print("Big Mug");

lcd.setCursor(0, 1);
lcd.print("Price: " + String(price) + " Rwf");
lcd.setCursor(0, 2);
lcd.print("Press ENT to proceed");
}
}

void handleConfirmation() {
char key = keypad.getKey();
if (key == 'E') {
lcd.clear();
lcd.print("Scan your card");
currentState = SCAN_CARD;
} else if (key == '<') {
showMenu();
}
}

void promptScanCard() {
if (readUID()) {
StrUID.toUpperCase();
lcd.clear();
lcd.print("Checking card...");
currentState = VERIFY_CARD;
}
}
```

```
void verifyCardAndBalance() {
if (WiFi.status() == WL_CONNECTED) {
HTTPClient http;
http.begin(serverURL);
http.addHeader("Content-Type", "application/x-www-form-urlencoded");
String postData = "id=" + StrUID + "&cost=" + String(price);
int httpCode = http.POST(postData);

if (httpCode == 200) {
String payload = http.getString();
Serial.println("Server response: " + payload);

if (payload.startsWith("success|")) {
lcd.clear();
lcd.print("Balance updated");
lcd.setCursor(0, 1);
String newBalance = payload.substring(payload.indexOf('|') + 1);
lcd.print("New Bal: " + newBalance);
delay(1500);
lcd.clear();
lcd.print("Put mug & press ENT");
currentState = ASK_PUT_MUG;  // ? Only here
}
else if (payload.startsWith("low|")) {
lcd.clear();
lcd.print("Low balance!");
lcd.setCursor(0, 1);
lcd.print("Top up card first");
delay(3000);
showMenu();  // This will set currentState = SHOW_MENU
}
else if (payload == "not registered") {
```

```
lcd.clear();
lcd.print("Card not registered");
lcd.setCursor(0, 1);
lcd.print("Register first");
delay(3000);
showMenu();  // Same
}
else {
lcd.clear();
lcd.print("Error response");
delay(2000);
showMenu();
}
} else {
lcd.clear();
lcd.print("HTTP Error: " + String(httpCode));
delay(2000);
showMenu();
}

http.end();
} else {
lcd.clear();
lcd.print("WiFi Disconnected");
delay(2000);
showMenu();
}
}

void askPutMug() {
char key = keypad.getKey();
if (key == 'E') {
currentState = PROCESS_PAYMENT;
```

```
}
}

void processPayment() {
lcd.clear();
lcd.print("Dispensing tea...");
digitalWrite(RELAY_PIN, HIGH);

// Open relay based on selected mug size
if (selected == 1) {         // Small mug
delay(2000);
} else if (selected == 2) {  // Medium mug
delay(3000);
} else if (selected == 3) {  // Big mug
delay(4000);
}

digitalWrite(RELAY_PIN, LOW);

lcd.clear();
lcd.print("Thank you!");
delay(2000);

void arrayToString(byte array[], unsigned int len, char buffer[]) {
for (unsigned int i = 0; i < len; i++) {
byte nib1 = (array[i] >> 4) & 0x0F;
byte nib2 = array[i] & 0x0F;
buffer[i * 2] = nib1 < 10 ? '0' + nib1 : 'A' + (nib1 - 10);
buffer[i * 2 + 1] = nib2 < 10 ? '0' + nib2 : 'A' + (nib2 - 10);
}
buffer[len * 2] = '\0';
}
```