

CHAPTER 3 – RESEARCH METHODS

This chapter focuses on describing the methods to achieve the objectives of the thesis project. Starting from the concept of design, design justifications, components of design, and performance tests. Every aspect of this project will be discussed here from the mechatronics point of view.

3.1 Research Workflow

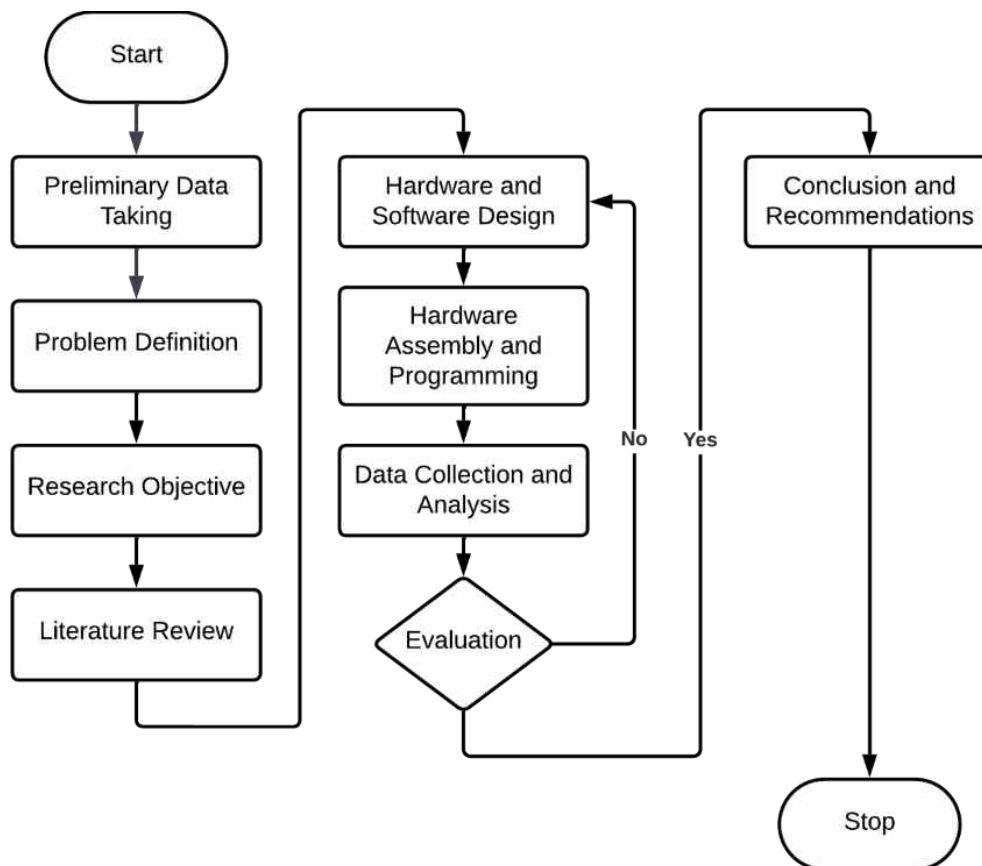


Figure 3.1 Research Workflow

The Figure 3.1 above shows the research workflow implemented during the research. The research started by determining the problem definition that want to be solved by the research. The problems defined then are converted into research objectives. Based on the defined research problems and objectives, a literature review then being done to find the best method to solve the problem and fulfill the objectives. Based on the

literature review results, the hardware and software design being done based on the most suitable method found in the literature review. The design up to the evaluation phase could be repeated or adjusted until the research objectives are fulfilled. Only until then, the research conclusions and recommendations could be concluded and the research ended.

3.2 Root Cause Analysis

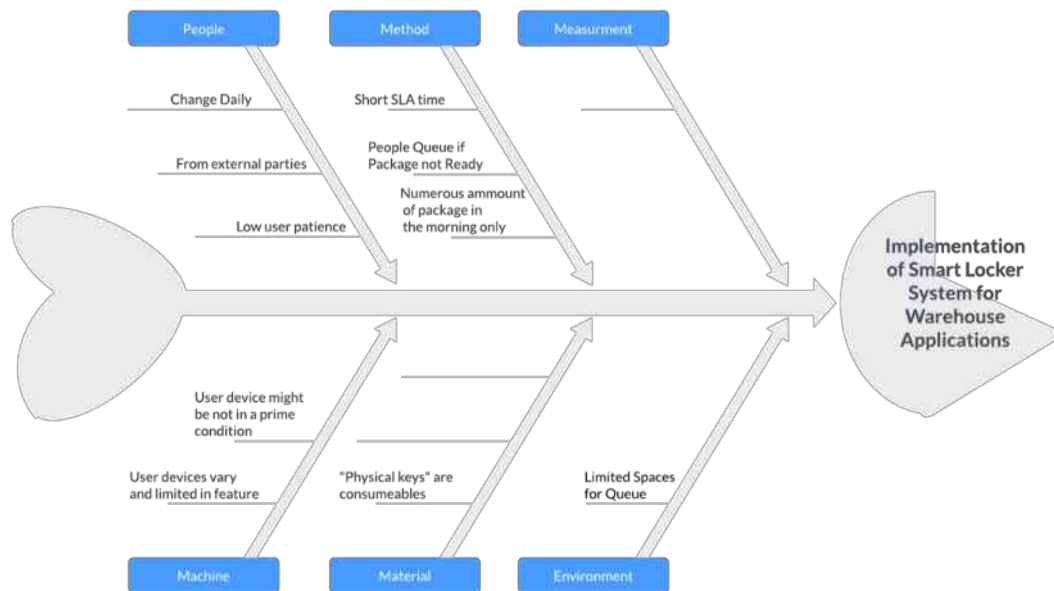


Figure 3.2 Fish Bone Diagram of the Implementation of Smart Locker System to Reduce Queue and Waiting Time in PT. XYZ Warehouse

The Figure 3.2 above shows the fishbone diagram showing the root cause analysis of the implementation of a smart locker system to reduce queues in PT. XYZ warehouse area is the main objective of this research.

