

# **IOT-BASED COMPUTER LABORATORY EQUIPMENT TRACKING SYSTEM: A CASE OF UNIVERSITÉ DU LAC TANGANYIKA**

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**A Project Report Submitted in Partial Fulfillment of the Requirements of the Award  
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## ABSTRACT

In today's digital age, computer laboratories' adoption in academic institutions and the security of equipment are crucial to ensure their effective functioning and prevent equipment loss or damage. These laboratories have valuable equipment, such as laptops, switches, routers, projectors, printers, and scanners, that require proper security measures to prevent losses or damages. Manual methods such as pen and paper, spreadsheets and tracking software have been commonly used in the past for equipment tracking. However, these approaches have certain limitations, such as being time-consuming, having limited storage and retrieval abilities, and not providing real-time updates. To overcome these challenges and enhance the lab equipment tracking system, the objective of the developed system is to identify the necessary requirements for designing, developing and validating an IoT-based computer lab equipment tracking system to manage high-value lab equipment at Université du Lac Tanganyika (ULT) university and prevent the unauthorised removal of equipment from the laboratory. The study employs Radio Frequency Identification (RFID) technology to track and identify automatically tags attached to the equipment. This study used Agile's Scrum framework as a system development approach, and a qualitative research approach, including interviews, observations, and focus group discussions, was used to collect data for the functional and non-functional requirements. An ESP32 microcontroller was used to collect and process data from sensors and send the data to the IoT cloud. An Advanced Encryption Standard (AES) encryption and decryption algorithm using a 128-bit key was implemented to ensure the secure transmission of RFID data. The system also features an automatic lock-unlock mechanism to prevent equipment from moving out of the lab without authorisation. A web application with a simple interface was developed for the equipment management system. Ultimately, the system validation process engaged 51 participants comprising IT managers, lab assistants, lab technicians, and lab users. All participants filled out a system evaluation form which resulted in positive responses. The results of the system validation analysis indicate an average of 87% of performance, availability, accuracy, efficiency, and effectiveness. Therefore, ULT University accepted the system due to its effectiveness, security features, and user-friendly interface.

## DECLARATION

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

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14/08/2023

Name of Candidate

Signature

Date

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Dr. Judith Leo



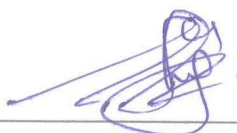
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## CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology a project report titled “*IoT-Based Computer Laboratory Equipment Tracking System: A Case of Université du Lac Tanganyika*” in partial fulfilment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

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## **DEDICATION**

I dedicate this work to my beloved family, especially my mother Ms. Spéciose Ndikumasabo, for her motivation and my late father Mr. Fortunat Ntafatiro.

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## LIST OF ABBREVIATIONS AND SYMBOLS

2D	Two-dimensional
3D	Three Dimensional
AC	Air Conditioning
AC	Alternative Current
AES	Advanced Encryption Standard
AWS	Amazon Web Services
CENIT@EA	Centre of Excellence for ICT in East Africa
CSS	Cascading Style Sheets
DC	Direct Current
DES	Data Encryption Standard
EDA	Electronic Design Automation
ESP32	Expressif System 32
GPS	Global Positioning System
HTML	HyperText Markup Language
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IoT	Internet of Things
IT	Information Technology
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LF	Low Frequency
MHz	Megahertz
NFC	Near Filed Communication

NM-AIST	The Nelson Mandela African Institution of Science and Technology
PC	Personal Computer
PCB.	Printed Circuit Boards
PHP	Hypertext Preprocessor
QR	Quick Response
RF	Radio Frequency
RFID	Radio Frequency Identification
RSA	Rivest Shamir Adleman
SQL	Structured Query Language
SSL	Secure Sockets Layer
TLS	Transport Layer Security
UHF	Ultra-High Frequency
ULT	Université du Lac Tanganyika
V	Voltage

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the Problem

Many academic institutions have invested in computer laboratories and Information and Communication Technology (ICT) equipment to support today's educational research, teaching, and learning sessions (Farag, 2020). It is crucial to adopt computer laboratories at all levels of education when providing ICT skills courses in the classroom with hands-on training as support tools to improve school activities' management (Fomunyan, 2019).

In general, a laboratory is a workplace, i.e. a building, a space or a room equipped with different instruments or equipment for carrying out scientific work such as research, demonstrations and discussions. According to Janbandhu (2015), a computer laboratory is a space or room equipped with computers and accessories used for scientific research, experimentation, and testing. It can be found in universities, colleges, schools, libraries, science labs, training centres, research centres or companies with Information Technology (IT) departments that necessitate such a place for their employees.

It is classified into two types which are classroom laboratory and research laboratory; whereby a classroom laboratory is a learning space in which the university faculty, teachers and students delve into the science of teaching and learning in a technology-rich environment. It incorporates practical and interactive teaching experiences into coursework, whereas a research laboratory is a facility designed primarily for conducting scientific research (Colton *et al.*, 2020). Additionally, the size of a computer laboratory is defined by the number of users and the number of equipment found inside, such as the number of computer units, switches, routers, projectors, printers, and scanners. Furthermore, it consists of tables, chairs for the users, a desk for the instructor or teacher, and a whiteboard (Muntholib *et al.*, 2018). Hence, it is essential for both private and government academic institutions to have these laboratories in order to provide a conducive environment that improves students' scientific and technological research and innovation abilities (Harron *et al.*, 2017). Therefore, computer laboratory equipment should be properly valued and managed in order to ensure safety and security.

Traditionally the most common method used to provide safety and security in the laboratories is the equipment tracking system through the use of a pen and paper where a list of all

equipment has been maintained, and each piece of equipment has been tagged with an identification number (Procedures, 2019). This practice has been obsolete and was replaced by the introduction and adoption of spreadsheets. Although the spreadsheets are paperless and easily shared and modified, they still provide limited accuracy and require manual data entry during initial entry and updating of the existing data. Additionally, barcode and Quick Response (QR) code techniques were the earliest technologies adopted to replace spreadsheets but were time-consuming due to the condition of processing the scan on one piece of equipment by one (Irakunda *et al.*, 2021).

Furthermore, intelligent technologies such as the Internet of Things (IoT) have evolved, and therefore, an effective equipment tracking mechanism can now be implemented due to the existence of Radio Frequency Identification (RFID), Global Positioning System (GPS), Bluetooth, and WI-FI techniques (Shokouhifar, 2021). These techniques can then be connected to a tracking software or platform to track equipment in real-time. Ultimately, with the digital information revolution, it is unlikely that the equipment tracking process could continue to take as much time as traditional methods.

Therefore, this study aims at developing an IoT-based equipment tracking system to monitor computer lab equipment in real-time in order to ensure that every piece of equipment is always in place. Then, the system notifies the lab assistant through a web application dashboard when equipment is moving out of the laboratory without authorisation. It also provides auto lock/unlock features to prevent someone from exiting the computer lab with unauthorised equipment. It automatically unlocks if the tracked equipment is returned to its place. The present study was conducted at an academic institution called Université du Lac Tanganyika (ULT), which is a private higher education institution located in Bujumbura, Burundi.

## **1.2 Statement of the Problem**

The Université du Lac Tanganyika (ULT) is a higher education institution founded in 1999 with the main objective of encouraging students and lecturers to sustain their intellectual, scientific, and research interests (ULT, 2019). The university has three computer laboratories and each is equipped with desktop computers, laptops, printers, routers, and projectors to facilitate an immersive and interactive learning experience. Figure 1 shows the computer laboratory image, and each ULT lab has dimensions of 5\*12 meters.



**Figure 1: Computer laboratory of ULT**

The current computer laboratory equipment management system at ULT university is handled manually by the lab assistant by writing down the equipment information, including their specifications, in a ledger book. Whenever a class or activity is scheduled to use the computer laboratory, a lab assistant informs a student representative of the current status of the equipment inside the computer lab. Then, the student representative verifies the status before allowing other students to use it. After using the computer laboratory, the student representative has to prepare a report of the lab equipment's current status, and the lab assistant has to check the report and verify the equipment as shown in Fig. 2 to confirm that what is recorded in the report tallies with the status of equipment that was in the laboratory before using it. The process is done manually and takes between 3 to 5 minutes, especially if different classes are scheduled to use the laboratory on the same day. Additionally, the lab technician is allowed to take any equipment out of the laboratory for maintenance or repair after being authorised by the lab assistant. The authorisation involves making a request by filling in the form, submitting it, and waiting for the lab assistant to confirm the request. The process can take 5-10 minutes if the lab assistant is present or available. Consequently, due to the wastage of time while handling the process, many activities require extended time, and this disrupts the timetable and the academic calendar. However, there has been advanced development in automatic tracking of the lab equipment through the use of barcodes and QR codes; unfortunately, these systems have

challenges such as limited data storage capacity, line of sight requirement, security and privacy concerns, reader compatibility and easy damage and obscuration (Thanapal *et al.*, 2017). Hence, there is a need to develop an effective IoT-based system for tracking computer lab equipment. The aim of this study is to develop an equipment tracking and management system base on RFID technology which removes all existing barriers and challenges in order to contribute to the general university progress.



**Figure 2: Lab assistant and student representative checking lab equipment after a session**

### **1.3 Rationale of the Study**

The ULT university aims at gaining a competitive advantage by adopting computer laboratories and ICT equipment to support research, teaching, and learning. Students tend to use the computer laboratory for different purposes; as a result, equipment tends to be misplaced or lost due to the lack of an automatic equipment tracking process. Additionally, the traditional tracking mode wastes time as the process involves counting the equipment and checking their identification. Furthermore, there is a high probability of human error while tracking equipment manually due to inaccurate supervision. Therefore, the developed intervention system is an IoT-based equipment tracking system that monitors the lab equipment, notifies the lab assistant



whenever equipment is moving out of the laboratory without authorisation and prevents the person from exiting the laboratory by locking the door automatically until the tracked equipment is returned to its place. Hence, the developed laboratory equipment tracking system increases the safety and security of lab equipment.

## **1.4 Objectives of the Study**

### **1.4.1 General Objective**

The general objective of this study is to develop an IoT-based equipment tracking system in order to effectively monitor computer laboratory equipment at ULT.

### **1.4.2 Specific Objectives**

The study aimed to achieve the following specific objectives:

- (i) To identify the necessary requirements for developing an IoT-based computer lab equipment tracking system.
- (ii) To develop an IoT-based computer lab equipment tracking system.
- (iii) To validate the developed system.

## **1.5 Research Questions**

The study intended to answer the following questions:

- (i) What are the necessary requirements for developing an IoT-based equipment tracking system for a computer laboratory?
- (ii) How can an IoT-based equipment tracking system for a computer laboratory be designed and developed?
- (iii) Is the developed system performing as intended?

## **1.6 Significance of the Study**

The developed system contributes to the safety and security of laboratory equipment in academic institutions, saves equipment from loss, theft and misplacement, and enhances the teaching and learning sessions in the laboratory as well. Additionally, the developed system

allows the lab assistant to monitor lab equipment in real-time and receive live data remotely through a ThingsSpeak dashboard. ThinkSpeak is an IoT cloud-based platform with various tools and features that allow users to visualise and analyse sensor data and control connected devices easily (Goudarzi *et al.*, 2022). The web application developed also provides real-time data analysis and visualisation. On the contrary, the traditional equipment management process used at ULT university is not convenient for lab users or assistants. This is because it is a long process with a high risk of making mistakes when identifying equipment, improper data storage, and time costly for lab assistants and lab users since they have to check together that all the equipment is in the laboratory.

### **1.7 Delineation of the Study**

Due to the budget and time constraints, the project study is only limited to tracking and managing equipment in the computer laboratory. This study, therefore, does not consider the management system of laboratory activities, lab users or environmental monitoring systems in the computer laboratory. Additionally, the ThingsSpeak platform was used for prototyping purposes due to its free availability. However, despite its disadvantage of being less secure, during the implementation phase, it is recommended to use Amazon Web Services (AWS), which is a cloud computing platform more secure that provides various services, including IoT services. The reason for not using Amazon Web Services during the prototype stage was due to cost constraints.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Theoretical Framework

A theoretical framework is a conceptual structure that outlines and organizes the key concepts, theories, variables, and relationships relevant to a research study (Grant *et al.*, 2014). It serves as a roadmap or a reference for developing the arguments and procedures of a research study

##### 2.1.1 Equipment Management System for Computer Laboratory

The laboratory equipment, network configuration and maintenance management systems have become an essential part of the construction of the laboratory room; for that reason, digital technology and specific measures are required to ensure effective management, safety and security and lower repair costs (Shao & Wang, 2021). A successful laboratory management scheme should improve students' efficiency, assist teachers, and extend equipment life, reducing the workload of later maintenance.

The main valuable equipment such as computer units, laptops, printers, monitors, and the necessary supplies for users and instructors such as tables and chairs, instructor desks, whiteboard, Liquid Crystal Display (LCD) screens, LCD projectors, cabinets, and Air Conditioning (AC) fan, must be adequately managed by the head of the laboratory and the laboratory technician.

Wei (2020) carried out research to investigate the framework for managing and maintaining university laboratories using computer-aided technology, emphasised the impact of adopting the intelligent management system in the computer laboratory to ensure orderly operation. This involved remote monitoring of services by using IoT technology. The operations included control of electricity, a remote door, a swipe card for identity verification, and remote control of equipment to track, check, and update their inventory in real-time; management data systematisation, including real-time data collection.

A computer laboratory is an expensive resource in terms of equipment, and information systems play a critical role in improving the coordination of equipment management. Accordingly, integrated management software that is intuitive and easy to use is required to

help the user to manage the equipment, schedule maintenance, and generate an inventory list and report. (Procedures, 2019).

Mavrommati *et al.* (2013) conducted a theoretical assessment of many theories constituting the foundation of the Internet of Things design to assist end-user development. The authors identify four critical factors to consider when developing any IoT system: end-user design, end-user programming, and semantic web/IoT System design, which are equal to system development techniques and overall system development.

### 2.1.2 Evolution of Assets Tracking Technologies

The Barcode is one of the oldest and most cost-effective asset-tracking technologies invented in 1948 by Bernard Silver and Norman Joseph Woodland for emerging grocery checkouts to scan the products automatically (Chanda, 2019). A barcode comprises varying width bars and spaces conventionally with black and white colours for the best possible detection and evaluation of the reflected light by their sensors. Figure 3 shows an image of the barcode structure. It comprises different elements to create a unique identifier for each product, such as left and right guard bars to ensure that the scanner can correctly identify the different parts of the barcode, the number system character that represents the number used by the manufacturer to assign product code, a manufacturer number, which is a series of digits that identify the specific manufacturer of the product, an item number to identify the specific product, a check digit which is a single-digit code that is used to verify whether the encoded barcode data are correct and a centre guard bar to separates the manufacturer number from the item number (Chanda, 2019).

Barcode scanners must be able to read the lines on products accurately and promptly. Once scanned, the scanner transmits the product information to a computer or checkout terminal, which can then compare it to a database of products to identify it quickly.



**Figure 3: Structure of Barcode (Jelic & Vrkic, 2019)**

However, as the use of barcodes spread, their limitations became apparent. The most obvious was that a barcode could hold a few alphanumeric information characters. Thus, in 1994, Denso Wave Incorporated invented the QR Code based on a two-dimensional (2D) matrix, as shown in Fig. 4, that could store a large amount of data and with high-speed reading using a portable device such as a smartphone or tablet equipped with a camera and the appropriate reader software to be able to scan the image of the QR code. With the increase in smartphone users, QR codes are becoming more and more popular and quickly gaining widespread acceptance. (Tiwari & Technologies, 2016).



**Figure 4: Structure of QR Code (Jelic & Vrkic, 2019)**

The tracking technology continued to evolve, and a combination of radio broadcast technology and radar made up the RFID technology that employs electromagnetic fields to detect and monitor items that carry either a passive or active tag (Zhang *et al.*, 2010). This was one of the earlier versions of the current IoT device. In addition, RFID tags provide a much more precise identification for items than barcodes and QR codes. As a result of their compact size, RFID tags have been integrated into everyday items such as passports, library books, clothes, and credit cards.

Further advancement continued, and Near Field Communication (NFC) was invented. It is similar to RFID in operation and based on the existing 13.56 MHz RFID. The NFC device has the ability to function as both a reader and a transmitter. It also has the benefit of communicating with a mobile device. The NFC is widely used for digital content exchange

and contactless payments (Singh, 2020). The NFC has a far shorter range than RFID, typically only a few centimetres. This limits its utilization in this project where longer-range tracking is required.

Global Positioning System (GPS) based asset tracking is another IoT tracking technology that has mainly been used to track goods that have left the factory and have been shipped to customer locations on trucks, including those shipped to distant countries. The GPS tracking necessitates installing a tracking device mounted on a vehicle, placed on an asset, or worn by a person. The device is capable of providing accurate information on its location and movements, thus facilitating real-time tracking (Shanmugasundaram *et al.*, 2021).

The main drawback of GPS tracking is that it is challenging to track items inside buildings due to the weak signal, as it requires a clear view of the sky for tracking. The advantage is that a GPS tag can be easily tracked even from a remote location by simply connecting it to the Internet. Table 1 presents a summary of the comparative analysis of the various technologies used for item tracking.