3.2.1 People

From the people's perspective, the user of the smart locker system changes daily due to all of the users coming from external parties outside PT. XYZ and all users have their time limit to fulfil the delivery resulting in users' low patience. All users want to get their package as soon as possible making it impossible for PT. XYZ to hand over the package based on the package availability. The people factor conditions make the smart locker solution with user-related data not suitable to be implemented.

3.2.2 Method

From the method point of view, the short SLA time and reduced queue act as strong factors for the implementation of simultaneous user access capabilities. By having simultaneous user access capabilities, more users could do the handover process than before resulting in shorter handover time and queueing time. The digitalization of the queueing system also could reduce the number of occurrences where the user is at the top of the queue while his/her package is not ready yet resulting in longer handover processing time and longer queue. Having a dynamically set active lockers also benefices PT. XYZ warehouse due to the behaviour of the orders that only peaks up at early morning. Compared to use human workers, using a smart locker system is more efficient from the economic point of view.

3.2.3 Machine

From the machine point of view, the solutions offered for PT. XYZ has to take into consideration of the users' devices' availability. The users mostly come from the lower economic class thus, most of them might not have the latest device with the latest technology. Due to the users' background working in an outdoor environment almost all day, the users' devices also might not be in prime condition. The screen might have some cracks or the camera slightly blurry.

3.2.4 Material

Due to the rapid changes of the users, no physical asset from PT. XYZ as the locker service provider should be kept by the users to reduce consumables costs. Making the user keep physical asset from the service provider also add the complexity of the solutions offered due to the need for a physical asset handover process and physical asset maintenance handling.

3.2.5 Environment

From the environmental point of view, the area in PT. XYZ warehouses is limited for both the queue and the packages stack. Due to space limitations, the circulation of packages and users' queues should flow as fast as possible so that the packages are not piling making them harder to handle.

3.3 Component of Design

3.3.1 Overview

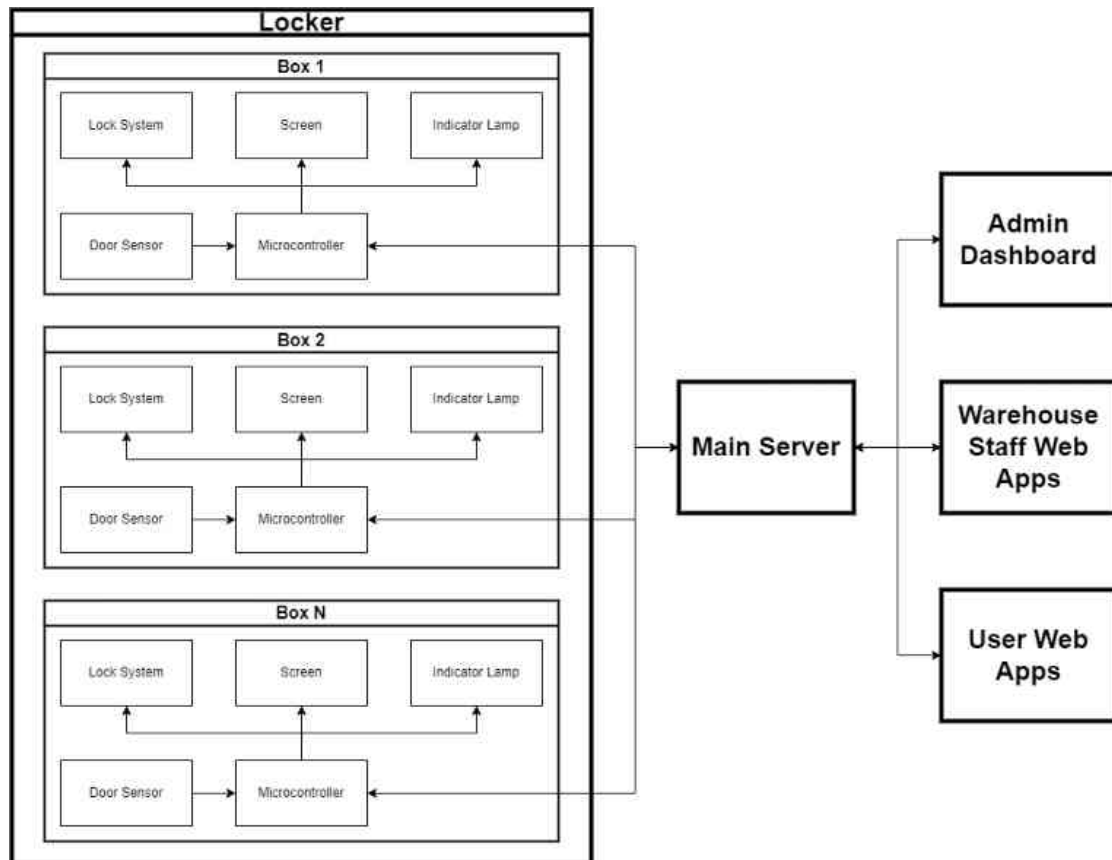


Figure 3.3 System Design Overview

The Figure 3.3 above shows the overall system design overview of the smart locker system. The locker consists of multiple number of boxes that have their own microcontrollers to be able to serve multiple users at a time and make the system modular. In case of microcontroller's failure, only 1 box will be affected and the other still operates normally. All of the microcontrollers will communicate directly to the main server. The main server then also serves information for three different applications which are:

1. Admin dashboard for overall system monitoring by admin
2. Warehouse staff web apps as an interface for warehouse workers to give information to the smart locker system which package is loaded to a box
3. User web apps as an interface for users to get information of where their packages located and claim their packages

In the ideal situation, the main server will be placed in the cloud. Putting it in the cloud will ensure that the message brokers zero downtime and easily accessible web apps for every parties. However, this research scope is limited to the development of the smart locker system and a minimum working prototype of the main server and user web apps in a local setup.