**Table 1: Comparative analysis of items tracking technologies**

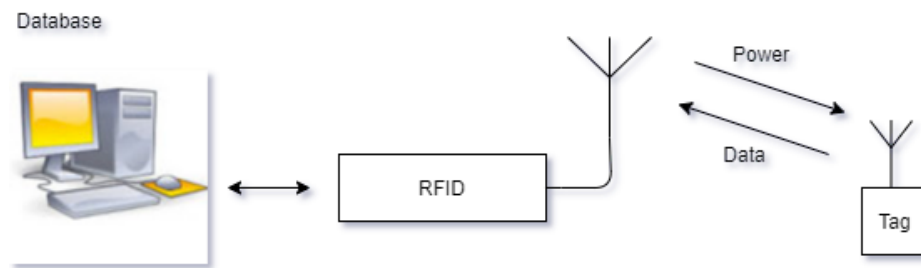
S/N	Attributes	Barcode	QR Code	RFID	NFC	GPS
1.	Range	Short	Short	Short to Long	Short	Unlimited
2.	Line of Sight	Required	Required	Not Required	Not Required	Not Required
3.	Data storage	10-25 Digits	Up to 7089 numeric digits	Passive: Up to 8KB Active: up to 128KB	Up to 8 MB	Transmits location information, doesn't store data.
4.	Data Transfer Rate	5-10 bits/s	8000bits/s	640 kbits/s	424kbits/s	50bits/s
5	Read Rate	Only one at time	Only one at time	Multiple tags reading at once	Only one at time	NA
6.	Accuracy	Medium	Medium	High	High	Medium
7.	Cost	Low	Low	Average	Average	High
8	Read/Write Capability	Only read	Only read	Read/Write	Read/Write	NA

As shown in Table 1, every tracking technology has its advantages and limitations, and the choice of technology depends on the specific requirements and use case. However, despite some limitations of RFID, technology, it remains a favored tool for tracking items, particularly when compared to other tracking technologies.

### 2.1.3 RFID Technology

The Radio Frequency Identification (RFID) is an automated wireless identification technology that uses radio frequency waves to automatically track and identify objects attached to tags as

they pass close to an RFID reader. The RFID technology comprises three fundamental components, as shown in Fig. 5. The first is the RFID Tags which contain information about the item or asset attached to it. The second is the RFID interrogator, which communicates with the RFID tag through radio wave, and the third element is the backend system, which connects the RFID tag reader to a centralised database. This database contains further specific information about each item RFID tagged item.



**Figure 5: Block diagram of RFID System**

#### 2.1.4 Frequencies Used in RFID Technology

Since the tag and reader communication in RFID technologies uses radio waves, they are then categorised based on the frequency bands in which they operate. The various frequencies are assigned by regulatory authorities, who establish particular rules for using each frequency. RFID systems operate from low frequency (LF) to ultra-high frequency (UHF). These frequencies have been standardised to avoid interference from other devices using different technologies (Lozano-Nieto, 2017). The frequencies used in RFID Technology are summarised in Table 2.

**Table 2: Passive RFID frequencies and ranges**

Band	Frequency	Max reads distance	Common Applications
LF RFID	120KHz-140KHz	20 cm	Access control and security needs
HF RFID	13.56MHz	1m	Smart card, contact-less access and security on library books and airline baggage
UHF RFID	868MHz-928MHz	10 m	Asset Tracking and inventory control



### **2.1.5 RFID Tags Types**

Radio Frequency Identification (RFID) tags can be classified into several different categories based on different criteria. However, the most common and widely recognised basis for classifying RFID tags is based on their power supply source because it has significant implications for the performance and functionality of RFID tags (Lozano-Nieto, 2017). Therefore, three categories are involved.

#### **(i) Active Tags**

The active tags have an onboard power source, usually a battery enabling them to transmit a signal. This type of tag can achieve a reading range of a hundred meters. They are primarily used to send large amounts of data over long distances. They are less integrated and require more maintenance than other systems, which is a disadvantage. They are also expensive.

#### **(ii) Semi-passive**

The semi-passive tag is defined as having an onboard power supply to power only the microchip. This makes it possible for the reader antenna to reflect more energy back to the interrogator. As a result, semi-passive tags have a greater read range than ordinary passive tags.

#### **(iii) Passive Tags**

The most widely used RFID tags are passive ones because of their low price, small size, and simple architectural design (Patel, 2019). As opposed to semi-passive and active tags, they lack a battery and an RF transceiver. This kind of tag responds to reader commands by using the backscattering technique. The backscattering technique involves modulating the electromagnetic wave incident from the reader that has been scattered. The passive tag is made up of an antenna for interacting with the reader and a memory-integrated electronic chip that can store transmitted data.

In this project, we focus on passive tags. Indeed, due to its low cost, long life and small size, passive UHF RFID has been chosen to track and identify laboratory equipment in real-time.

Evidently, in order to maximise IoT adoption, the theories discussed in the aforementioned literature have been taken into account.

## 2.2 Related Works

Several studies have been conducted and come up with different solutions to overcome the limitation caused by manual equipment management systems in computer laboratories.

In 2019, a project was conducted by Raad *et al.* (2019) to establish a more efficient method that can be used to identify an item, track and monitor it and add security value. The study's goal was to create an RFID technology system for managing high-value lab equipment inventory by attaching low-cost battery-free tags to the equipment. The system has a unique feature of allowing both smart cards and RFID tags to be used for checkout authentication; however, the system could only send an SMS alarm in case of equipment theft or unauthorised loan, but not avoid unauthorised equipment in real-time.

Li *et al.* (2020) designed a cloud-based and IoT intelligent laboratory management system. The system incorporated several components such as RFID tags, RFID readers, smoke, infrared, temperature, and humidity sensors, and camera devices, which are primarily used to collect information in the sensing layer. The Network layer transmitted the gathered information to the cloud platform server. The application layer provided user management and service functions such as laboratory equipment, personal laboratory information, asset inventory, and laboratory environment information and performed statistics and analysis of the data collected. However, although the system was a benefit to users, it lacks a security alarm system in case of unauthorised equipment checkout.

Farag (2020) have conducted a research project to manage student activities while using the computer laboratory. The project was based on Local Area Network (LAN), analysed their practical work, and tracked their attendance and activities. However, the system could only monitor terminal activity to improve teaching and learning sessions in a computer lab but cannot monitor the lab equipment.

Brindha *et al.* (2020) designed a system that allows medical equipment tracking, and a web application was used to visualise and track the medical equipment. This study concluded that asset-tracking systems based on RF technologies could be implemented in healthcare and different laboratories.

Wicaksono *et al.* (2021) created an RFID and IoT-based Technology to establish the inventory system for laboratory equipment focusing on borrowing lab equipment with a security feature

for both cupboards and tools. Users could borrow equipment through RFID smart cards that have been previously registered. They could also unlock cupboards using the same card, take the items from the cupboard or return them; later, The system could also automatically directly send the information to the cloud server. The outcome demonstrated that the system successfully identified the equipment stored in the cupboard and monitored the borrowing of lab equipment but was only limited to the borrow and return activity in equipment management. However, this study did not consider proper security features at the RFID card level. Unauthorised individuals could quickly access data stored on RFID cards, leading to data breaches and the exposure of sensitive information.

To efficiently manage the equipment inventory in real-time, Raguindin and Ronquillo (2019) created an automated laboratory asset with an inventory system and security features that used passive RFID to maintain control and accurate record of the in and out of the equipment in the dispensing area in order to manage the real-time inventory of equipment effectively. The RFID reader was directly connected to a server that hosted the database, and the server ran software that read data from the RFID reader and saved it in the database. However, due to the lack of a microcontroller for data processing, this study was limited to only tracking and recording data. Its inability to perform complex tasks makes it unsuitable for advanced applications. The system was less secure and did not consider the security alarm in case of unauthorised access.

Hasan *et al.* (2020) implemented an AES encryption method with a key length of 256 bits to secure personal data. The encrypted data was subsequently transformed into QR codes for storage. The PyCrypto, a Python-based cryptography library, was used to perform the encryption and decryption. The Raspberry Pi, a single-board computer, was used to process the encryption and decryption tasks and build the entire system. Although the encryption algorithm operated at high speed, using the Raspberry Pi made the system costly. Additionally, it is noteworthy that due to the high-level nature of Python 3, it is not deemed appropriate for use in embedded microcontrollers such as the ESP32.

Lim *et al.* (2021) implemented a combination of symmetric and asymmetric encryption techniques to provide a robust and secure solution for protecting sensitive information stored on RFID tags. This approach used Triple Data Encryption Standard (DES) for data encryption and RSA for securing the encryption key exchange. Although the algorithm offered a high level of security, the algorithm necessitated a computer with substantial processing power and a considerable amount of memory to manage the computational requirements of encryption and

decryption operations. As a result, this algorithm may not be suitable for implementation on microcontrollers due to their limited processing power and memory capacity.

Considering the above studies, it is clear that smart equipment tracking systems significantly impact the performance of computer laboratories in academic institutions. It is also essential to note that the smart equipment tracking system is more likely to improve equipment visibility, safety and security.

This is where the study of an IoT-Based High-Value equipment tracking system based on secured RFID technology aims at resolving the existing challenge caused by the traditional process by bringing the capability of a computer laboratory more suitable to mitigate security threats based on theft and allowing real-time equipment monitoring without human intervention.

### **2.3 Existing Technical Gap**

Research has shown that RFID technology is deemed a top-performing tool in the field of IoT for real-time asset tracking and management due to its long-range capability, ability to store large amounts of data, real-time monitoring, adaptability to various environments, cost-efficiency, and durability. However, a survey conducted by Al *et al.* (2021) shows that several existing tracking systems based on RFID Technology lack security and privacy features making it challenging to ensure the security and privacy of asset-tracking data. Radio Frequency identification (RFID) tags can be easily cloned, and this makes it challenging to ensure the security and authenticity of the data being transmitted (Beqqal & Azizi, 2017). Hence, more secure RFID tracking systems are needed to protect sensitive data and prevent unauthorised access. Therefore, the unique feature of this developed system relies on symmetric RFID Tag encryption using AES, whereby the algorithm generates a 128 secure key bits to encrypt the data stored on the tag and decrypts it using the mbed library and an ESP32 microcontroller. This provides a level of security for the system and ensures that data remain secure during transmission and cannot be intercepted or tampered with by unauthorised individuals. The AES method was selected due to its high performance on both hardware and software, ease of implementation, and strong security level (Becker, 2022) as compared to DES and Rivest, Shamir, Adleman (RSA). Although DES has hardware implementation capabilities, it is a relatively slow encryption algorithm and has been reported to be vulnerable to attacks such as brute force and differential cryptanalysis (Sumartono & Siahaan, 2018). The brute force

involves cracking passwords or encryption keys by trying every possible combination until the correct one is found, and differential cryptanalysis, is a type of attack that can reveal information about the encryption key by analysing the differences between ciphertexts encrypted with different plaintexts. Rivest, Shamir, Adleman (RSA) is unsuitable for hardware implementation because its encryption and decryption processes are computationally intensive, which may result in slow performance. Table 3 provides a comparison of AES, DES, and RSA, the three primary encryption types.

**Table 3: Comparison of between encryption AES, DES and RSA**

S/N	Factors	AES	DES	RSA
1.	Key Size	128, 192, 256 bits	56 bits	>1024 bits
2.	Algorithm	Symmetric	Symmetric	Asymmetric
3.	Ciphering & deciphering key	Same key used for Encrypt and Decrypt	Same key used for Encrypt and Decrypt	Different key used for Encrypt and Decrypt
4.	Security	Excellent Secured	Not secure enough	Least Secure
5.	Power consumption	Low	Low	High
6.	Hardware & Software Implementation	Faster	Better	Not efficient
7.	Encryption and Decryption time	Faster	Moderate	Slower

## **CHAPTER THREE**

### **MATERIALS AND METHODS**

#### **3.1 Project Case Study**

The project was carried out within a computer laboratory that is managed by the Information Technology (IT) department of ULT, a private higher education institution located in Bujumbura, Burundi, where the internship was conducted. Appendix 1 shows the internship acceptance letter. The ULT university was chosen because it offers several academic and non-academic facilities and services with access to on-campus computer laboratories to students and their stakeholders. Therefore, maintaining lab equipment is essential or primordial to ensure safety and security and reduce the university's repair and maintenance costs. The project aims to track, monitor and manage high-value computer lab equipment such as Personal Computers (PC), desktops or laptops, printers, routers, projectors and central processing units moving in and out of the laboratory.

#### **3.2 Research Methods**

This study employed a qualitative research approach. This was chosen to gain a deeper understanding of the experiences and perceptions of the involved participants, evaluate the current equipment management system and determine what improvements might be needed to get an effective equipment tracking and management system.

The qualitative research method entails collecting and analysing data from individuals' personal experiences, introspection, narratives, interviews, observations, interactions, and visual texts to comprehend ideas, perspectives, and experiences (LaMarre & Chamberlain, 2021). This method is significant in this study because the study was not intended to make generalisations, and the result of the study can be used in practice. In this study, various techniques were employed to collect data, including interviews, observations, focus group discussions, and documentation.

#### **3.3 Target Population**

The target population for this project is 54 participants based on a combination of statistical considerations, resource constraints, precision requirements, and the practicality of data collection. It involved IT department staff at ULT university and lab users. The staff involves

the IT manager, laboratory assistants and technicians. The IT manager is the head of the department, the lab assistant manages the laboratory equipment, and technicians are responsible for equipment maintenance and repair. Lab users are lecturers and students.

### **3.4 Sampling Technique and Sample Size**

A purposive non-probability sampling method was utilised for participant selection in this study. The study focused on IT department staff and lab users; the participants were chosen based on their availability and willingness to participate. The study had a total of 54 participants, and 32 participants were engaged through interviews and 22 participants for focus group discussions to get their expectations on laboratory equipment tracking and management system.

### **3.5 Data Collection Methods**

Data collection is gathering, organising and analysing data about the research of interest to answer a given hypothesis or a research question (Byrne, 2017). This was conducted to get accurate information regarding the equipment tracking system in the computer laboratory. In this project, data collection aimed to understand the expectations and desires of different stakeholders regarding the equipment tracking system for computer laboratories in academic institutions. The data collection methods were classified into two categories, secondary data and primary data.

#### **3.5.1 Secondary Data Sources**

**Study existing documents:** previous papers and documentation of earlier works on equipment management systems for computer laboratories and technology used were studied and revised. This involved identifying challenges that were encountered and examining both existing solutions and areas that require further attention. The reviewed documents on computer laboratory equipment tracking and management system explained the challenges and opportunities the developed system can solve.

### **3.5.2 Primary Data Sources**

#### **(i) Interviews**

The interview questions were structured logically and grouped into four sections, as shown in Appendix 2, to ensure relevance to equipment tracking and management system. The first question consisted of open questions concerning the favourable place for the interview; the second section consisted of preliminary questions to understand the services within the IT department. The third session involved critical questions about the existing equipment tracking and management system, their expectations and their needs in automating the existing manual process. The last session involved the concluding question. The objective was to identify the challenges faced by the department and understand how the information flow within the manual process. The goal was to identify and comprehend the technical requirements for the developed system. The interview was conducted in the IT department of ULT university, and the interviewers were the IT manager, the lab assistant, the technicians and lab users. The interview took approximately 1 hour per person to complete, and the feedback was recorded by taking notes.

#### **(ii) Observations**

This method was used to observe the process of existing equipment tracking systems within the computer laboratory of ULT, how the lab assistant tracks equipment in and out, manages the equipment, and how long the process could take. The observation checklist is on Appendix 4 and the observation activity was conducted for one month.

#### **(iii) Focus Group Discussions**

The focus group was held in the IT department at ULT University, where sessions were planned for the topic presentation of the study. Questions were brought up during the focus group discussion, and answers, suggestions, and comments were given. Additionally, the focus group discussions suggested that the desired requirements would be gathered to create the developed system.

### **3.6 Data Analysis**

After gathering data from interviews, observation and focuss group discussions, the following step was to organise, structure, and analyse the data to meet the project's objectives. Data were



analysed by creating a coding scheme from the in-depth interviews and focus group discussions. This involved comparing responses in order to identify common themes and patterns. Afterwards, Matplotlib, a Python 2D plotting library, was used to create charts to illustrate the findings. From the data gathered, it was evident that there was a need to develop a real-time equipment tracking system to manage the computer laboratory equipment.

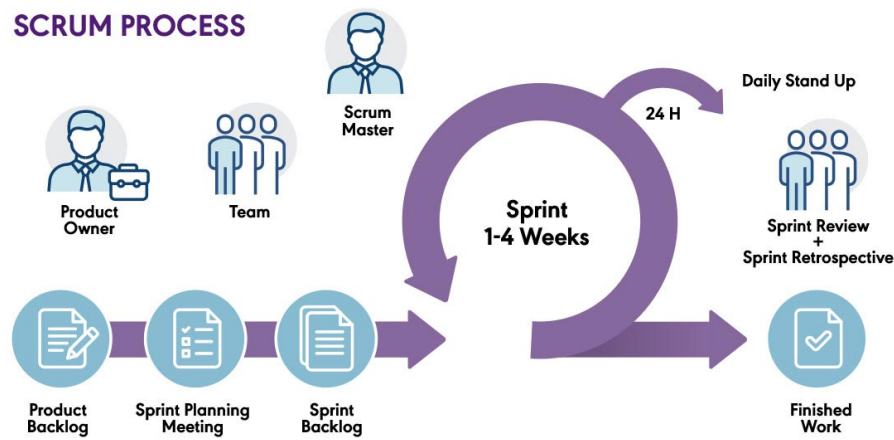
### 3.7 System Development Approach

The Agile development methodology was used for this project. This methodology entails a cycle of planning, requirement analysis, designing, building, and testing to manage a project (Waja *et al.*, 2021). This allows the development and testing of the project in stages known as iterations until the entire project is completed. A specific Agile development framework used in this project is Scrum, and it has been chosen for its rapid development due to collaboration and open communication among team members, especially within a small team. Scrum projects progress through a series of iterations known as sprints with the same duration to enable the product owner to work closely with developers to classify and prioritise the system's functionality in the product backlog, which is a list of all the project-related tasks and requirements that need to be completed (Altameem, 2015). Figure 6 shows the scrum process. At the beginning of every sprint, a brief 15-minute meeting takes place so that the team members can agree to produce a Sprint Backlog. The Sprint Backlog is a list of tasks that must be completed during the sprint and assigned tasks. The developers discuss the patterns to be used before beginning the analysis, coding, and testing tasks. A session marks the end of the sprint to present the completed work to the scrum owner for review. After the sprint review, the sprint retrospective takes place to evaluate and identify any problems that arose and plans ways to improve for the following Sprints.