3.3.2 Simulation

The simulation was done by simulating the average processing time, initial couriers arrived before the opening time, and couriers' arrival rate in one of the busiest days of PT. XYZ warehouses. The simulation was made by using a simple python script counting the number of queues together with the waiting time of each person

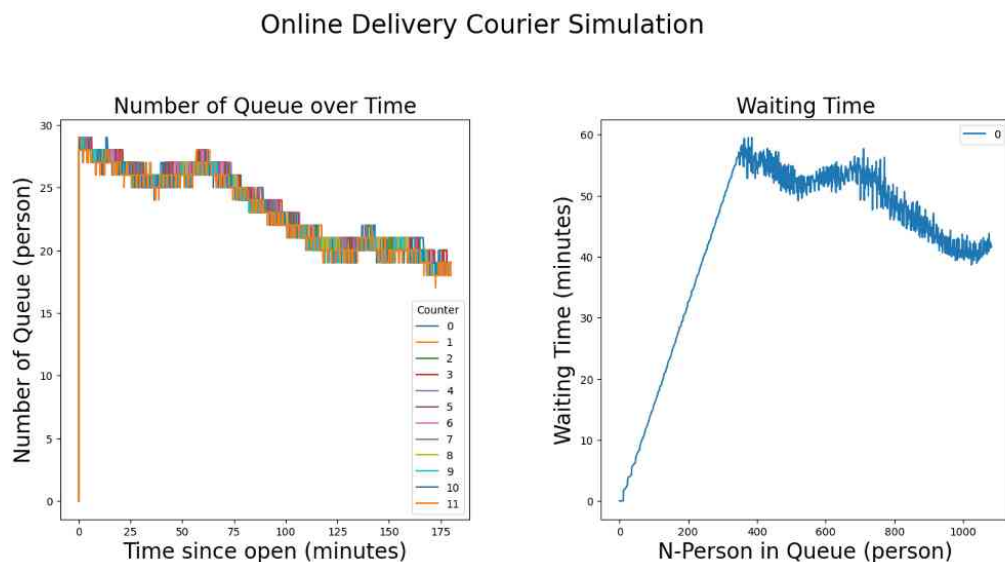


Figure 3.4 Online Delivery Courier Handover Simulation with Existing Conditions

The Figure 3.4 above shows the simulation result of current situation in PT. XYZ warehouse handover area. Where the initial number of couriers coming is set to be 350-person, average arrival time 5 person per minutes, number of counters of 12, in total 7000 package to be hand overed, and average processing time of 2 minutes. Based on the left side of the Figure 3.4 that shows the number of queues in the first 180 minutes since open reaches around twenty-nine in the morning for majority of the handover counters. Furthermore, the right side of the Figure 3.4 shows the waiting time for each

person where the peak happened at around 300th person in the queue of around 60 minutes waiting time not including the 2 minutes processing. Clearly the 60 minutes waiting time is over from the allocated time by PT. XYZ warehouse management team of 5 minutes waiting time in the handover process as stated in part 2.1.1.

In order to optimize the handover process to achieve the maximum 5 minutes handover time since arrival to receiving the package, the number of smart locker box needs to be calculated. With an assumption that the processing time is reduced to 1 minutes by the implementation of the smart locker system where 30 seconds is allocated for warehouse team reloading the locker while couriers finding the assigned locker and the rest 30 seconds is for the courier to open the door. The number of boxes could be calculated by using:

$$n = \frac{p \cdot t}{T - t} \quad (3.1)$$

Where:

- n = Number of boxes needed (box)
- p = Initial user (person)
- t = Processing time (minutes)
- T = Maximum waiting time (minutes)

Inserting value to equation 1 of:

- p = 350 persons
- t = 1 minutes
- T = 5 minutes

The number of boxes needed (n) could be acquired as 88 boxes (rounded up from 87.5).

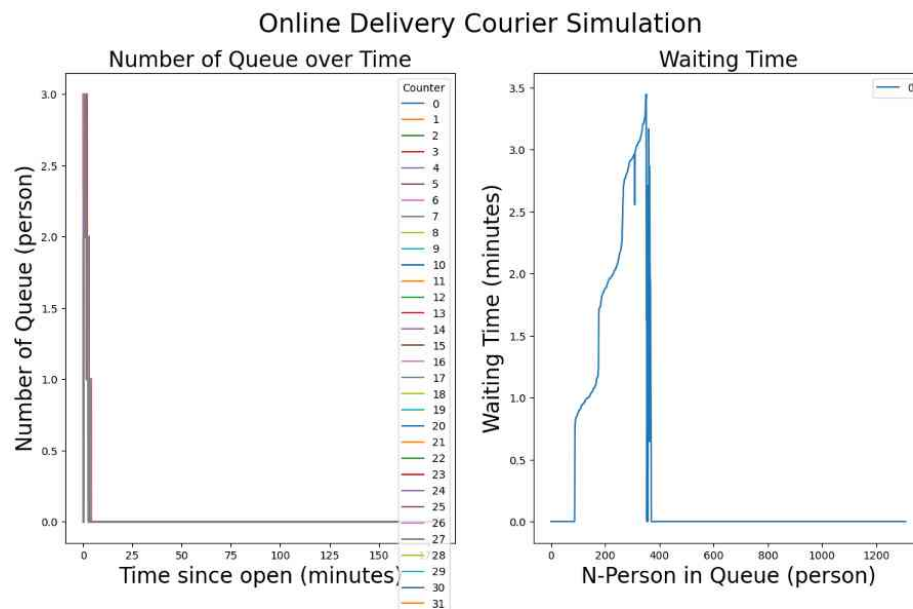


Figure 3.5 Online Delivery Courier Handover Process Simulation with Smart locker System

The Figure 3.5 above shows the online delivery courier handover process simulation with the same algorithm as being used previously in Figure 3.4 with the adjusted parameters of 1 minute's processing time and 88 box or counter. As could be clearly seen in the left part of Figure 3.5, the queue only occurs in the beginning only with maximum number of queues of 4 person, significantly drop from 29 person. Furthermore, the right side of the Figure 3.5 shows that the maximum waiting time is also reduced to maximum of around 3.4 minutes. Where in total with the 1 minute's processing time still satisfy the 5 minutes handover time allocation of the PT. XYZ warehouse management team. Based on the simulation result, could be concluded that as long as the time needed for the user to claim package once they have found the assigned locker is less than 30 seconds, the smart locker system satisfies the PT. XYZ warehouse management team requirements.

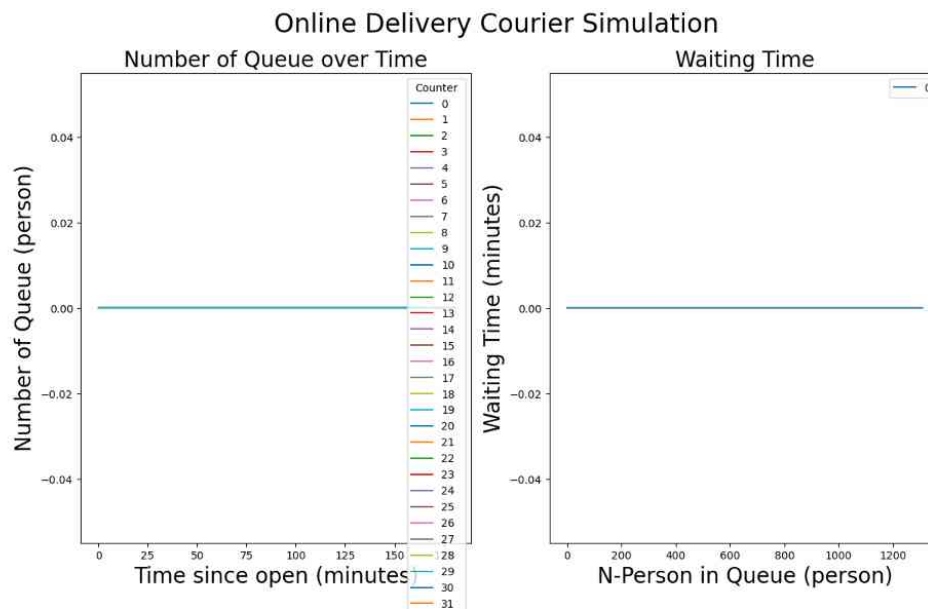


Figure 3.6 Online Delivery Courier Handover Process Simulation with 400 Smart Locker Units Simulation Results

The Figure 3.6 above shows the online delivery courier handover process simulation with the same algorithm as being used previously with 400 units of Smart locker doors as being planned by PT. XYZ. As could be seen at both side of the figure, both the number of queue and waiting time significantly reduce to 0. No more queue and waiting time occurs in the online delivery courier handover process. There will be only the 1 minute estimated processing time left giving more space for the actual delivery process.

3.3.3 Electrical System Design

This section discusses the details of electrical system design shown in the left part of Figure 3.3 covering the wiring diagram and the PCB design. All of the electrical system design will be in the Box level only due to the modular design. All of the boxes are common and only shares common 12 VDC power sources following the commonly available lock mechanism working at 12 VDC.

Table 3.1 Input Output Table

Component	Category	Function
Limit Switch	Digital Input	Detect the door status
OLED Display	Output via I2C	Show the QR Code
Indicator Lamp	Digital Output	Activity indicators
Lock mechanism	Digital Output	Open the door

The Table 3.1 above shows the input and output list of the system. As could be seen also in the Figure 3.3, the overall system has two digital outputs, one digital input, and addition of OLED screen as an output medium via I2C communication protocol. The lock mechanism is being used to control the door. The lamp is being used to interact with user, showing status and give feedback for the user to know which locker they are assigned to. In the input point of view, a digital input of limit switch is being used to sense the door status as feedback. Furthermore, an Organic Light Emitting Diode (OLED) screen is being used to display the dynamic scannable QR codes via I2C communication protocol.