There are three primary roles in Scrum that ensure that project objectives are met:

- (i) **The scrum owner:** for this system development, the scrum owner refers to the product customer, ULT University. At the end of each sprint, the university's IT department has the authority to verify and validate the developed system and provide comments and recommendations.
- (ii) **The scrum master:** involves the project supervisor. There are two academic supervisors and one host supervisor for this project. They were in charge of facilitating, motivating, and coaching the scrum team.

- (iii) **The scrum team:** the development team typically consists of 6 to 10 people. The team for this project consisted of one person who is the author of this project report.



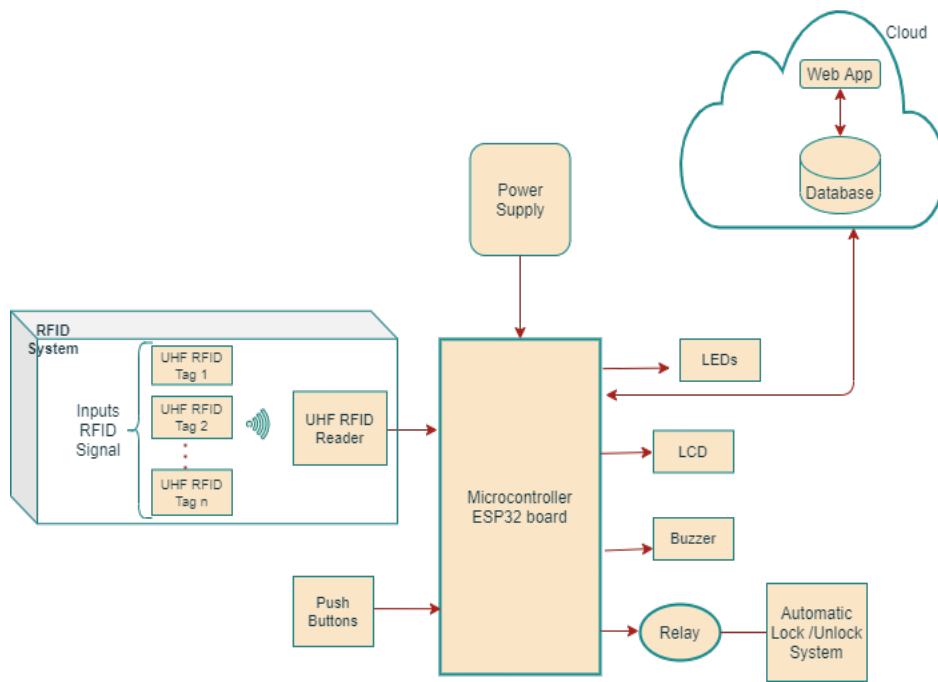
**Figure 6: The agile SCRUM framework (Altameem, 2015)**

### 3.8 System Design

System design defines a system's architecture, modules, interfaces, and data to satisfy specified requirements (Teixeira *et al.*, 2020). It involves the whole system creation process, from the initial functional specification to the final implementation. The goal of the system design is to create a system blueprint that outlines and fulfils the system requirements and constraints of the problem it intends to solve.

#### 3.8.1 Block Diagram

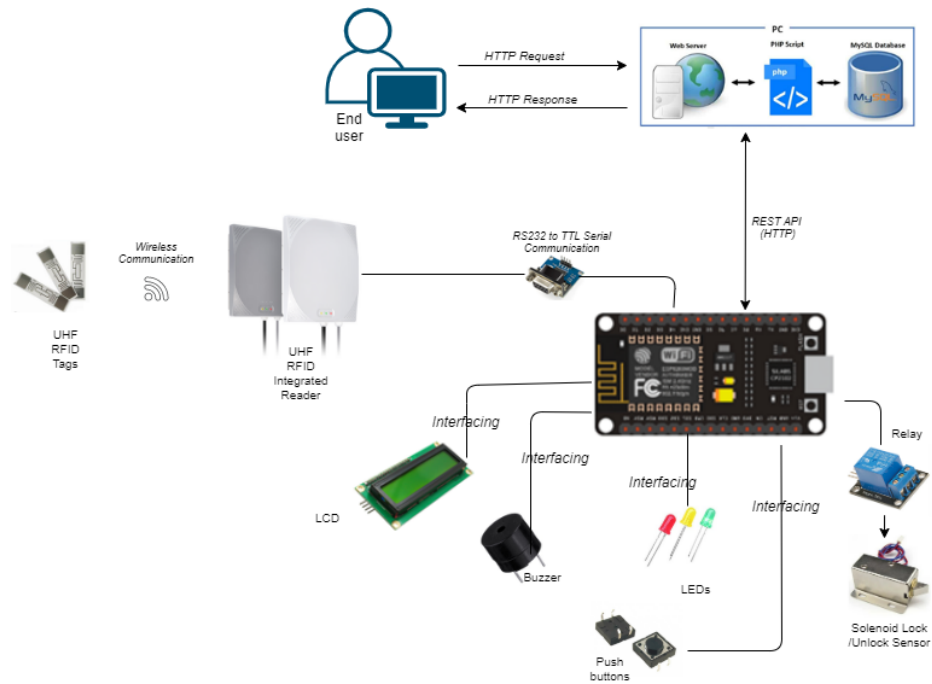
The developed system is represented in the block diagram shown in Fig. 7. A block diagram is a graphical representation of a system or process composed of blocks to represent components or functions and lines to illustrate the connections between blocks (Sosnenko, 2021).



**Figure 7: Block diagram**

### 3.8.2 Architecture Design

Figure 8 shows a system architectural diagram which is a visual representation of the components of a system and their relationships/interactions (Mavridou *et al.*, 2016). It depicts the overall structure of the system as well the interactions and dependencies between the components. It also shows how the system interacts with other systems and with the external environment.

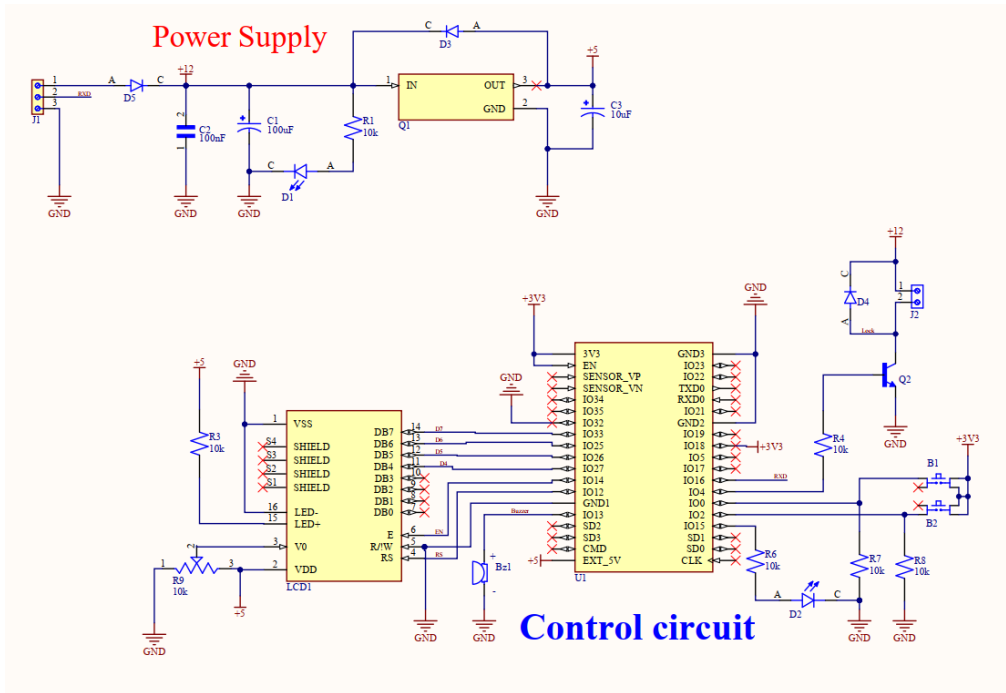


**Figure 8: System architectural design**

The developed system consists of a tracking system with a UHF RFID Reader module that receives real-time data from the UHF RFID tags; the data is processed and analysed by the microcontroller ESP32. When the tracked RFID tag leaves out the reading range of the RFID reader without authorisation, the buzzer generates beep sounds, and the LED blinks red to alarm the environment, and the solenoid gets locked automatically, and it is then unlocked automatically if the tracked RFID tag is back in the reading range. Information on the overall system is displayed on a web application's dashboard hosted on the cloud. The LCD displays information on the state of the system.

### 3.8.3 Circuit Diagram Design

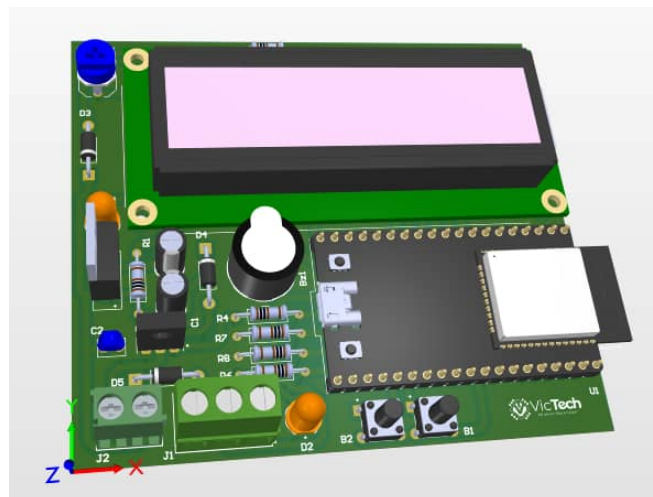
Figure 9 represents the electrical schematic diagram of the power supply and the control circuit of system components and their interconnections. The circuit was designed using KiCad 5.1.10, an open source software suite for electronic design automation (EDA) that facilitates the designing schematics of electronic circuits and printed circuit boards (PCB).



**Figure 9: Circuit diagram of the main control circuit of the system and power supply**

### 3.8.4 A 3D-printed circuit board with components connected

Figure 10 shows a preview image of a 3D-printed circuit board with various components connected to it before printing. The purpose of 3D printed circuit boards is to provide a reliable platform for integration or interactions with the rest of components used. It allows faster prototyping, more creativity, and more flexibility.

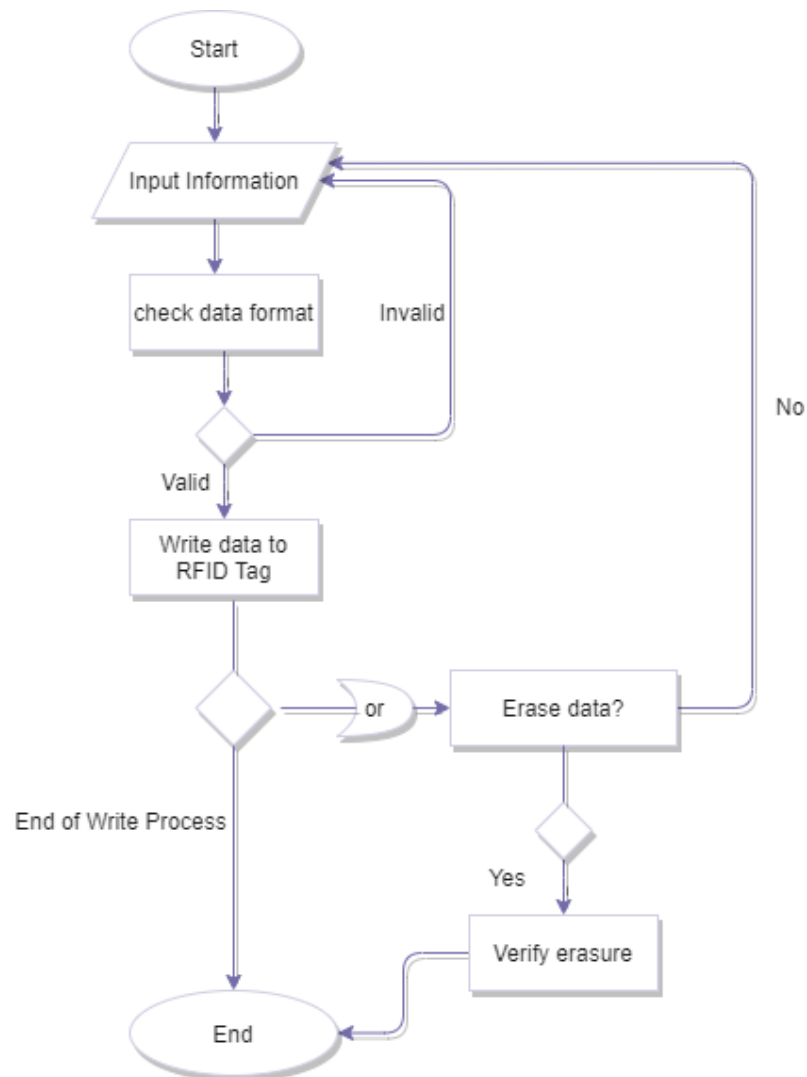


**Figure 10: The 3D view of the main control circuit before printing**

### 3.8.5 Flowchart Diagrams

#### (i) Flowchart diagram of RFID information copy and erase process

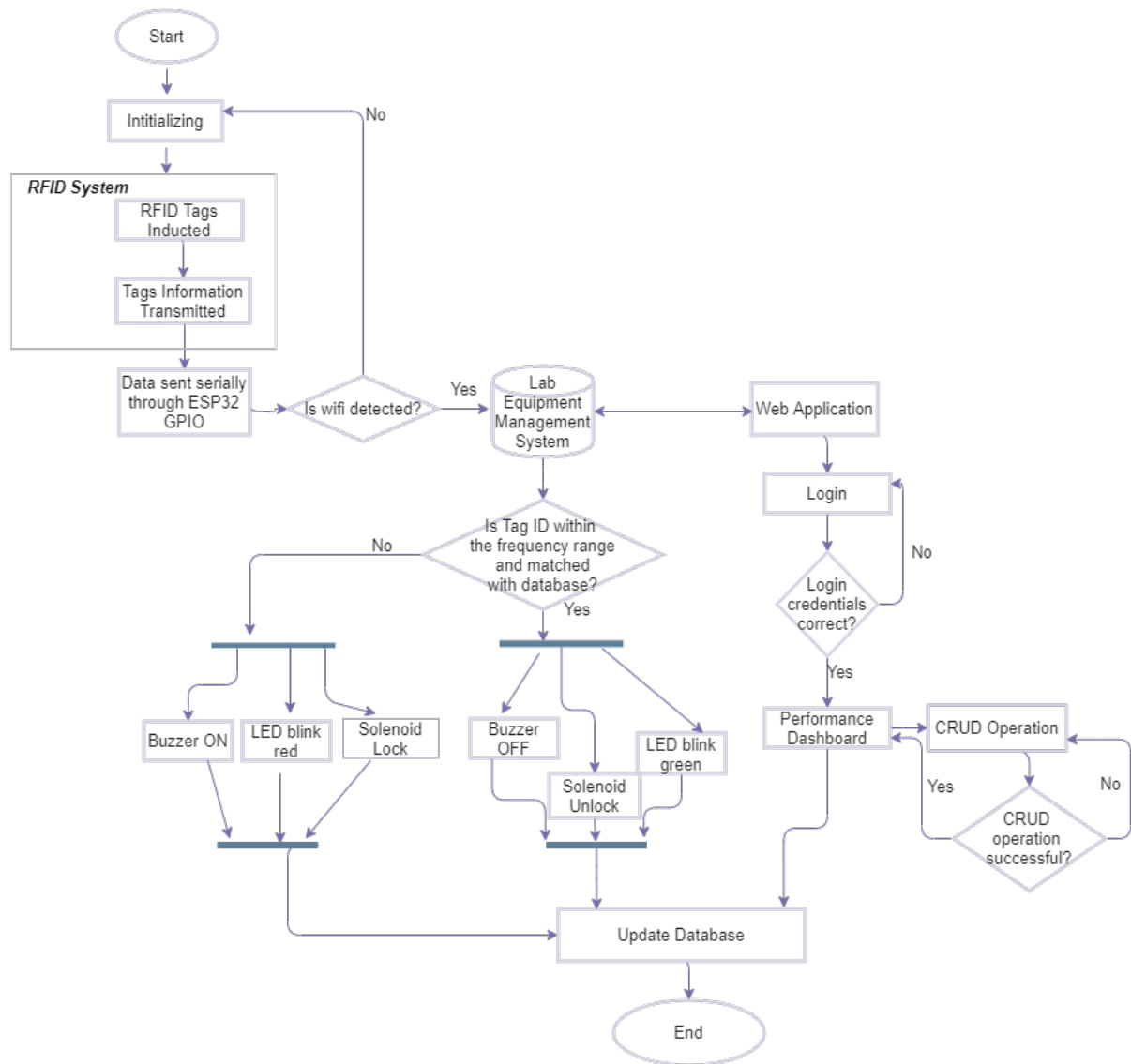
Figure 11 represents the flowchart diagram that shows how the information is copied into RFID tag and how They are erased.