3.3.3.1 Wiring Diagram

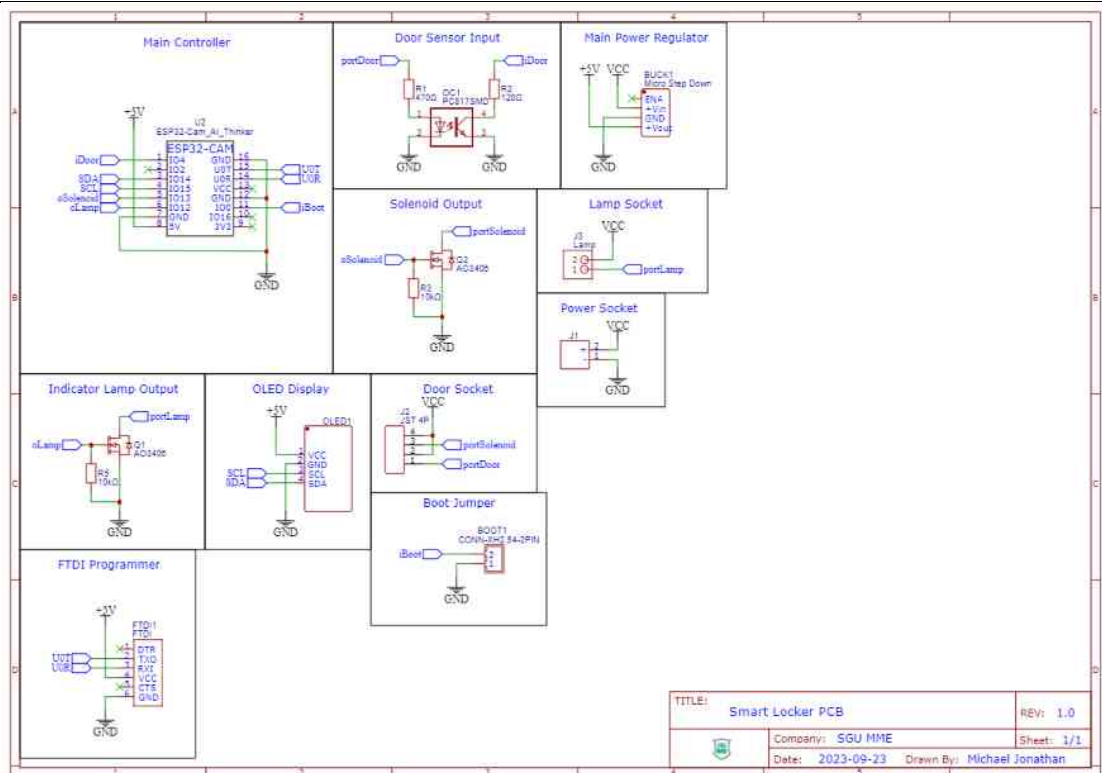


Figure 3.7 Microcontrollers Electrical Wiring Diagram

The Figure 3.7 above shows the microcontrollers electrical wiring diagram. Each microcontroller is responsible for one box or locker door. They act individually enabling the simultaneous user access features. The microcontrollers that are being used is ESP32 CAM due to its small form factor, built-in Wi-Fi capabilities, and external antenna support. The external antenna support is a nice backup feature to have in bad signal area. The 12V supply voltage that are critical to actuate the actuators is regulated down to 5V to powers up the microcontrollers and internal circuit voltage. The 12V external circuit voltage is also chosen to minimize the voltage drop effect that might occurs due to the length of the cable. The FTDI programme is being used to flash program to the microcontroller due to the absence of the onboard programmer on the ESP32 CAM.

As could be seen also in the wiring diagram, an optocoupler is used for the input port interface. The optocoupler is being used to secure the microcontrollers input pin. The long wire connecting the input port and the limit switch could create a significant voltage drop or even catch noises from induction. Both of the issue might cause a serious issue for production deployment. The microcontrollers pin that work based on cutoff voltage value might suffer from the voltage drop caused by the long wire,

especially where the microcontrollers relatively work in low voltage level that are more prone to the issues. Optocoupler comes to solve this problem by using the optical insulation working based on the current level which are more suitable for implementation with long cable. No matter how high or low the voltage, as long as the current flows through the emitting diode side the optically actuate transistor inside could react. Furthermore, with the optocouplers nature of working based on current flows making it more immune to sudden voltage surge that might occur due to induction from the environment to the long cable. The sudden surge voltage often burnt the microcontrollers input pin making it blind or even the whole microcontrollers making it into a brick. Having optocoupler would be a nice feature to have to protect the microcontrollers and for a robust application. In case of failure, the microcontrollers still could send data to the server and the anomaly of the system could be detected for quick response by the maintenance team. The cost also will be less since only the optocoupler need to be changed.

On the output side, mosfet are being used as the interface. Microcontrollers output pins have low working voltage level and current limit. Having mosfet could solve both of the problem. Mosfet could be driven by relatively low voltage compared to the output voltage it could handle. Furthermore, it requires theoretically zero ampere currents flow through it and could drive high power actuators. An additional pulldown resistor is needed to be added across each mosfet's Drain and Source pin to prevent noises. Using mosfet also protects the circuit from the actuator's failure or accident short circuit that might occur during maintenance or trial. Similar to the usage of optocoupler for the input port, using mosfet to interface the output port also reduce the risk of the output pin of the microcontrollers burnt and need to replace the mosfet only.

3.3.3.2 PCB Design

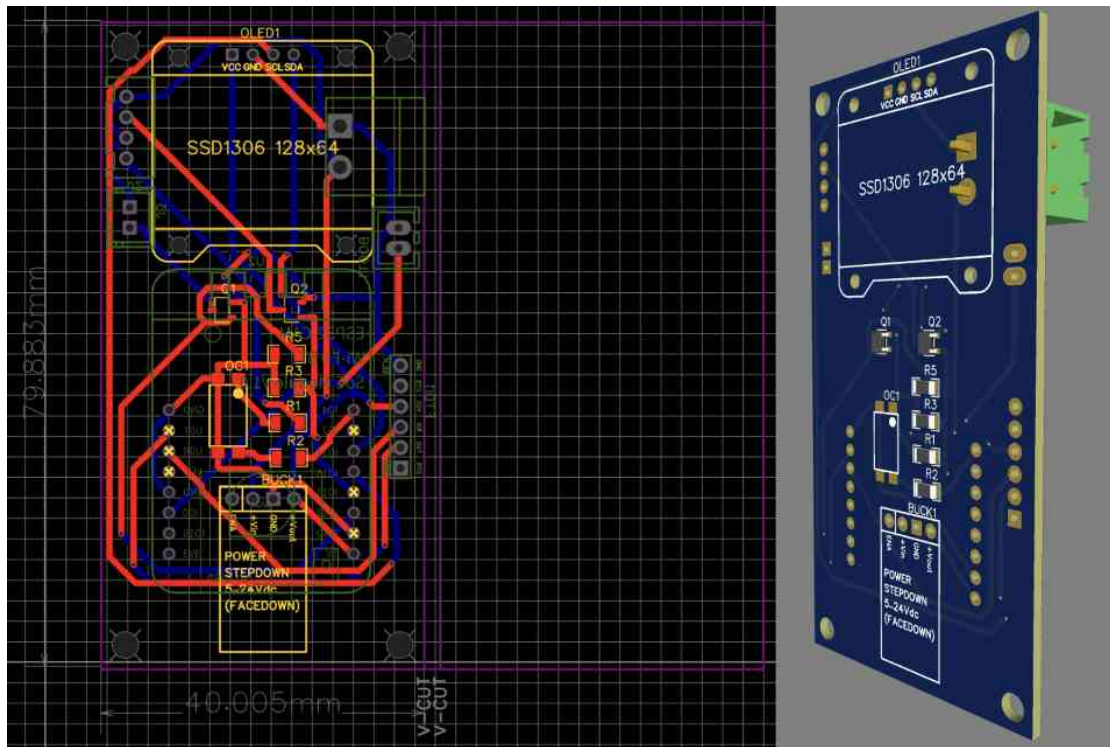


Figure 3.8 Printed Circuit Board (PCB) Design

The Figure 3.8 above shows the Printed Circuit Board (PCB) for the microcontrollers and electrical components inside each door with overall dimensions of around 80 x 40 mm. The dual layer PCB and Surface Mount Device (SMD) components are being used to make the PCB size compact. The external components connected to the PCB are connected via a plug and play connectors to ease the assembly and maintenance process where the engineers could connect and disconnect components without mandatory additional tools. The design of the PCB is made to be vertically slim to mimic the shape of door handle. Four mounting holes are provided for M3 bolts so that the PCB could sit nicely to the housing using four M3 bolt.

3.3.4 Mechanical Design

This section discusses the mechanical design of the smart locker system as shown at the left part of Figure 3.3.

3.3.4.1 Overall Locker Design

The smart locker system will be made and modified based on readily available locker in the market. There is no restriction on the locker dimension and all dimension could be adjusted to the needs of the services provider. For this research purposes, only one locker dimension with three door wood lockers will be used. To adjust with the PT. XYZ warehouses needs, the back part of the locker will be exposed for easy access by the lockers operator for both package loading and emergency situation handling.

Manual overwrite ability in emergency situation handling is essentials for real applications operations. The abilities could ensure the daily operations of the handover process could still be running even if the locker system is down due to unpredictable reasons. When the system failure occurs, the smart locker system operator could easily open the door manually from the openings in the back side of the lockers and do the handover manually. Moreover, the back side of the smart lockers are intentionally left opened to ease the PT. XYZ smart locker operators to load package inside. By doing that, the operators could directly put the package inside from the back side of the lockers without the needs to open the locker first. Furthermore, this approach also separates the working area of the operator and the user enabling flawless simultaneous access for both users and operators. As an addition, QR code or barcode as unique identifier of each locker doors will be placed at the back side of the lockers. The system will require the operators to scan the QR code as a confirmation to the package loading process. Hence this part of software will not be discussed in this research and out of this research scope.

3.3.4.2 Locking Mechanism



Figure 3.9 Locking Mechanism Assembly and Lock Buckle

The Figure 3.9 above shows the locking mechanism that is chosen for this research. The silver lock buckle shown at the left side of the figure is attached at the door leaf side. It has two mounting points using M3 nuts. The locking mechanism itself is attached at the side of the lockers. When the buckle hook is pressed into the lock body gap, it will move the internal lever (grey, inside the gap) and latch the lever. This kind of actuation triggers the latching mechanism inside the lock body. Once the internal lever latched and the buckle hooked into it, the locker door is locked. The latch mechanism could be released by actuating the external lever downside. Once being released, the internal lever has spring mechanism that could press the hook mechanism outward making the door opens automatically.



Figure 3.10 Lock Body Internal Mechanism

The Figure 3.10 above shows the internal mechanism of the lock body. As could be seen in the figure, the external lever mechanism to release the internal lever could be done either manually or using the titanium memory wire. When electricity flows through the memory wire through red and black wire, the memory wire shrink causing downward force to the external lever. As a safety measures to prevent extensive current flows, the memory wire is routed in series with the limit switch which could cut the electricity flows once the internal lever is released. This approach could increase the memory wire lifetime since it will be energized only as much as needed. Furthermore, the limit switch output could also accessible via the yellow and blue wire.

The top lever shown in the Figure 3.10 consists of two different materials. As could be seen, the locking part has silver colour like the internal lever made of metallic part. The external lever for manual actuation has black colour and made out of plastic material. The reason of the different material usage is safety. As could be seen, the memory wire is attached to the locker body using cable head screwed directly to the body. As could be seen at the left bottom part of the wire is secured directly to the metallic body. To prevent unwanted electrical leakage or short circuit, the other part of the wire is secured into a plastic body as an insulator.