**Figure 11: Flowchart diagram of RFID information copy and erase process**

#### (ii) Flowchart diagram of the overall system

Figure 12 shows a flowchart diagram of the overall system. A flowchart diagram is a graphical representation that depicts the separate steps of a process.

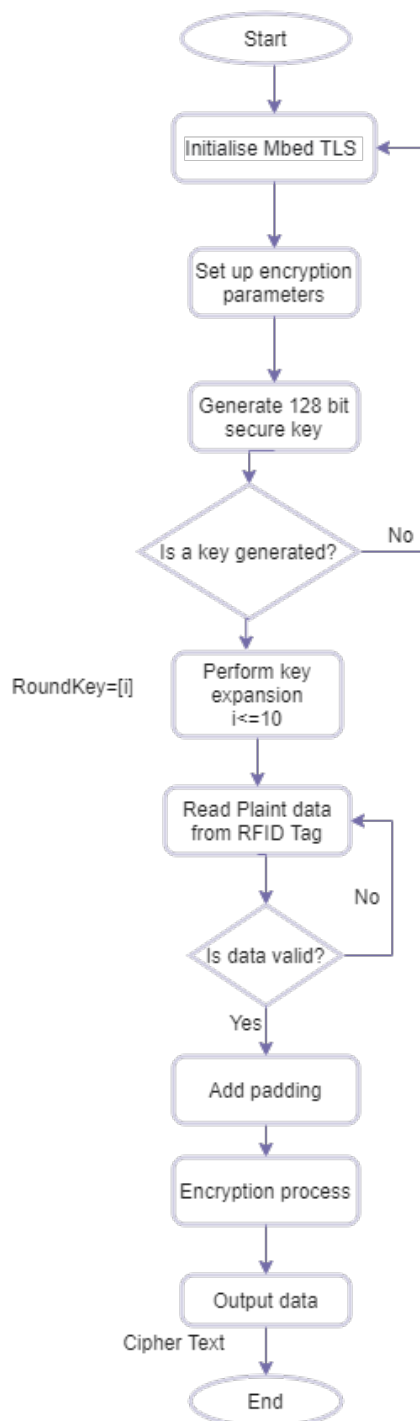


**Figure 12: Flowchart diagram**

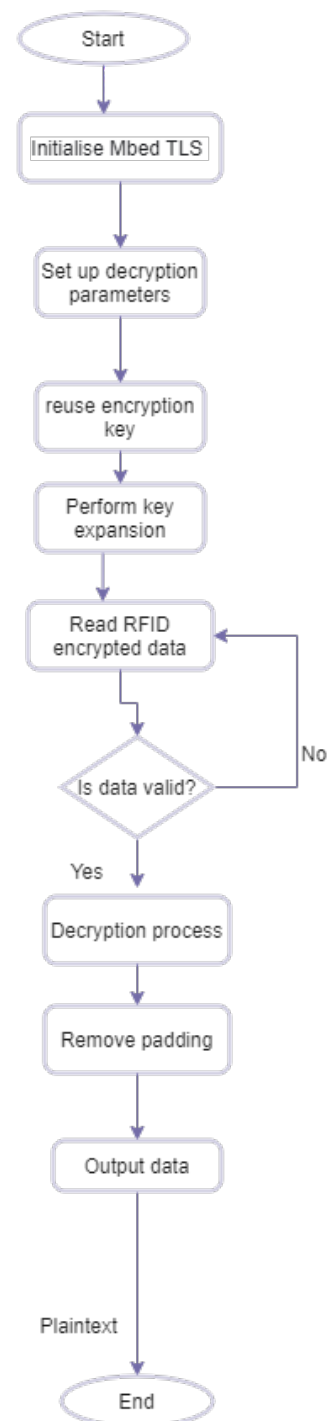
**(ii) Flowchart diagram for AES encryption and decryption for RFID data transmission**

Figure 13 illustrates the process of AES encryption and decryption using a 128-bit key. The algorithm involves initialising the mbed library, creating a secure key, and performing key expansion to create round keys for each round of encryption or decryption. For encryption, the input data is padded before being processed through multiple rounds, each round represented by “i” consisting of byte substitution, row shifting, column mixing, and adding the round key. The encrypted data is the output in the end. For decryption, the encrypted input data is processed through the same number of rounds in reverse order, and then the padding is removed from the output to recover the original plaintext.

### Encryption



### Decryption



**Figure 13: The AES encryption and decryption flowchart diagram for RFID data transmission**

## 3.9 System Development

The system development is the process of designing, creating, implementing, and maintaining a computer-based information system to meet specific business or organizational needs. It



involves a structured and systematic approach to develop, the hardware, software or information systems that address specific requirements, improve efficiency, and provide solutions to complex problems.

### 3.9.1 Hardware Requirements and Tools to be Used

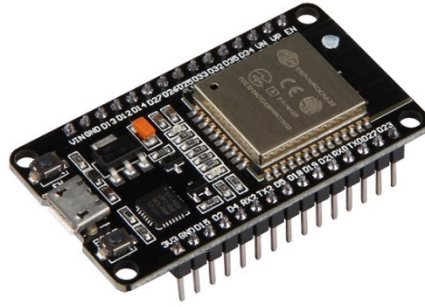
The main components needed for an equipment tracking and management system to operate effectively are listed in Table 4.

**Table 4: Hardware components for the developed system**

S/N	Hardware Components	Specifications
1.	Microcontroller	ESP32
2.	UHF RFID Reader	SR682 UHF RFID Integrated Reader
3.	UHF RFID Tags	YARONGTECH UHF RFID Tag 9662 ISO18000-6C C1G2 Alien H3
4.	Resistor	10K Ohn
5.	Buzzer	Piezoelectronic buzzers type PS1440P02BT
6.	LED	Light Emitting Diodes Types
7.	Solenoid Sensor	12 V solenoid lock
8.	LCD	16*2 type
	Capacitor	a 1000 Uf 35V Radial 105 deg

#### (i) ESP 32 Microcontroller

The ESP32 is a microcontroller with built-in Wi-Fi and dual-mode Bluetooth that is cost-effective and energy-efficient. It is designed for low cost and low power consumption, making it a popular choice for IoT devices and other embedded systems (Babiuch *et al.*, 2019). It can be used in various applications such as devices, wearable electronics, or home automation systems. In this project, the ESP32 microcontroller was utilised to connect various sensors, collect data and process data by executing instructions stored in its on-chip memory and transmitting data over the Internet.



**Figure 14: The ESP32 Microcontroller (Cameron, 2021)**

## **(ii) Ultra High Frequency RFID Reader**

The RFID reader, known as a transmitter, is a device that uses radio waves to communicate with and read data from RFID tags. Ultra High Frequency RFID readers operate in the 860 MHz to 960 MHz frequency range within a distance of tens of meters and are used for long-range identification and tracking applications. They are typically used in supply chain management, asset tracking, and inventory control systems (Tatiparthi *et al.*, 2021). In this project, an SR682 UHF RFID Integrated Reader was used to track and identify the RFID tags attached to the equipment. Ultra High Frequency RFID integrated reader typically consists of an antenna to transmit and receive RF signals, a radio frequency module to process the signal, and the controller manages the communication between the reader and the connected computer or device



**Figure 15: Ultra-High Frequency Radio Frequency Identification Integrated Reader (Tatiparthi *et al.*, 2021)**

### (iii) Ultra High Frequency RFID PassiveTAG

Adhesive Inlay RFID tags designed with a tamper-evident feature to detect any unauthorised removal or tampering of the tag were chosen to be attached to the equipment. They are designed for UHF categories with an operating frequency of 860-925 MHz and a reading range of 6 meters. Adhesive Inlay Tags can be attached to various surfaces, such as metal, plastic, and paper. It comprises a storage capacity of 240 bits, a dimension of 16\*11\*3.8mm and a readable and writable working mode (Evizal *et al.*, 2013).



**Figure 16: The UHF RFID Adhesive Inlay Tag (Evizal *et al.*, 2013)**

### (iv) Buzzer

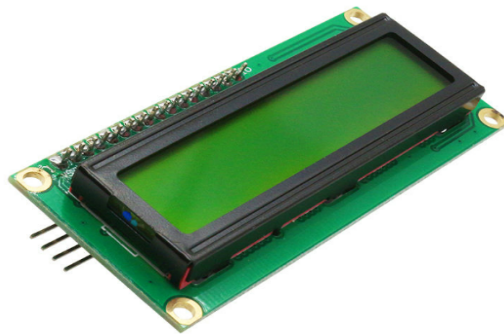
A buzzer is an electromechanical device with two pins that convert the audio model into a sound signal. It is designed to operate with 5 V DC and is used to alarm (Svhc-free, 2022). The buzzer sound can be different depending on the type and application. In this project, a buzzer was used to trigger a beep sound if any tracked RFID tag is out of the read range.



**Figure 17: Buzzer (Svhc-free, 2022)**

**(v) Liquid Crystal Display**

A liquid-crystal display (LCD) is an electronic device that uses liquid crystal to display data from electronically optically modulated input devices (Cameron, 2021). In most cases, LCD devices are used as system user interfaces. LCDs have 16 pins, operate at 5 V DC voltage, and are currently available in various sizes in electronic markets. In this project, an mRC2004A, which is a monochromatic LCD with 16\*2 alphanumeric characters, was used to display the information on the state of the system



**Figure 18: Liquid Crystal Display (Cameron, 2021)**

**(vi) Solenoid sensor**

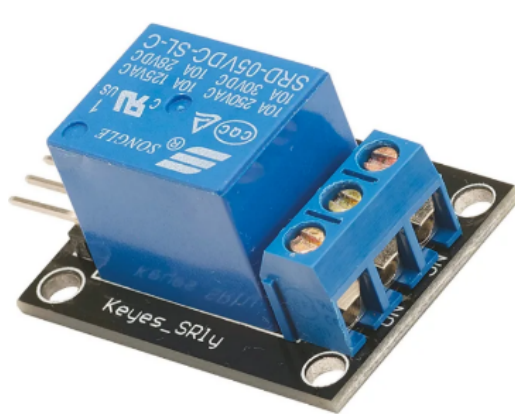
A solenoid lock sensor is a device that detects the presence or absence of a magnetic field in a lock. It is typically used to determine whether a lock is open or closed and can trigger alarms or other security measures if the lock is tampered with or opened without authorisation (Campero *et al.*, 2018). Solenoid lock sensors are commonly used in residential and commercial security systems and access control systems for buildings and vehicles. In this project, the solenoid sensor was used to lock automatically if unauthorised equipment gets out of the computer laboratory and unlock automatically if the equipment is taken to the right place.



**Figure 19: Solenoid Lock Sensor (Campero *et al.*, 2018)**

### (vii) Relay

A relay is an electromagnetic switch that enables a low-voltage circuit to control the operation of a high-voltage circuit. It comprises a coil of wire that creates a magnetic field when an electrical current passes through it, an armature that is attracted to the magnetic field, and a set of contacts that can be opened or closed by the movement of the armature (Hameed *et al.*, 2020). In this project, a relay was used to control the flow of electricity to the solenoid lock sensor, which is responsible for locking or unlocking the door automatically and protecting against overloads and short circuits. When the relay closes the switch, it allows an electrical current to flow through the solenoid sensor, causing it to unlock. Conversely, it locks when the relay opens the switch.



**Figure 20: Single Line Relay (Hameed *et al.*, 2020)**

### (viii) Led

A light-emitting diode (LED) is a semiconductor that emits light as an electric current flows through it. Light is produced when two electronic elements, known as electrons and holes, are combined within a semiconductor material. It has two pins and operates on a 3V DC voltage. (Ziegelberger *et al.*, 2020). The LEDs come in various colours, such as red, green, yellow and blue. In this project, it is used as a system indicator; the lights appear in red only if there is a piece of equipment missing in the laboratory, and the green light indicates that the system operates properly and tracks all the equipment that it was supposed to track.



**Figure 21: Light-emitting diode (Ziegelberger *et al.*, 2020)**

**(ix) Push buttons**

Push buttons are types of switches that are activated when pressed. When a push button is pressed, a spring-loaded mechanism is activated, causing a metal contact to be pressed against another metal contact. This creates an electrical circuit, allowing current to flow through the button and initiate the desired action or function (Gaspar *et al.*, 2019). In this project, push buttons were used to control some functions of the system, such as the start, stop cancel. Some buttons are configured to actuate on a single press, and others on multiple presses.



**Figure 22: Push buttons (Gaspar *et al.*, 2019)**

**(x) Resistors**

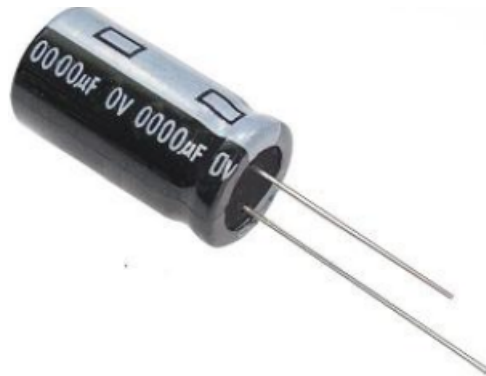
A resistor is an electronic component that resists the flow of electric current through it. It is used to control the flow of electricity in a circuit by reducing the amount of current that flows through it. In this project, resistors of 10 k $\Omega$  were used to limit the amount of current that flows through a circuit by providing resistance, and this helped to prevent the circuit from overheating and damaging components.



**Figure 23: The 10 k $\Omega$  resistors (Langheim, 2018)**

### **(xi) Capacitor**

A capacitor is an electronic component that stores electrical energy in an electric field for later use. In this project, a 1000  $\mu$ F 35 V Radial 105 deg Capacitor was used to smooth out fluctuations in a DC voltage supply by storing charge and releasing it back into the circuit as needed to maintain a stable voltage.



**Figure 24: Capacitor (Langheim, 2018)**

## **3.9.2 Software Requirements and Tools to be Used**

The software requirements for this system comprise backend and frontend development, including the software used to design the schematic circuit and diagram and simulate the developed system

### **(i) Arduino IDE**

The Arduino Integrated Development Environment (IDE) is a software application that provides a variety of tools and features for writing, compiling and uploading code to an

Arduino board for execution (Fezari & Dahoud, 2018). The Arduino IDE is widely used by educators, and professional engineers for prototyping and developing a wide range of electronic projects, from simple interactive devices to complex control systems. This project used Arduino IDE to write and upload the code to the ESP32 microcontroller board.

## **(ii) Proteus**

Proteus is a software tool for simulating electronic circuits. It provides a graphical interface for drawing and testing electronic circuits and includes a library of components and models for simulating a wide range of electronic devices and circuits. Proteus allows users to analyse the performance of circuits under various operating conditions and to test and debug circuits before they are physically implemented (Cai & Tong, 2017).

## **(iii) Kicad**

KiCad is a software suite that is free and open-source, intended for use in Electronic Design Automation (EDA). It is utilised in the design and creation of PCB. With KiCad, we can design schematics for the circuits, create and position footprints for components, and use the built-in auto router to generate PCB layouts. It has the ability to create 3D models of PCBs and generate gerber files, which can be used to manufacture PCBs (Team, 2016).

## **(iv) Backend development**

Backend development refers to developing the server side of a website or web application. This involves creating the code and logic that runs on the server, such as handling requests and responses from the frontend, accessing and manipulating data from a database, and performing other tasks that are not visible to the end user (Singhal, 2022). The Hypertext Preprocessor (PHP), a server-side programming language used to create dynamic and interactive web pages, was used in this project due to its simplicity and flexibility. The PHP code is executed on the server, and the results are displayed in the client's browser. MySQL, an effective open-source relational database management system for storing, organising, and retrieving structured data, was used. MySQL can be used to store data in various formats, including text, numbers, and images, and can be accessed and manipulated using Structured Query Language (SQL) (Matallah *et al.*, 2021). In this project, it was used to store information of users such as login details of the end users and information about laboratory equipment and their status.



### **(v) Frontend development**

Frontend development refers to the development of the user-facing parts of the application. This includes the app's design, layout, and interactivity as experienced by the user through the web browser. HyperText Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript were used to build the visual and interactive elements of the application. HTML was used to structure the content on a web application page, CSS was used to style the content and layout, and JavaScript was used to add interactivity and dynamic behaviour to a web page.

### **(vi) Mbed TLS**

MbedTLS is an open-source C cryptographic library that implements the SSL/TLS protocols and a variety of cryptographic algorithms, including AES encryption. It is created to offer secure communication over the Internet and is widely used in embedded systems, IoT devices, and web servers (Fiterau-Broştean *et al.*, 2020). In this project, MbedTLS was utilised for encrypting and decrypting RFID data using the Advanced Encryption Standard (AES) encryption method. The flowchart diagram depicting the AES encryption and decryption algorithm is illustrated in Fig. 12, while the corresponding code is presented in Appendix 4 B. The data was first encrypted using AES encryption as implemented by MbedTLS and then stored on the RFID tag. To access the data, the RFID reader decrypted it using the same AES encryption algorithm and key used for encryption. This enhances the security of the RFID technology and allows for safe storage and transfer of sensitive information on the RFID tags.