3.3.4.3 PCB Enclosure

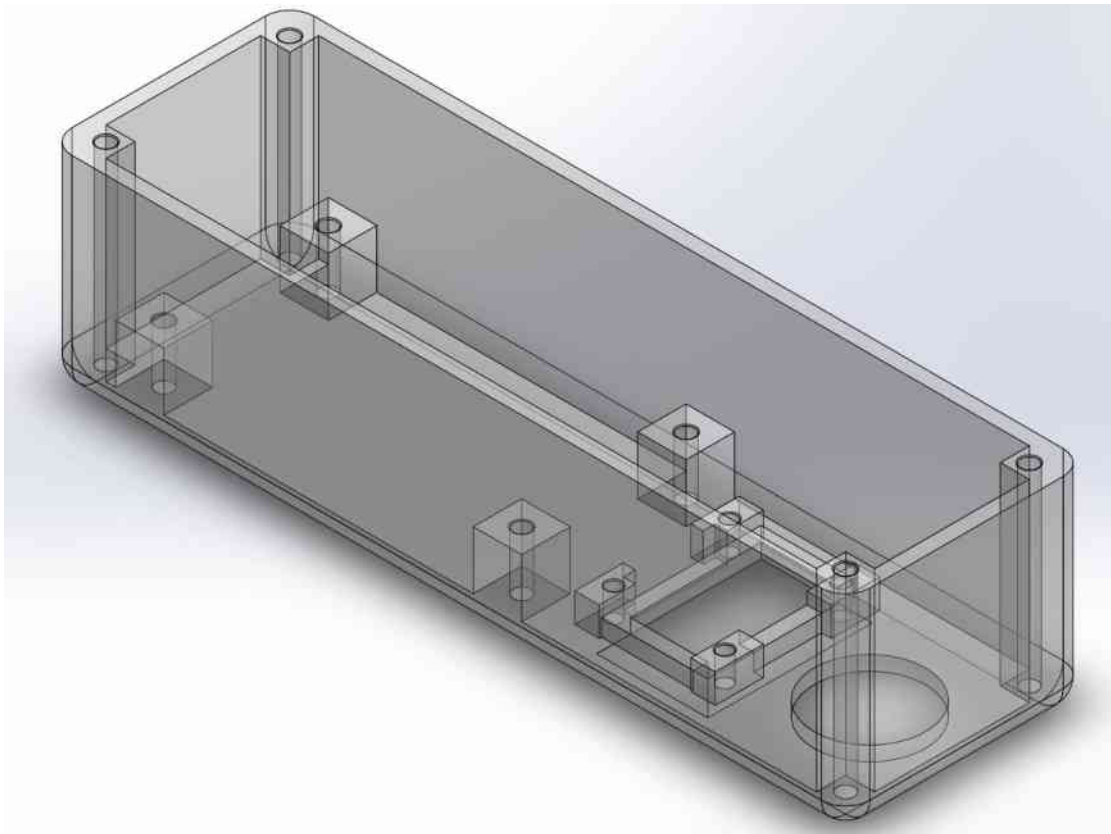


Figure 3.11 PCB and Electrical Part Enclosure Design

The Figure 3.11 above shows the PCB and electrical part enclosure design. The design is made to be 3D printed with plastic materials for manufacturing easiness and allows the Wi-Fi signal penetrate the enclosure without the needs of adding external antenna. There are two big holes for the indicator lamp mount and the OLED screen display. The indicator lamp does not require special mounting point in the case due to its ability to be secured by its own nut pinching the enclosure. The OLED screen display is secured to the enclosure by using four M2 bolts. The PCB is secured to the enclosure by four M3 bolts. The enclosure itself will be secured to the locker door using four M3 nuts. All of the bolts are secured to insert nuts applied on each available hole. As mentioned previously, the overall design is made to be thin and tall to mimic the shape of the commonly used door handle. By doing so, the user is expected to adapt quickly.



Figure 3.12 Brass Insert Nut

The Figure 3.12 above shows the brass insert nut that are being used to give threads to the enclosure. It could be fitted into the provided holes in the 3D printed enclosure by applying heat to melt the 3D printed part. Once the 3D printed part melted, the insert nut will fit inside the holes. After several time, the melted 3D printed part will merge with the insert nut outer texture and harden making strong mechanical bounds between the insert nut and 3D printed enclosure. Using insert nut instead of directly tapping or even 3D printed threads is much stronger and providing abilities to assemble and disassemble the parts since the thread itself is metallic.

3.3.5 Software Flow Diagram

This section discusses the software flow diagram as shown in the Figure 3.3. This research is only limited to the design of the microcontrollers inside lockers at the left side of the figure and basic functionality of the main server as the coordinator in the middle part of the figure. The communication between microcontrollers and the main server will be done via MQTT protocol.