## **3.10 System Testing**

### **3.10.1 Unit Testing**

The unit testing was conducted by testing individual modules and components of both software and hardware with the goal of validating that each unit produced the expected output for a specific input. Each hardware component was tested individually to validate the output. Four key components, namely ESP32, the UHF RFID transmitter and transponders, the solenoid lock sensor, and the buzzer, were tested individually and functioned effectively as intended. Throughout the development of the web application, unit testing was performed on the login and registration process for both users and equipment, the dashboard, and the report generation functionality.

### **3.10.2 Integration Testing**

Integration testing was conducted after each module or component was tested individually in the unit testing phase. This was done to identify any issues that may arise when different modules or components of a system are combined and interact with each other. The integration test was conducted between ESP32, UHF RFID System, and solenoid lock, buzzer and LED. These sensors were combined and interfaced with the ESP32 to observe their input and output functionalities on the control circuit; the devices behaved as intended. The goal was to ensure that the integrated modules function correctly and effectively together as a system.

### **3.10.3 System Validation**

Validation is the process of assessing and testing fundamental requirements to determine whether system specifications are appropriate for use. It is defined as the process of ensuring that specifications are correctly presented and that the required system specifications are met (Kamalrudin & Sidek, 2015). This test was conducted by the end-users to verify the software and hardware requirements.

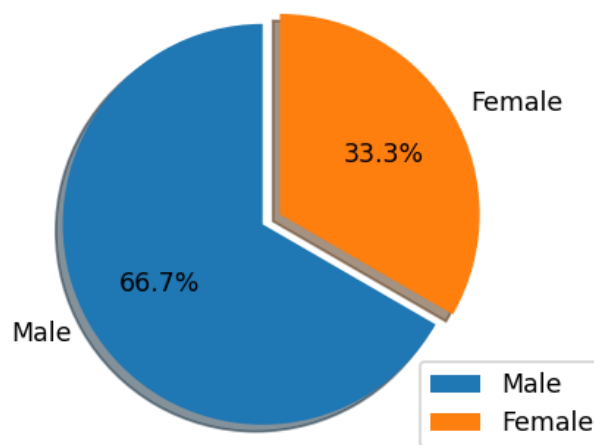
## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Findings from Responders

##### 4.1.1 Demographic Information

A total of 54 responses were gathered from the institution's IT Department staff and lab users. and all the respondents opted to reveal their gender, whereby 36 (66.7%) of the respondents being men, and 18 (33.3%) being women. Figure 25 displays a gender analysis of the respondents. It would have been preferable to have more respondents; however, because the institution has a policy of keeping internal information about equipment management and how information is flown within the IT Department, only the staff members currently employed by the institution were taken into account as respondents. Therefore, the number of female respondents was less than that of male respondents this is because the institution has fewer female employees in the IT department than males.

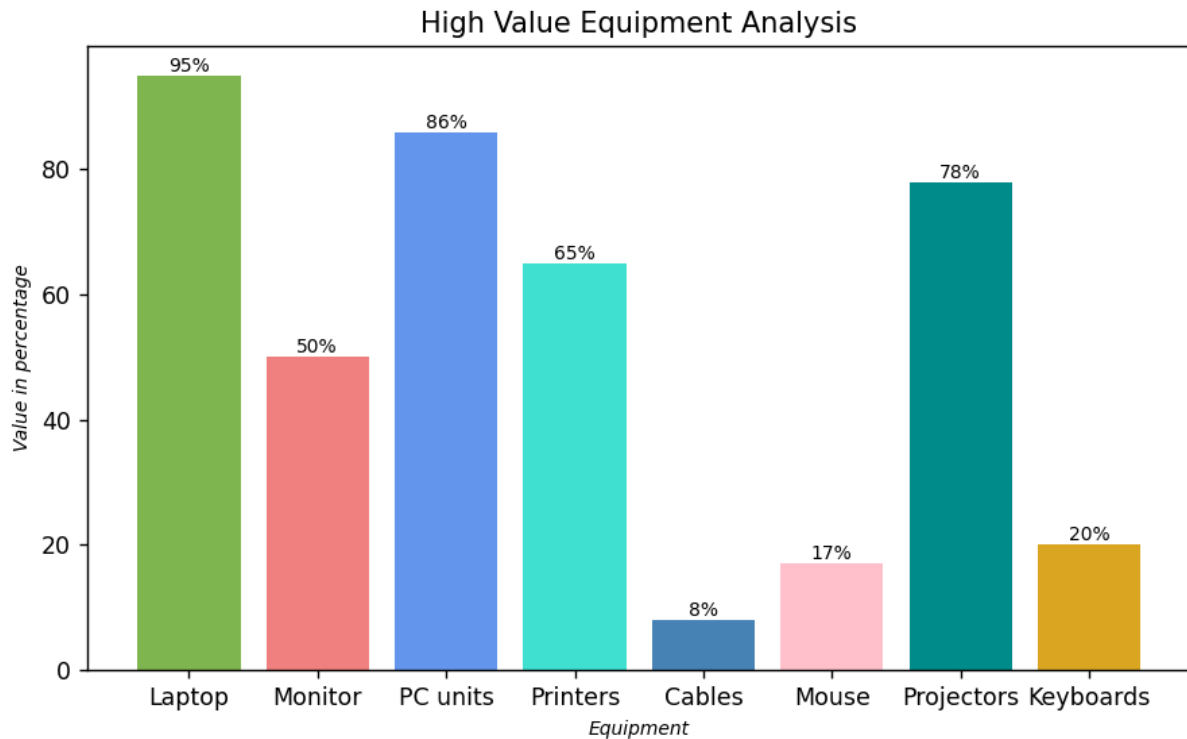


**Figure 25: Gender analysis of respondents**

##### 4.1.2 High-Value Equipment Analysis in the Computer Laboratory of ULT University

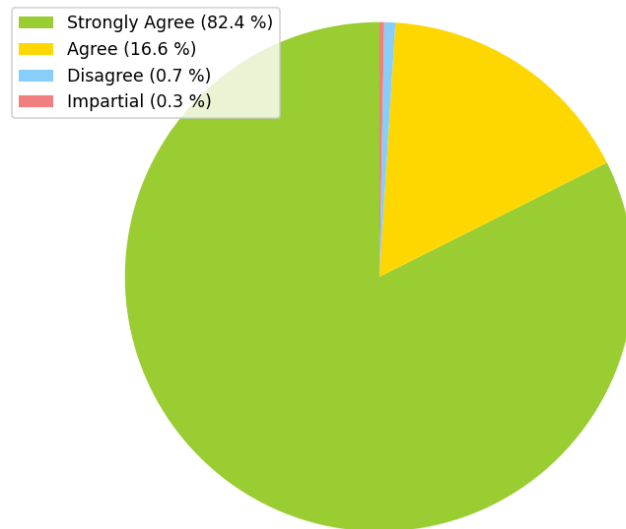
According to the survey findings from data collection, the majority of responders stated that the value of the equipment is primarily based on the cost and that the cost is often associated with the equipment's quality, performance, and durability. The survey results indicated that the more expensive the equipment is, the more value it is perceived to have. Fig 26 reveals the results from the survey whereby laptops were rated as high-value equipment by 95% of value,

followed by PC units with 86%. Projectors with 78%, printers with 65%, monitor with 50%, keyboard with 20%, mouse with 17%, and cables with 8%. The percentage values are obtained from the perceptions of respondents.



**Figure 26: High Value Equipment Analysis**Willingness to adopt an automated system for tracking and managing laboratory equipment

According to the survey results, 82.4% of respondents strongly agreed and believed that an automated system should be adopted to track and manage laboratory equipment, followed by 16.6% of responders who also agreed with the idea. However, 0.7% were indifferent about the idea, and 0.3% of the respondent disagreed; this is seen in Fig. 27.



**Figure 27: Response to the willingness to adopt an automated system for tracking and managing laboratory equipment**Result from requirement analysis

#### 4.1.3 Functional and Non-Functional Requirements

Various information was collected from interviews and focus group discussions. This information was then analysed and used to identify the functional and non-functional requirements of the users. These requirements were then used to guide the design and development of the system. Table 5 displays the result of the functional requirement for the hardware, Table 6 displays functional requirements for web applications, and Table 7 shows the result of the non-functional requirement for the entire system. Functional requirements refer to the essential tasks or actions that a system is required to perform. In comparison, the non-functional requirements define the constraint and qualities that a system could have, such as performance, security, and usability.

**Table 5: Functional requirement for the hardware system**

No.	Requirements
1.	The system should be able to track and identify tags attached to equipment if it is within the reader's range
2.	The system should automatically lock the solenoid if there is unauthorised equipment out of the reading range
3.	The system should unlock automatically if the tracked equipment is returned in the reading range
4.	The system should have the capability to show the system's functioning on an LCD screen
5.	The system should allow the user to navigate to the status of equipment using a button
6.	The system should permit the user to navigate to the previous activity and Use the cancel button
7.	The system should be able to blink a green LED if the system is functioning properly
8.	The system should be able to blink a LED red and sound a buzzer if there an equipment out of the range of the reader or if there is any critical system status

**Table 6: Functional requirements of the web application**

No.	Requirements
1.	The system shall allow for registration, login and logout of the system user. The user's name, email, role and password are required during registration.
2.	The system shall allow the user to edit equipment information. Either registering (adding), or deleting (removing) an equipment record
3.	The system shall provide a Graphical User Interface (GUI) to enable the administrator to : <ul style="list-style-type: none"> <li>(i) Register in the database new RFID-tagged equipment</li> <li>(ii) Check in and out tagged equipment when it is taken out and returned in the laboratory</li> <li>(iii) Check on a dashboard the information regards to tagged equipment reported missing or reported under maintenance</li> <li>(iv) provide event logs of the tagged equipment that is within the range of the reader</li> <li>(v) The system should have the capability to generate a weekly report and allow the user to download a report at any time needed</li> </ul>

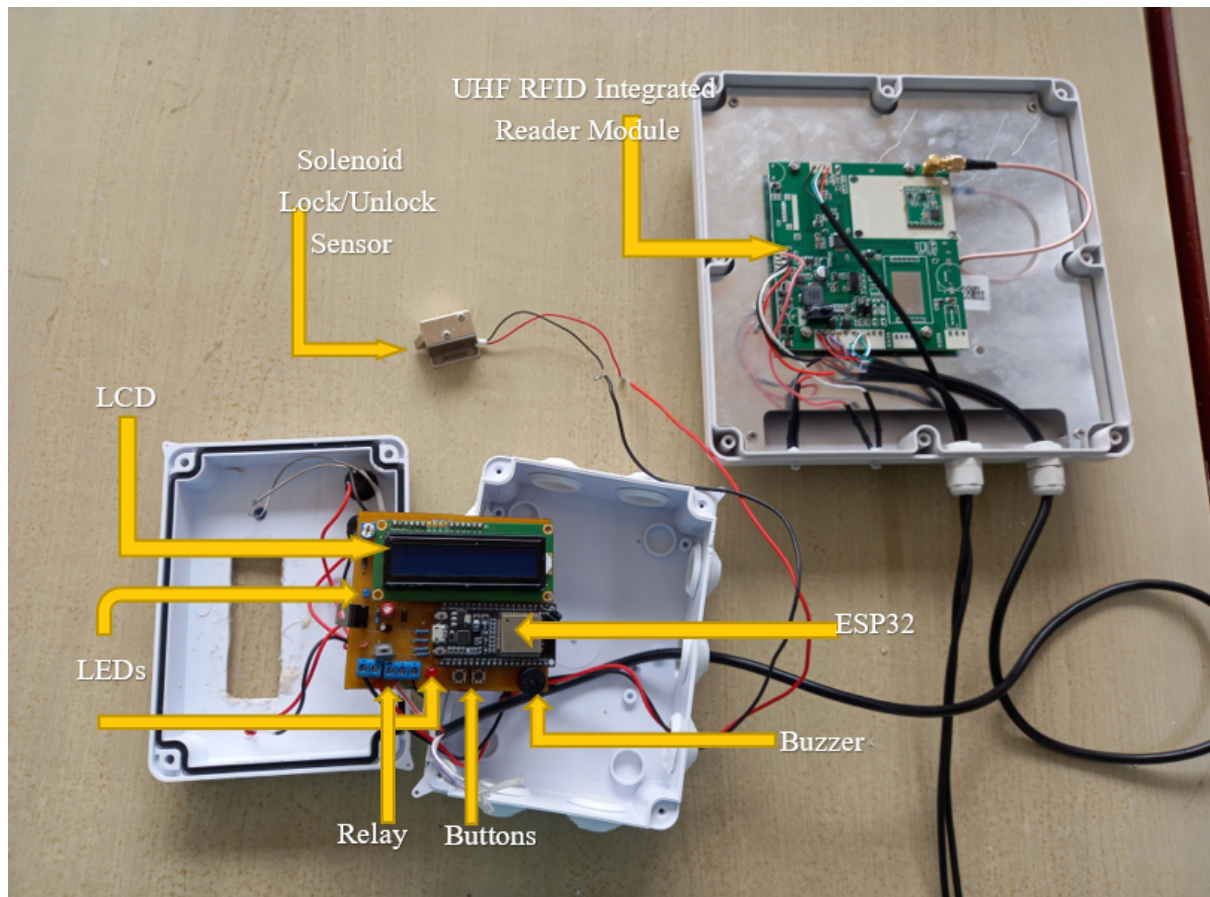
**Table 7: Non functional requirements of the system**

No.	Non Functional Requirements
1.	The system shall be safe to be used in the computer laboratory
2.	Both LCD display and web application shall have a simple, easy-to-use interface.
3.	The system shall provide compatibility with a different version of the operating system
4.	The system shall be highly reliable and available to use and shall operate 24/7
5.	The web application shall be compatible with various devices, browsers and operating system

## **4.2 System Development Results**

### **4.2.1 Results of the Hardware Assembling**

The prototype image, shown in Fig. 28, represents the electronic component assembly after the etching and soldering process of the control PCB Circuit. The system was designed to allow the UHF Integrated RFID reader to capture and process data from the RFID tag attached to the equipment within the range frequency, which subsequently activates the solenoid to lock or unlock accordingly. The system also incorporated a buzzer and LEDs for alarm indication. When the equipment is out of reader range, the buzzer sounds, and the LED blinks red as an indication. Furthermore, a 16\*2 LCD screen is also incorporated to display information about the system's status and operation. The prototype also features buttons to easily control and monitor the system's performance. The overall system is interfaced with the microcontroller ESP32.



**Figure 28: Electronic components assembly etching and soldering process of the PCB control**

#### 4.2.2 Results for UHF RFID Equipment Tagging Process

Figure 29 represents an image of UHF RFID tags attached to different pieces of equipment. And the yellow arrow indicates where the tag is placed. In the process of equipment tagging, some factors were considered. The tags were placed on flat surfaces where they are not affected by other electronic devices, materials or equipment's operation that may interfere with the radio frequency signals.



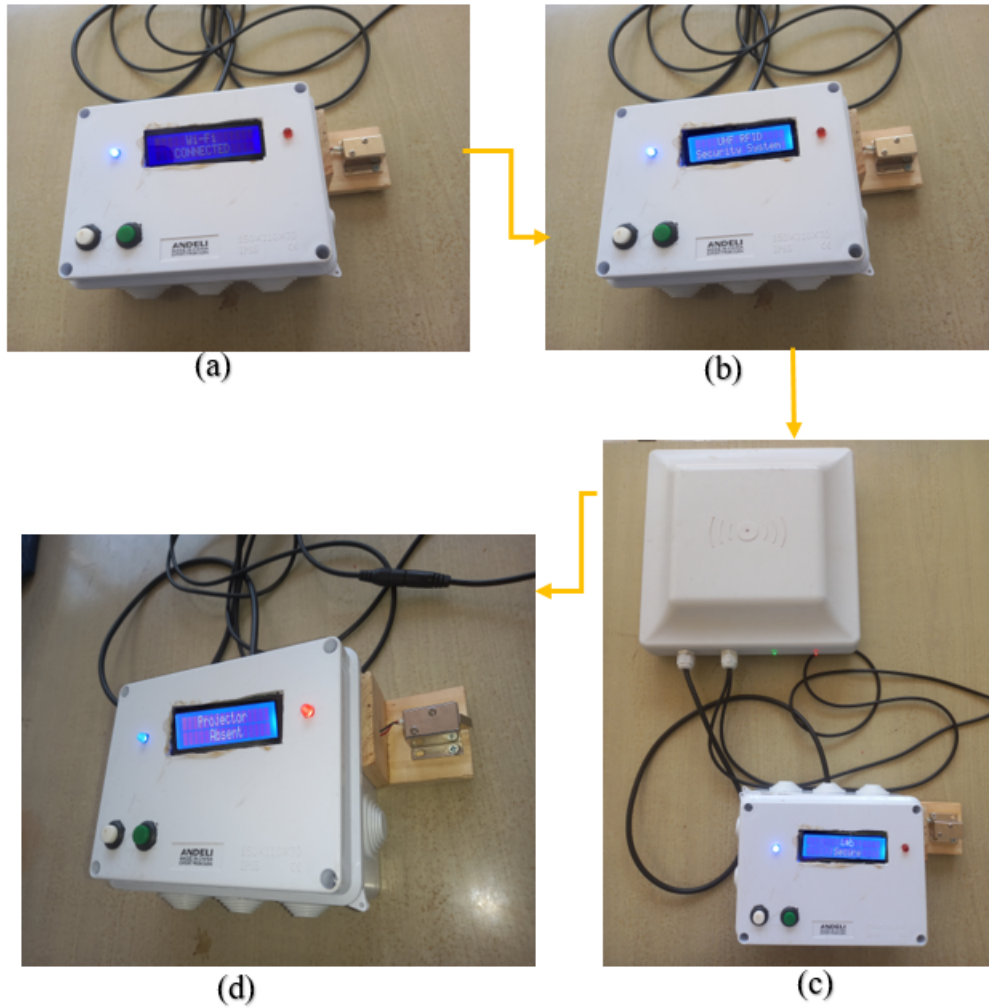


**Figure 29: Equipment tagging**

#### **4.2.3 Results for Overall System Operation**

The operation process starts with searching for a Wi-Fi connection on the network. Figure 30(a) shows that the system has successfully connected to the network. Thereafter, the LCD displays "UHF RFID Security System," as shown in Fig. 30(b) if the connection between the ESP32 microcontroller and the server is established. This ensures that the system can both send data from the ESP32 microcontroller to the server and receive data from the server.

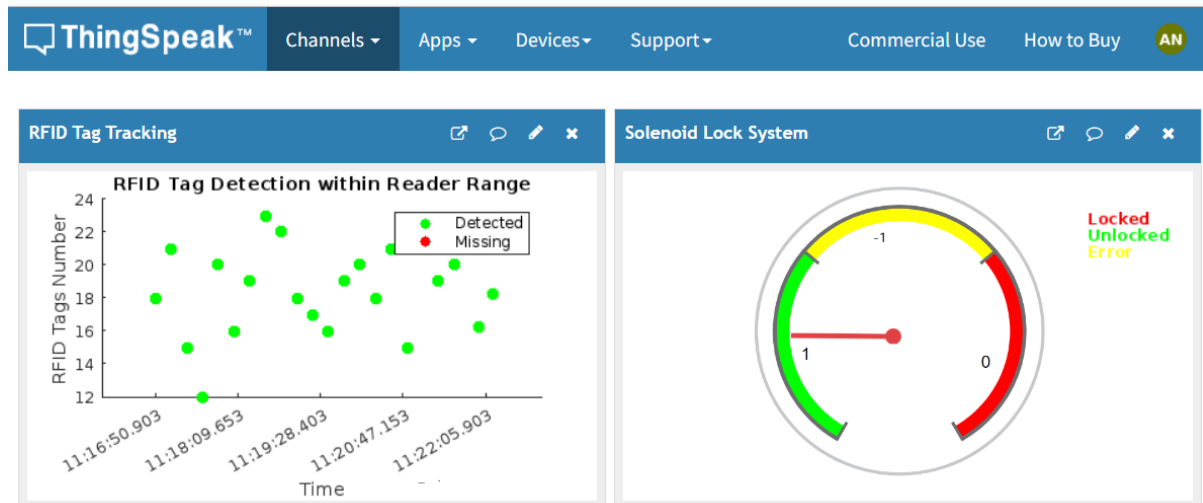
When the connection is established, the system starts reading the tags attached to the equipment and verifying that their identifications match the database. Figure 30(c) shows the system operates properly and that the laboratory equipment is secure. A tag attached to the projector was removed from the reads to check the system's actuation, the solenoid automatically locked, blinking red, sounding the buzzer, and LCD displayed "Project Absent", as shown in Fig. 30(d).



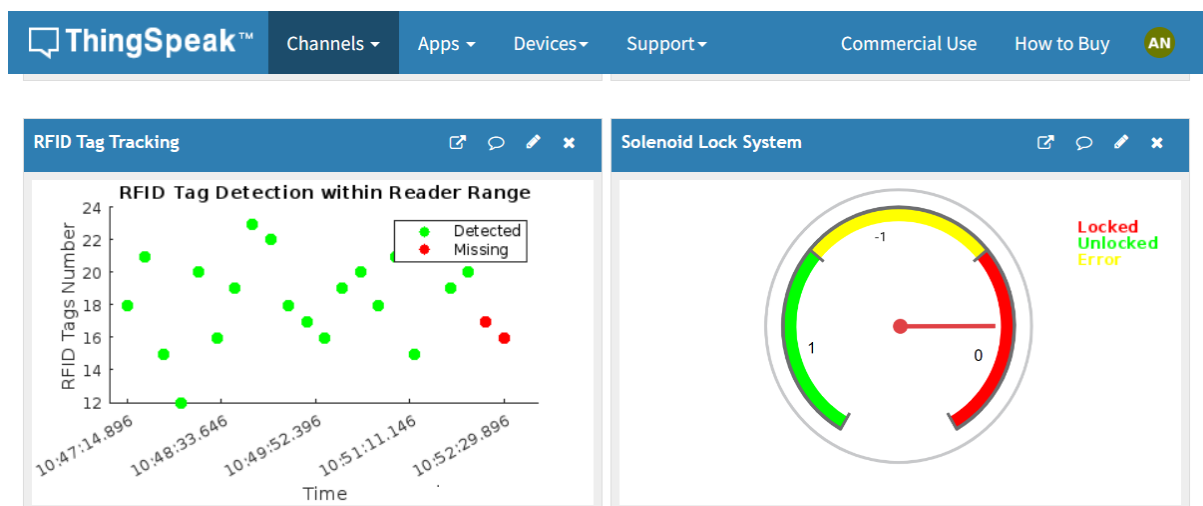
**Figure 30: System Overall Operation**

#### 4.2.4 Results from the ThingSpeak Platform

The hardware sensor results are automatically sent to the ThingSpeak platform to facilitate efficient and organised data management. The scatter plot was utilised to represent the data, where the green dots indicate successfully tracked tags, and the red dots signify missed tags that fall out of the reader's range. Additionally, a gauge chart was also included to visualise the solenoid's status, whether it was locked, unlocked, or had encountered an error. Figure 31 demonstrates that the system successfully tracked all tags within the reader's range. At the particular time, two tags were taken out of the reader's range to visualise the live data. As depicted in Fig. 31, the system was unable to read the tags represented in red colour, and the gauge pointer indicated that the solenoid was locked to prevent the unauthorised removal of items from the laboratory. The use of these visualisation aimed to easily, quickly, and accurately monitor the performance of the system and identify any issues that need to be addressed.



**Figure 31: Visualisation of RFID reader range plot with full tag detection**



**Figure 32: Visualisation of tracked data indicating missed tags within the reader's range**

#### 4.2.5 Web-Based Application System Results

The following figures demonstrate the developed web-based application, including the database, registration, the login page, dashboard panel, and menu board such as equipment states, inventory and report module. This is meant to provide better interaction with users. Only individuals who have registered on the systems can access the Lab Equipment Management System (LEMS).

## (i) Database Design Section

The outcomes of the table database design are shown in Fig. 32. The MySQL Server was utilized to implement the database successfully, and the results were visualized in PhpMyAdmin.

phpMyAdmin

Recent

Favorites

tracking\_system

Type to filter these. Enter to search all

New

aauth\_groups

aauth\_group\_to\_group

aauth\_login\_attempts

aauth\_perms

aauth\_perm\_to\_group

aauth\_perm\_to\_user

aauth\_rms

aauth\_user

aauth\_users

aauth\_user\_to\_group

aauth\_user\_variables

blog

blog\_category

captcha

cc\_options

cc\_session

crud

crud\_custom\_option

crud\_field

crud\_field\_validation

crud\_input\_type

crud\_input\_validation

details

device\_details

equipment

Server: 127.0.0.1 » Database: tracking\_system

Structure

SQL

Search

Query

Export

Import

Operations

Privileges

Routines

Events

More

<input type="checkbox"/>	crud_input_validation	★							37	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	details	★							0	InnoDB	utf8mb4_general_ci	48.0 KiB	-
<input type="checkbox"/>	device_details	★							4	InnoDB	utf8mb4_general_ci	16.0 KiB	-
<input type="checkbox"/>	equipment	★							13	InnoDB	utf8mb4_general_ci	16.0 KiB	-
<input type="checkbox"/>	equip_state	★							6	InnoDB	utf8mb4_general_ci	32.0 KiB	-
<input type="checkbox"/>	form	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	form_custom_attribute	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	form_custom_option	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	form_field	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	form_field_validation	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	keys	★							1	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	laboratory	★							2	InnoDB	utf8mb4_general_ci	16.0 KiB	-
<input type="checkbox"/>	maintenance	★							2	InnoDB	utf8mb4_general_ci	32.0 KiB	-
<input type="checkbox"/>	menu	★							26	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	menu_type	★							2	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	migrations	★							1	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	page	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	page_block_element	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	person	★							5	InnoDB	utf8mb4_general_ci	16.0 KiB	-
<input type="checkbox"/>	rest	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	rest_field	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	rest_field_validation	★							0	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	rest_input_type	★							3	InnoDB	utf8_general_ci	16.0 KiB	-
<input type="checkbox"/>	test	★							2	InnoDB	utf8mb4_general_ci	16.0 KiB	-
	45 tables	Sum							434	InnoDB	utf8mb4_general_ci	784.0 KiB	0 B

Figure 33: Table database design visualization viewed through PhpMyAdmin

## (ii) Registration Part

The process of registering begins upon the successful login of the administrator into the system. The administrator can register various operations, including equipment and their states and maintenance. The administrator can also register personnel to create accounts for system users. A user has to initially log in using the administrator's assigned username and password as shown in Fig. 35. After logging in, he is directed to the appropriate pages based on his roles. Several screenshots of the application's registration section can be seen in Fig. 33 through Fig. 35.

A person must first sign in by entering the username and password assigned by the administrator, as shown in Fig. 34. Once he has logged in, he is redirected to the appropriate web pages in accordance with his designated role.

**LEMS ULT** Admin

MAIN NAVIGATION

- Dashboard
- User management
- Equipment
- Maintenance & Repair
- Inventory
- Reports
- Administration <

**Person** New Person Home > Person > New

**First Name \***   
Input F Name Max Length : 50.

**Last Name \***   
Input L Name Max Length : 50.

**Gender \***   
Input Gender Max Length : 50.

**Position \***   
Input Position Max Length : 50.

**Reg. Number \***   
Input Reg Number Max Length : 20.

**Username \***   
Input Username Max Length : 50.

**Password \***    
Input Password Max Length : 50.

**Figure 34: Personnel registration**

**LEMS ULT** Admin

MAIN NAVIGATION

- Dashboard
- User management
- Equipment
- Maintenance & Repair
- Inventory
- Reports
- Administration <

**Equipment** New Equipment Home > Equipment > New

**Name \***   
Input Name Max Length : 50.

**Model \***   
Input Model Max Length : 50.

**Description \***   
Input Description Max Length : 100.

**Date Of Manufacturing \***

**Figure 35: Equipment registration**

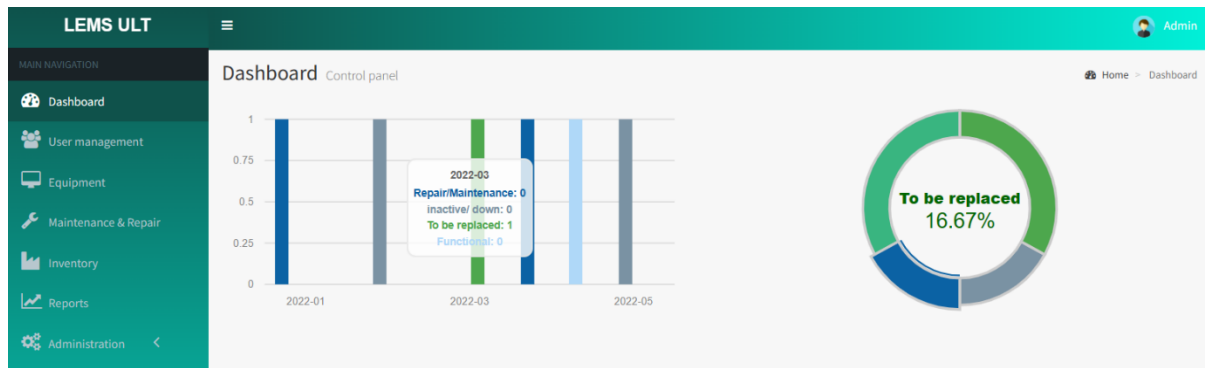
**Figure 36: Maintenance registration**

### (iii) Login page

Figure 36 presents a login page where users are obliged to submit their usernames and password in order to obtain the privileges assigned to them by the administrator. Based on their user permissions, they are directed to a particular webpage.

**Figure 37: Login page**

After signing in, the administrator is able to view details regarding the registered system users and equipment and determine their current status through the dashboard of a web app. As shown in Fig. 37, the dashboard presents the relevant information on the equipment state and the system administrator can access the web application configurations panel and navigate through all the system menus.



**Figure 38: Dashboard of the web application**

#### (iv) Inventory as equipment states

The 'Equip State' page shows a table with 6 items. The columns are Id Equipment, State, Date, and Action. The table lists the following equipment:

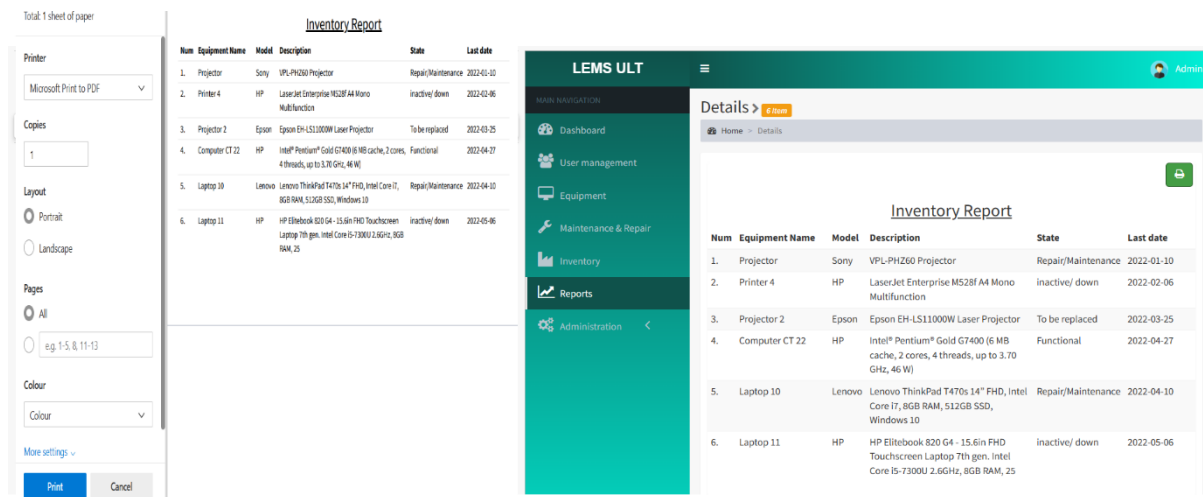
Id Equipment	State	Date	Action
Laptop 11	inactive/ down	2022-05-06	[Icons]
Laptop 10	Repair/Maintenance	2022-04-10	[Icons]
Computer CT 22	Functional	2022-04-27	[Icons]
Projector 2	To be replaced	2022-03-25	[Icons]
Printer 4	inactive/ down	2022-02-06	[Icons]
Projector	Repair/Maintenance	2022-01-10	[Icons]

**Figure 39: Inventory**

#### (v) Report

The report module enables the intended personnel, such as the IT manager or lab assistant, to access, retrieve, and print reports in PDF format about specific information, such as equipment states in the previous month or within the period he would like to know. Figure 39 shows an example of a report printed from a web application.





**Figure 40: Report generation and view of equipment inventory**

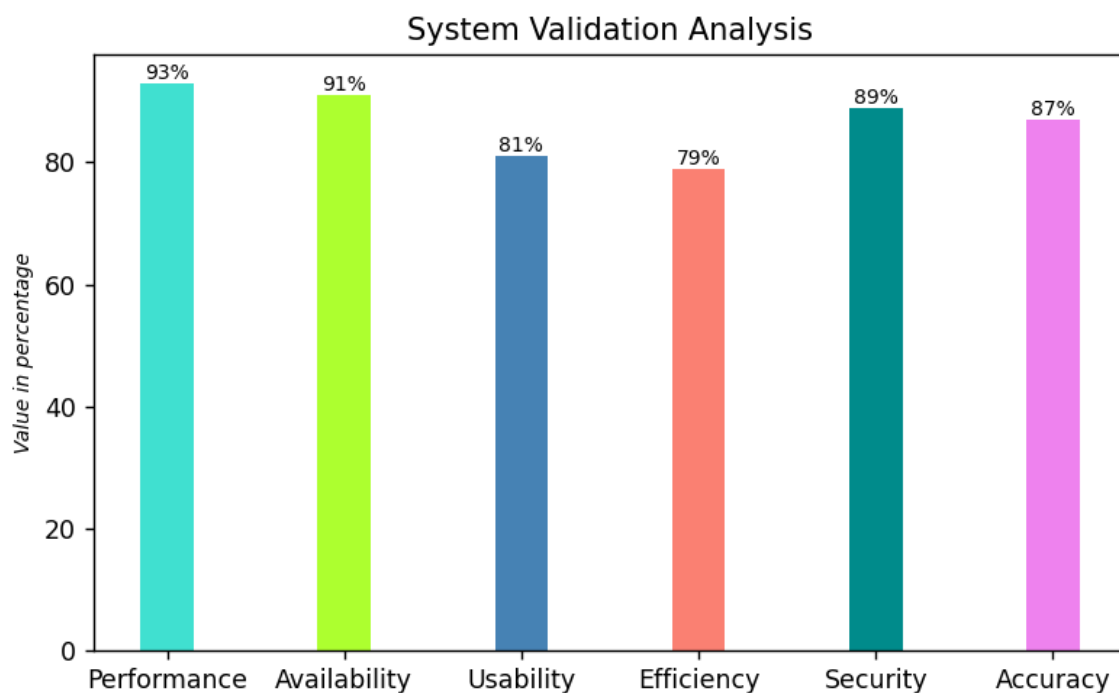
### 4.3 User Acceptance Results

User acceptance refers to the evaluation process to determine if a system or product aligns with the intended users' requirements and expectations and is acceptable for use. The sample question for user acceptance validation is in Appendix 3. During testing phase, 51 participants were involved, including 18 IT experts, 11 lab assistants, 8 lab technicians, and 14 lab users. The sample of 54 respondents was not used in user acceptance testing. Certain participants were excluded based on specific criteria as they did not meet criteria that were necessary for testing the system effectively. Moreover, The majority of participants reported that the system significantly reduced the time required for tasks and improved the accuracy of results, as shown in Table 8. Overall, the system was deemed efficient, user-friendly, and effectively improved workflow processes. A bar graph was used to quickly grasp and visualise the essential information gathered from the user acceptance results in a clear and concise manner as shown in Fig. 40.



**Table 8: User acceptance results**

	Respondents			
	Strongly Agree (%)	Agree (%)	Disagree (%)	Not sure (%)
The RFID tracking system operates in accordance with the requirement	92	8	0	0
The system provides automatic lock/unlock features for security purposes	89	10	1	0
The system is user friendly	85	12	0	3
The system is available for use	96	4	0	0
The web application's interface is well organized	100	0	0	0
The web application allows users to perform equipment management tasks and generate a weekly report	100	0	0	0
Does the developed system produce accurate results?	87	11	2	0

**Figure 41: System validation analysis**

#### 4.4 Discussion

The experiments carried out in the laboratory, and the field demonstrated that RFID technology effectively tracks valuable assets without human intervention. The communication between components was found to be successful, as shown in Fig. 27. Various components, including UHF RFID reader, an LCD display, a buzzer, LEDs, and a solenoid lock/unlock sensor, are interfaced with the microcontroller ESP32 and are all connected to the Printed Circuit Board (PCB). Figure 28 shows the successful equipment tagging process which involved attachment of the UHF RFID tags to lab equipment on flat surfaces where the RFID reader could conveniently read them. The UHF RFID Reader was able to track and identify the UHF RFID tags attached to the lab equipment, providing real-time, automatic control of locking and unlocking a solenoid and displaying the system's current state on an LCD as shown in Fig. 30. The data was also automatically sent to the ThingSpeak cloud for storage and remote visualisation, as seen in Fig 31 and Fig. 32. This provides assistance to the Lab manager in monitoring equipment status and analyzing data remotely without being physically present in the laboratory. The main features of the equipment management system web application are displayed in Figs. 33-39, and user feedback was positive, as shown in Table 8.

The developed system is interactive and provides a secure tracking process based on AES encryption, making it unique compared to existing systems. Eventually, the system's performance, availability, accuracy, efficiency, and effectiveness were confirmed through the observations, results, and evaluations conducted during the system validation as shown in Fig. 40.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

The study aimed at developing an IoT-based equipment tracking system based on UHF RFID Technology for computer laboratories to ensure equipment safety and security, improve inventory management, reduce loss or theft of equipment, and make data-driven decisions about equipment utilisation and maintenance. Therefore, this study presented the analysis and the results from the research carried out in the computer laboratory of ULT university located in Bujumbura, Burundi. The developed IoT-based equipment tracking system effectively addresses existing limitations. It is capable of tracking and identifying RFID tags attached to equipment within the RFID reader's range, securely processing RFID data using ESP32 and a 128-bit AES key for protection. The system also executes tasks and transmits information to the ThingSpeak IoT cloud. Additionally, it features an automatic lock-unlock mechanism for enhanced security. The system is further enhanced by a user-friendly web application for streamlined equipment management.

A test was carried out to determine if RFID Reader is able to track all the labels attached to the equipment within the range of interrogating and updating the database in real-time. The locking system has been tested to determine its capability of automatically locking and unlocking the solenoid and how long the process would take.

The findings indicate that the developed system is practical, user-friendly, dependable, and scalable and would play a role in advancing the IT department of ULT university of the laboratory management system. Aside from reducing the potential of human errors caused by paper-based handling, the system has significantly reduced the amount of time spent on manual tracking processes and improved the efficiency of lab management by allowing the IT manager to easily check the inventory and generate the report at any time he wishes.

## **5.2 Recommendations**

The results of this study suggest that the developed IoT-based tracking system for a computer laboratory is highly recommended for use, particularly by ULT university. This system effectively addresses their current challenges with equipment tracking and management. Furthermore, the system is recommended for use by educational institutions, research organisations, government agencies and businesses with IT departments that have computer labs. IT managers, lab assistants, and lab technicians should be encouraged to use the web application to perform tasks such as registration, updating, and report generation to improve their work processes more efficiently.

Moreover, this study recommends that the decision makers and policy makers establish a clear and smooth roadmap and policies to facilitate the implementation of this system in academic institutions and colleges to support education and teaching and learning.

Finally, future research could concentrate on enhancing the current system by incorporating additional features, such as CCTV cameras and Biometric Systems, to maximize the security of lab equipment. Additionally, implementing a machine learning tool that utilizes algorithms to analyze RFID tag data would enable predicting when an asset is likely to malfunction, thus facilitating proactive maintenance scheduling and recommending equipment maintenance.

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## APPENDICES

### Appendix 1: Internship Offer Letter



Bujumbura, le 07/12/2021

A Mlle NTAFATIRO ALVAREZE

**Objet:** Confirmation de stage

Mademoiselle,

Faisant suite à votre requête du 28/11/2021 de demande de stage de 6 mois au sein de notre institution pour pouvoir faire la recherche en rapport avec votre projet de fin d'étude « **Système de détection d'occupation d'espace en temps réel basé sur l'Internet des objets connectés dans un bâtiment universitaire** », nous avons l'honneur de vous informer que nous marquons notre accord.

Veuillez agréer, Mademoiselle, l'assurance de notre considération distinguée.

Recteur de l'Université du Lac Tanganyika

Prof. NGAYIMPENDA Evariste



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Q. Kigobe, B.P. 5403 Mutanga, Tél/Fax : 22 243645/22 246843

## **Appendix 2: An interview guide for developing an IoT-Based computer Laboratory Equipment Tracking System**

### **Session A: Opening Questions**

1. Would you mind if we conducted this interview in your office? If not, do you have any suggestions for a more comfortable place?
2. Could you introduce yourself and tell us a little about you and your department (lab manager, lab assistant, lab technician, other)
3. How long have you been working in this institution?
4. Before we continue with our interview, do you have any questions for me?

### **Session B: Introductory questions**

#### **(For Lab Manager)**

1. What do you like most about being a computer laboratory manager?
2. How many computer laboratories the institution have?
3. What kind/types of equipment do you have in your computer laboratory
4. What are the valuable equipment among them? And why do you consider them as valuable equipment
5. How much experience do you have managing computer lab equipment?
6. How do you manage inventory of laboratory equipment?
7. Do you have any support digital tools to manage laboratory equipment?
8. What is the most difficult problem you've encountered at workplace in terms of equipment management? And how do you overcome the challenge/problem

#### **(Lab Assistant)**

1. How is your experience of working in this department?
2. What do you like most about being a computer laboratory assistant?
3. What kind/types of equipment do you have in your computer laboratory
4. Among them what are the valuable equipment?
5. Is all lab equipment labelled? How do you distinguish with them from others?
6. How do you track the equipment within the computer laboratory?
7. How much times could the process take?

**(Lab Technician)**

1. How is your experience of working in this department?
2. How do you track the equipment within computer laboratory?
3. Are you allowed to take equipment out the laboratory without permission for technic purpose? If yes, what are the procedure to request permission?
4. How much does it take to get the feedback?
5. How do you register states of equipment for inventory purpose?
6. What are the most challenges of using paper-based process in your domain?
7. How do you inform the lab assistant that an equipment is under maintenance, to be replaced or functional?
8. What are the most challenges of using paper-based process to track equipment?
9. Will it be convenient to develop a system to assist the IT department workers in tracking lab equipment in real-time, managing the equipment, and maintenances, printing reports and other features?
10. Which features of lab equipment management system do you think are helpful to IT department workers

**Session C: Key Questions****Lab Manager**

1. How do you communicate with the lab assistant and the lab technician?
2. What is your method for managing report errors?
3. What is the most difficult problem you've encountered at workplace in terms of equipment management? And how do you overcome the challenge/problem
4. Is a paper-based system bringing challenged to IT department workers in their working environment?

**Lab Assistant**

1. How do you evaluate the states of equipment using the current manual process?
2. How do you communicate with the lab technician regarding the authorization of in and

3. What is the most difficult problem you've encountered at the workplace regarding of equipment tracking?
4. How do you try to overcome these challenges?

#### **Lab Technician**

1. What are the most challenges of using the paper-based process to register equipment states and requesting access equipment?
2. What strategy do you use to overcome the challenge?

#### **Session D: Concluded Question**

1. Do you think an optimal IoT-based Lab High-Value Equipment tracking system for computer laboratory can be used in your Institution?
2. What would be the benefits of adopting an Optimal IoT-based Lab High-Value Equipment tracking system for computer laboratory?
3. Are there any important information that we missed in our discussion today?

### Appendix 3: Sample Questions for User Acceptance Validation

		Respondents			
S/N		Strongly Agree	Agree	Disagree	Not sure
1	Does the RFID tracking process operate in accordance with the requirement?				
2	Does the system provide automatic lock/unlock features for an unauthorised access?				
3	Does the system ensure user-friendliness?				
4	Is the web application's interface well organised?				
5	Does the web application allow users to perform equipment management tasks?				
6	Can the web application generate weekly reports?				
7	Does the developed system produce accurate results?				

## **Appendix 4: Observation Checklist**

### **Observation checklist**

#### **1. Physical Layout:**

Observe the physical layout (size) of the computer laboratory to understand the arrangement of equipment and potential tracking points.

#### **2. Lab Access Control:**

Observe how lab access is managed (e.g., key cards, biometric access) and assess its effectiveness in controlling equipment usage.

#### **3. Labeling and Identification:**

Check if the equipment is already labelled with unique identifiers (e.g., asset tags, QR codes)

#### **4. Record-keeping Process:**

Observe how equipment data is currently recorded (e.g., in a spreadsheet, asset management software) and evaluate the efficiency and accuracy of the process.

#### **5. Maintenance Procedures:**

Observe how maintenance and repair activities are currently logged, including any equipment downtime.

#### **6. Data Input Methods:**

Determine how data is currently entered into the system (e.g., manual entry, barcode scanning) and assess the ease of use and potential for errors.

#### **7. Inventory Assessment:**

Observe the current management process.

List all the lab equipment and devices that need tracking (e.g., computers, monitors, printers, scanners, projectors, etc.).

Note down their individual specifications (make, model, serial number, etc.).



## **Appendix 5: Code used to developed an IoT based computer Laboratory Equipment Tracking System**

### **A. Arduino Sketch for overall system**

```
#include <ThingSpeak.h>
#include <WiFi.h>
#include <LiquidCrystal.h>
#include "Decralation.h"
#include "WiFi_credentials.h"
#include "Functions.h"

void setup() {
  pin_conf();
  Serial.begin(9600);
  Serial2.begin(9600);
  lcd.begin(16, 2);

  WiFi.begin(ssid, password);
  WiFi_connection();
  lcd_print("Wi-Fi", "CONNECTED"); delay(1e3);
  lcd_print("UHF RFID", "Security System");
  ThingSpeak.begin(client);
}

void loop() {
  WiFi_connection();
  for (byte i = 0; i < no_of_cards; i++) {
    Serial.println("Scanning card");
    card_status[i] = scan_card(card[i]);
    lcd_print(card_id[i], card_status[i]);

    if (card_id[i] == warning_card && card_status[i] == "Present") warning = false;
    if (card_status[i] != previous_status[i]) {
      Serial.println("Send a data request");
```

```

    send_request("device_id=" + card_id[i] + "&status=" + card_status[i]);
    previous_status[i] = card_status[i];
    if (card_status[i] == "Absent") {
        warning_card = card_id[i];
        warning = true;
    }
}
}

```

```

if (digitalRead(btn1_pin) == LOW) {
    while(digitalRead(btn1_pin) == LOW)
        lcd_print("Show missing IDs", "DONE");
    digitalWrite(ind_pin, HIGH); delay(2e3);
    while (true) {
        for (byte i = 0; i < no_of_cards; i++) {
            if (card_status[i] == "Absent") {
                lcd_print("Missing ID", card_id[i]);
                delay(1e3);
            }
        }
        if (digitalRead(btn1_pin) == LOW) {
            lcd_print("QUIT", ""); delay(1e3);
            lcd_print("UHF RFID", "Security System");
            break;
        }
    }
    digitalWrite(ind_pin, LOW);
}

```

```

if (digitalRead(btn2_pin) == HIGH) {
    while(digitalRead(btn2_pin) == HIGH)
        lcd_print("Cancel alert", "DONE");
}

```

```

warning = false;
lcd_print("UHF RFID", "Security System");
}

if (warning) {
  for (byte i = 0; i < 3; i++)
    warning_indicator();
} else {
  digitalWrite(lock_pin, HIGH);
}

/*ThingSpeak.setField(2,no_of_cards);
ThingSpeak.setField(3,lock_pin);
ThingSpeak.setField(4,buzzer_pin);
ThingSpeak.setField(6,WiFi.RSSI());

ThingSpeak.writeFields(channel_id,channel_api_key);
delay (15000);*/
}

#define ind_pin 15
#define btn1_pin 0
#define btn2_pin 2
#define lock_pin 4
#define buzzer_pin 23
#define no_of_cards 4
#define scanning_time_limit 5000
#define host "10.30.19.43"
#define port 80
#define url "/cle_ms/lems_web/api/update.php?"

byte rs = 13, en = 14, d4 = 27, d5 = 26, d6 = 25, d7 = 33;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
WiFiClient client;

```

```
boolean warning;
```

```
String previous_status[no_of_cards];
```

```
String card_status[no_of_cards];
```

```
String warning_card;
```

```
String card[no_of_cards] = {
```

```
    "147159141229235",
```

```
    "147159149229235",
```

```
    "147159145229235",
```

```
    "147159153229235"
```

```
    "147159168229235",
```

```
    "147159169229235",
```

```
    "147159180229235",
```

```
    "147159181229235",
```

```
    "147159182229235",
```

```
    "147159186229235",
```

```
    "147159188229235",
```

```
    "147159190229235"
```

```
};
```

```
String card_id[no_of_cards] = {
```

```
    "Projector_3",
```

```
    "Laptop C7 ",
```

```
    "PC Unit",
```

```
    "Printer",
```

```
    "Projector_4",
```

```
    "Projector_7",
```

```
    "Router ",
```

```
    "Switch 7",
```

```
    "Printer 9",
```

```
    "Projector_3",
```

```
    "Laptop C8 ",
```

```
    "Laptop C9",
```

```

        "Laptop C10",

        "PC Unit 2",
        "PC Unit 3",
        "Printer 9",
    };

void pin_conf(){
    pinMode(ind_pin, OUTPUT);
    pinMode(btn1_pin, INPUT);
    pinMode(btn2_pin, INPUT);
    pinMode(lock_pin, OUTPUT);
    pinMode(buzzer_pin, OUTPUT);
}

String scan_card(String card_to_scan){
    byte byte_data;
    String card_no = "";
    unsigned long initial_time = millis();
    boolean is_present = false, in_time = true;

    while(!is_present){
        while (Serial2.available()) {
            byte_data = Serial2.read();
            card_no = card_no + String(byte_data);
        }

        if (card_no.indexOf(card_to_scan) != -1)
            return "Present";

        if(millis() - initial_time >= scanning_time_limit)
            return "Missing";
    }
}

```

```
}  
}
```

```
String cut_string(String typing, byte _length) {  
    typing = typing.substring(0, _length);  
    return typing;  
}
```

```
void lcd_print(String str1, String str2) {  
    lcd.clear();  
    const byte column = 16;  
    if (str1.length() > column) str1 = cut_string(str1, column);  
    if (str2.length() > column) str2 = cut_string(str2, column);  
  
    byte pre_space1 = (column - str1.length()) / 2;  
    byte pre_space2 = (column - str2.length()) / 2;  
  
    lcd.setCursor(pre_space1, 0); lcd.print(str1);  
    lcd.setCursor(pre_space2, 1); lcd.print(str2);  
    delay(500);  
}
```

```
void send_request(String _data){  
    if (!client.connect(host, port)) {  
        Serial.println("Client to server connection fail");  
        //lcd_print("Client to Server", "connection fail");  
        return;  
    }  
}
```

```

Serial.println(String("GET ") + url + _data + " HTTP/1.1\r\n" +
    "Host: " + host + "\r\n" +
    "Connection: close\r\n\r\n");
client.print(String("GET ") + url + _data + " HTTP/1.1\r\n" +
    "Host: " + host + "\r\n" +
    "Connection: close\r\n\r\n");

delay(100);

while (client.available()) {
    String payload = client.readStringUntil('\r');
    Serial.println(payload);
}
}

void WiFi_connection(){
    while(WiFi.status() != WL_CONNECTED){
        lcd_print("Wi-Fi", "Connecting.");
        lcd_print("Wi-Fi", "Connecting..");
    }
}

void warning_indicator(){
    Serial.println("Warning Detected");
    digitalWrite(lock_pin, LOW);
    digitalWrite(ind_pin, HIGH);
    digitalWrite(buzzer_pin, HIGH);
    delay(1e3);
    digitalWrite(ind_pin, LOW);
    digitalWrite(buzzer_pin, LOW);
    delay(1e3);
}

```

## B. C++ code for the AES encryption/decryption algorithm

```
#include "mbedtls/aes.h"
#include <string.h>

// Initialize mbedtls AES context
mbedtls_aes_context aes_ctx;
unsigned char key[16] = {0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6, 0xab, 0xf7,
0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c};
unsigned char iv[16] = {0};

// Encryption function
void aes_encrypt(unsigned char *input, unsigned char *output)
{
    // Set AES key for encryption
    mbedtls_aes_setkey_enc(&aes_ctx, key, 128);

    // Perform initial round
    mbedtls_aes_crypt_ecb(&aes_ctx, MBEDTLS_AES_ENCRYPT, input, output);

    // Perform 9 rounds of AES
    for(int i=1; i<=9; i++)
    {
        // Byte substitution
        for(int j=0; j<16; j++)
        {
            output[j] = s_box[output[j]];
        }

        // Row shifting
        unsigned char temp[16];
        for(int j=0; j<4; j++)
        {
            temp[j*4] = output[j*4];
            temp[j*4+1] = output[(j*4+1+4)%16];
```



```

    temp[j*4+2] = output[(j*4+2+8)%16];
    temp[j*4+3] = output[(j*4+3+12)%16];
}
memcpy(output, temp, 16);

// Column mixing
for(int j=0; j<4; j++)
{
    unsigned char tmp = output[j] ^ output[j+4] ^ output[j+8] ^ output[j+12];
    unsigned char t = output[j];
    output[j] ^= Rcon[i] ^ xtime(output[j]^output[j+1]) ^ tmp;
    output[j+4] ^= xtime(output[j+4]^output[j+5]) ^ tmp;
    output[j+8] ^= xtime(output[j+8]^output[j+9]) ^ tmp;
    output[j+12] ^= xtime(output[j+12]^output[j+13]) ^ tmp;
}
}

// Final round
for(int j=0; j<16; j++)
{
    output[j] = s_box[output[j]];
}
unsigned char temp[16];
for(int j=0; j<4; j++)
{
    temp[j*4] = output[j*4];
    temp[j*4+1] = output[(j*4+13)%16];
    temp[j*4+2] = output[(j*4+10)%16];
    temp[j*4+3] = output[(j*4+7)%16];
}
memcpy(output, temp, 16);
for(int j=0; j<16; j++)
{
    output[j] ^= key[j];
}

```

```

    }
}

// Decryption function
void aes_decrypt(unsigned char *input, unsigned char *output)
{
    // Set AES key for decryption
    mbedtls_aes_setkey_dec(&aes_ctx, key, 128);

    // Perform initial round
    mbedtls_aes_crypt_ecb(&aes_ctx, MBEDTLS_AES_DECRYPT, input, output);

    // for(int i=1; i<=9; i++)
    {
        // Byte substitution
        for(int j=0; j<16; j++)
        {
            output[j] = s_box[output[j]];
        }

        // Row shifting
        unsigned char temp[16];
        for(int j=0; j<4; j++)
        {
            temp[j*4] = output[j*4];
            temp[j*4+1] = output[(j*4+1+4)%16];
            temp[j*4+2] = output[(j*4+2+8)%16];
            temp[j*4+3] = output[(j*4+3+12)%16];
        }
    }
}

```

### C. Code for different components of web application

```
<?php
defined('BASEPATH') OR exit('No direct script access allowed');

/**
 * -----
 * Auth Controller
 * -----
 * For authentication
 */
class Auth extends Admin
{
    public function __construct()
    {
        parent::__construct();
    }

    /**
     * Login user
     */
    public function login()
    {
        if ($this->aauth->is_loggedin()) {
            redirect('administrator/dashboard','refresh');
        }
        $data = [];
        $this->config->load('site');

        $this->form_validation->set_rules('username', 'Username', 'trim|required');
        $this->form_validation->set_rules('password', 'Password', 'trim|required');

        if ($this->form_validation->run()) {
            if ($this->aauth->login($this->input->post('username'), $this->input->post('password'),
$this->input->post('remember'))) {
                redirect('/administrator/dashboard','refresh');
            } else {
                $data['error'] = $this->aauth->print_errors(TRUE);
            }
        } else {
            $data['error'] = validation_errors();
        }
        $this->template->build('backend/standart/administrator/login', $data);
    }

    /**
     * Register user member
     */
    public function register()
    {
        $data = [];

        $this->form_validation->set_rules('username', 'Username',
'trim|required|is_unique[aauth_users.username]');
        $this->form_validation->set_rules('password', 'Password', 'trim|required|min_length[5]');
        $this->form_validation->set_rules('full_name', 'Full Name', 'trim|required');
        $this->form_validation->set_rules('email', 'Email',
'trim|required|valid_email|is_unique[aauth_users.email]');
        $this->form_validation->set_rules('agree', 'Agree', 'trim|required');
        $this->form_validation->set_rules('captcha', 'Captcha',
'trim|required|callback_valid_captcha');

        $this->form_validation->set_message('is_unique', 'User already used');

        if ($this->form_validation->run()) {
            $save_data = [
                'full_name' => $this->input->post('full_name')
            ];
        }
    }
}
```

```

        $save_user = $this->aauth->create_user($this->input->post('email'), $this->input->post('password'), $this->input->post('username'), $save_data);

        if ($save_user) {
            set_message('Your account sucessfully created');
            $this->aauth->add_member($save_user, 4);
            redirect('administrator/login', 'refresh');
        } else {
            $data['error'] = $this->aauth->print_errors();
        }
    } else {
        $data['error'] = validation_errors();
    }

    $this->template->build('backend/standart/administrator/register_member', $data);
}

/**
 * User forgot password
 *
 * @var String $id
 */
public function forgot_password()
{
    $data = [];

    $this->form_validation->set_rules('email', 'Email',
'trim|required|valid_email|is_unique[aauth_users.email]');
    $this->form_validation->set_rules('captcha', 'Captcha',
'trim|required|callback_valid_captcha');

    $this->form_validation->set_message('is_unique', 'User already used');

    if ($this->form_validation->run()) {
        //custom your action
        $reset = $this->aauth->remind_password($this->input->post('email'));
        if ($reset) {
            set_message('Your password reset link send to your mail');
        } else {
            set_message('Failed to send password reminder', 'danger');
        }
        redirect('administrator/login', 'refresh');
    } else {
        $data['error'] = validation_errors();
    }

    $this->template->build('backend/standart/administrator/forgot_password', $data);
}

/**
 * User session logout
 *
 */
public function logout()
{
    $this->aauth->logout();
    redirect('/');
}
}

/* End of file Auth.php */
/* Location: ./application/controllers/administrator/Auth.php */

```

```

<?php
defined('BASEPATH') OR exit('No direct script access allowed');

class Model_equipment extends MY_Model {

    private $primary_key    = 'id_equipment';
    private $table_name     = 'equipment';
    private $field_search   = ['name', 'model', 'description', 'date_manufacturing'];
}

```

```

public function __construct()
{
    $config = array(
        'primary_key' => $this->primary_key,
        'table_name'   => $this->table_name,
        'field_search' => $this->field_search,
    );

    parent::__construct($config);
}

public function count_all($q = null, $field = null)
{
    $iterasi = 1;
    $num = count($this->field_search);
    $where = NULL;
    $q = $this->scurity($q);
    $field = $this->scurity($field);

    if (empty($field)) {
        foreach ($this->field_search as $field) {
            if ($iterasi == 1) {
                $where .= "equipment.".$field . " LIKE '%" . $q . "%' ";
            } else {
                $where .= "OR " . "equipment.".$field . " LIKE '%" . $q . "%' ";
            }
            $iterasi++;
        }

        $where = '('.$where.')';
    } else {
        $where .= "(" . "equipment.".$field . " LIKE '%" . $q . "%' )";
    }

    $this->join_avaiable()->filter_avaiable();
    $this->db->where($where);
    $query = $this->db->get($this->table_name);

    return $query->num_rows();
}

public function get($q = null, $field = null, $limit = 0, $offset = 0, $select_field = [])
{
    $iterasi = 1;
    $num = count($this->field_search);
    $where = NULL;
    $q = $this->scurity($q);
    $field = $this->scurity($field);

    if (empty($field)) {
        foreach ($this->field_search as $field) {
            if ($iterasi == 1) {
                $where .= "equipment.".$field . " LIKE '%" . $q . "%' ";
            } else {
                $where .= "OR " . "equipment.".$field . " LIKE '%" . $q . "%' ";
            }
            $iterasi++;
        }

        $where = '('.$where.')';
    } else {
        $where .= "(" . "equipment.".$field . " LIKE '%" . $q . "%' )";
    }

    if (is_array($select_field) AND count($select_field)) {
        $this->db->select($select_field);
    }

    $this->join_avaiable()->filter_avaiable();
    $this->db->where($where);
    $this->db->limit($limit, $offset);
    $this->db->order_by('equipment.'.$this->primary_key, "DESC");
    $query = $this->db->get($this->table_name);
}

```

```

        return $query->result();
    }

    public function join_avaiable() {

        return $this;
    }

    public function filter_avaiable() {

        return $this;
    }
}

/* End of file Model_equipment.php */
/* Location: ./application/models/Model_equipment.php */

```

```

<?php
defined('BASEPATH') OR exit('No direct script access allowed');

/**
 *| -----
 *| Dashboard Controller
 *| -----
 *| For see your board
 *|
 */
class Dashboard extends Admin
{

    public function __construct()
    {
        parent::__construct();
        $this->load->model('model_details');
    }

    public function index()
    {
        if (!$this->aauth->is_allowed('dashboard')) {
            redirect('/', 'refresh');
        }

        $firstChartData = " { year: '2008', value: 20 },
        { year: '2009', value: 10 },
        { year: '2010', value: 5 },
        { year: '2011', value: 5 },
        { year: '2012', value: 20 }";

        $data = [
            "test" => $firstChartData
        ];
        $this->render('backend/standart/dashboard', $data);
    }

    public function getDataFromBd() {

        $data_maintenance = $this->model_details->getUserDetails([]);
        $newDataMaintenance = array();
        $newDataEquipment = array();
        $newDataMaintenanceDetails = array();

        $dataEquipments = $this->db->query("
        SELECT state, COUNT(*) appear FROM equipment, equip_state WHERE
        id_equipment_equip_state=id_equipment GROUP BY state")->result();

        $dataEquipmentsDetails = $this->db->query("SELECT state, COUNT(*) appear,date FROM equipment,
        equip_state WHERE
        id_equipment_equip_state=id_equipment
        GROUP BY
        CAST(YEAR(date) AS VARCHAR(4)) + '-' + right('00' + CAST(MONTH(date) AS VARCHAR(2)), 2);")-
        >result();
    }
}

```

```

$nombreGot = $this->db->query("
SELECT COUNT(*) totalGet FROM equipment, equip_state WHERE
id_equipement_equip_state=id_equipement ")>row()->totalGet;

if ($nombreGot <= 0) {
    $nombreGot = 1;
}

foreach ($dataEquipments as $value) {
    $newDataEquipment[] = [
        "value" => number_format((float)$value->appear/$nombreGot*100,2),
        "label" => $value->state,
    ];
}

foreach ($data_maintenance as $value) {
    $newDataMaintenance[] = [
        "equipement" => (int)$value->id_equipement_maintenance,
        "date" => $value->date_maintenance,
    ];
}

foreach ($dataEquipmentsDetails as $value) {

    $dateGotten = $value->date;
    $subject = explode("-", $dateGotten);

    $getOndate = $this->db->query("SELECT state,date
FROM equipment, equip_state WHERE
id_equipement_equip_state=id_equipement AND
date LIKE '". $subject[0]."-". $subject[1]."%' ");

    if($getOndate->num_rows()){
        $repairMaint = 0;
        $inactiveDown = 0;
        $toBeReplaced = 0;
        $function = 0;

        foreach($getOndate->result() as $resultonDate){

            if($resultonDate->state == "Repair/Maintenance"){
                $repairMaint += 1;
            }
            if($resultonDate->state == "inactive/ down"){
                $inactiveDown += 1;
            }
            if($resultonDate->state == "To be replaced"){
                $toBeReplaced += 1;
            }
            if($resultonDate->state == "Functional"){
                $function += 1;
            }
        }

        $newDataMaintenanceDetails[] = ["date" => $subject[0]."-". $subject[1],
        "Repair/Maintenance" => $repairMaint, "inactive/ down"=> $inactiveDown,
        "To be replaced"=> $toBeReplaced, "Functional"=> $function];
        // print_r($newDataMaintenanceDetails);
    }

    $recordMaintainanceDetails = array();
    $newMaintenanceDetailsData = array();
    foreach(array_reverse($newDataMaintenanceDetails) as $key=>$value){
        if(!in_array($value['date'], $newMaintenanceDetailsData)){
            $newMaintenanceDetailsData[] = $value['date'];
            $recordMaintainanceDetails[] = $value;
        }
    }
    // print_r($recordMaintainanceDetails);
}

}

$dataSend['dataMaintenance'] = $newDataMaintenance;

```

```

        $dataSend['dataEquipment'] = $newDataEquipment;
        $dataSend['newDataMaintenanceDetails'] = array_reverse($recordMaintenanceDetails);

        echo json_encode($dataSend);
    }

    public function chart()
    {
        if (!$this->aauth->is_allowed('dashboard')) {
            redirect('/', 'refresh');
        }

        $data = [];
        $this->render('backend/standart/chart', $data);
    }
}

/* End of file Dashboard.php */
/* Location: ./application/controllers/administrator/Dashboard.php */

```

```

<?php
defined('BASEPATH') OR exit('No direct script access allowed');

class Model_maintenance extends MY_Model {

    private $primary_key    = 'id_maintenance';
    private $table_name     = 'maintenance';
    private $field_search   = ['id_equipment_maintenance', 'description_maintenance',
'date_maintenance'];

    public function __construct()
    {
        $config = array(
            'primary_key'    => $this->primary_key,
            'table_name'     => $this->table_name,
            'field_search'   => $this->field_search,
        );

        parent::__construct($config);
    }

    public function count_all($q = null, $field = null)
    {
        $iterasi = 1;
        $num = count($this->field_search);
        $where = NULL;
        $q = $this->scurity($q);
        $field = $this->scurity($field);

        if (empty($field)) {
            foreach ($this->field_search as $field) {
                if ($iterasi == 1) {
                    $where .= " maintenance.".$field . " LIKE '%" . $q . "%' OR equipment.name LIKE
 '%" . $q . "%' ";
                } else {
                    $where .= " OR " . " maintenance.".$field . " LIKE '%" . $q . "%' ";
                }
                $iterasi++;
            }

            $where = '('.$where.')';
        } else {
            $where .= "(" . " maintenance.".$field . " LIKE '%" . $q . "%' )";
        }

        $this->join_avaiable()->filter_avaiable();
        $this->db->where($where);
        $query = $this->db->get($this->table_name);

        return $query->num_rows();
    }
}

```



```

public function get($q = null, $field = null, $limit = 0, $offset = 0, $select_field = [])
{
    $iterasi = 1;
    $num = count($this->field_search);
    $where = NULL;
    $q = $this->scurity($q);
    $field = $this->scurity($field);

    if (empty($field)) {
        foreach ($this->field_search as $field) {
            if ($iterasi == 1) {
                $where .= " maintenance.".$field . " LIKE '%" . $q . "%' OR equipment.name LIKE
 '%" . $q . "%' ";
            } else {
                $where .= " OR " . "maintenance.".$field . " LIKE '%" . $q . "%' ";
            }
            $iterasi++;
        }

        $where = '('.$where.')';
    } else {
        $where .= "(" . " maintenance.".$field . " LIKE '%" . $q . "%' )";
    }

    if (is_array($select_field) AND count($select_field)) {
        $this->db->select($select_field);
    }

    $this->join_avaiable()->filter_avaiable();
    $this->db->where($where);
    $this->db->limit($limit, $offset);
    $this->db->order_by('maintenance.'.$this->primary_key, "DESC");
    $query = $this->db->get($this->table_name);

    return $query->result();
}

public function join_avaiable() {
    $this->db->join('equipment', 'equipment.id_equipment=maintenance.id_equipment_maintenance',
'LEFT');
    return $this;
}

public function filter_avaiable() {
    return $this;
}
}

/* End of file Model_maintenance.php */
/* Location: ./application/models/Model_maintenance.php */

```

## Appendix 5: Poster Presentation