3.3.5.1 Overall Software Flow Diagram

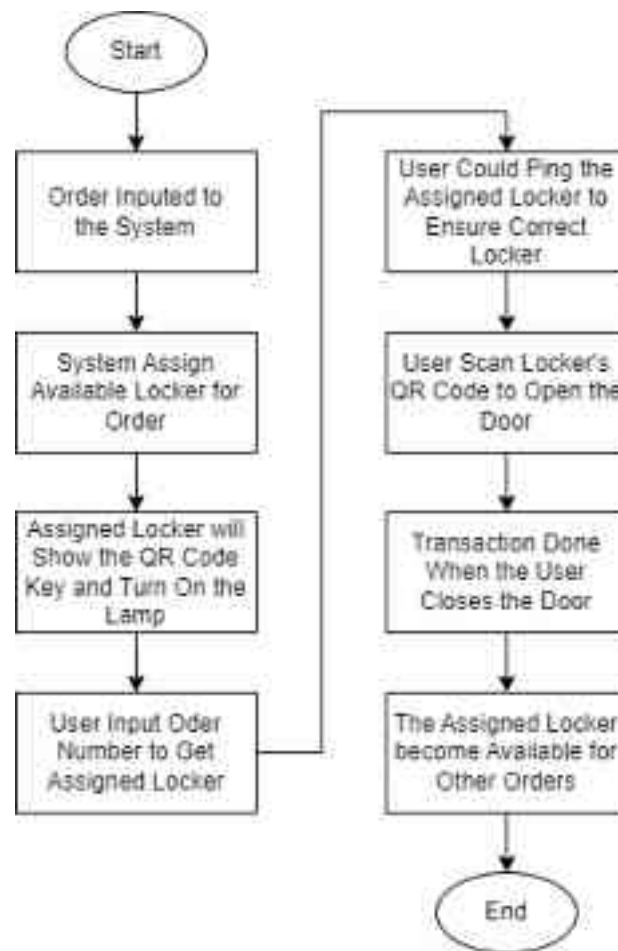


Figure 3.13 Overall Software Flow Diagram

The Figure 3.13 above shows the overall software flow diagram of the smart locker system. The process initiated by order number input by a warehouse operator to the system to be stored inside the locker. The system then will decide which locker door or box should be used for the transaction. To add more flexibility and robustness to the system, the warehouse operators are required once more time to scan the locker door QR Code to ensure that the packages are being stored in appropriate box. This feature also useful in the cases where the actual package dimension is different with the registered data in the system that might causes the package is not fit inside the assigned door. Once the order is assigned to the locker, the assigned locker will show the QR Code as a key to open the door and turn on the indicator lamp. The QR Code itself will be generated automatically by the system.

On the user side, the user will be required to input the order number to get the direction of where the package is located. If the system found the desired order number, the user will be directed to the locker location. To ensure the user scan the right locker, the user also could ping the indicator lamp of the assigned locker. When the ping button on the web-apps is pressed, the locker then will turn off the indicator lamp for short period. After the user scan the QR code shown by the assigned locker, the system then will verify the combination between the order number and assigned locker QR code as the key. If the verification is successful, the locker then will be opened.

The transaction will be closed once the user close the door. The locker state will be set to initial available state with no QR code shown and indicator lamp turned off waiting for next transaction. As being mentioned earlier in the overview part, this research focuses mainly on the microcontrollers part of the system and minimum working part of the backend system. Most of the web apps and backend system will not be covered in this research.

3.3.5.2 Microcontroller Software Flow Diagram

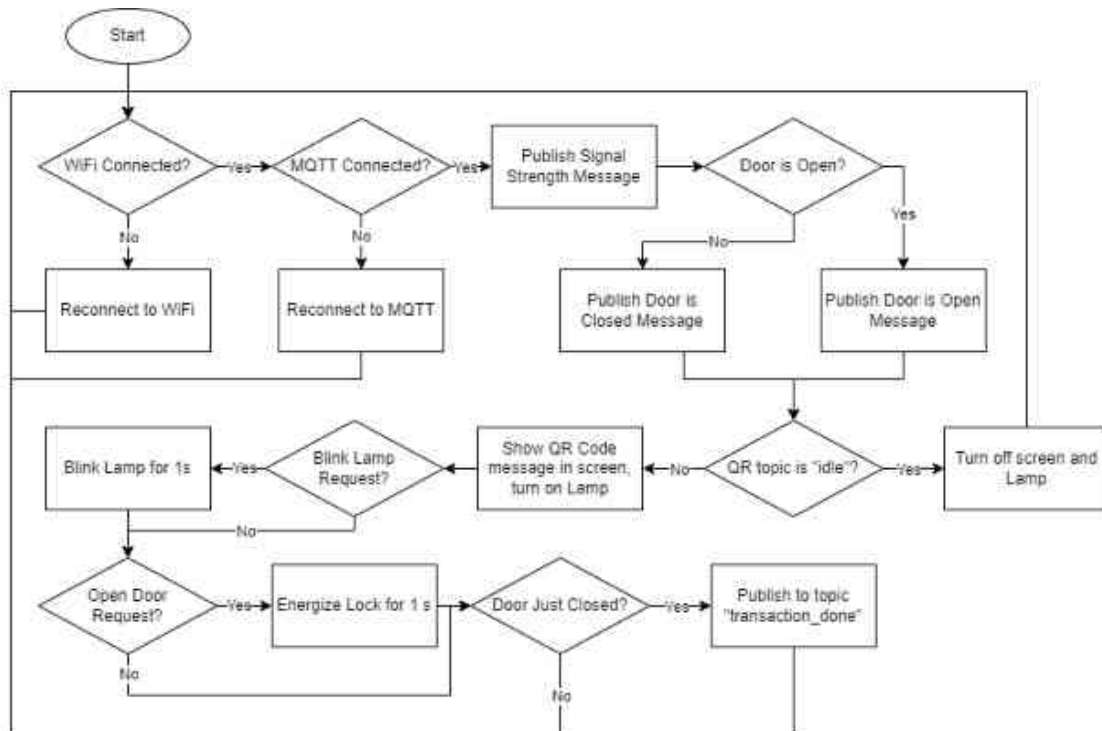


Figure 3.14 Microcontrollers Software Flow Diagram

The Figure 3.14 above shows the software flow diagram on the microcontrollers side where each microcontroller is responsible for one locker. Each loop cycle starts with checking the connectivity status between the microcontrollers and the network. It will ensure that it has live connection with both the Wi-Fi network and MQTT broker. On both condition when the Wi-Fi or MQTT connection is not established, it will re-do the reconnection protocol. The microcontrollers rely on the MQTT communication protocol to communicate with the server.

Once the connection with the MQTT broker established, the microcontrollers will periodically push the signal strength data and door status based on limit switch readings. The signal strength information is useful to troubleshoot the possible network issues in production. The door status value is essentials for the smart locker operator to ensure that all users already closed the door so that the operator does not need to manually check the door one by one. Then, based on the QR topic sent from the server, the microcontroller will determine its status. If the QR value from the server is equals to “idle” then the microcontroller will enter inactive status and just repeat the process mentioned earlier. Other than that, the microcontroller will enter the active state.

On the active state, the microcontroller will show the QR topic value as a QR code in the OLED screen. At the same time the indicator lamp also energized to indicate active status of the locker door. In the active state, the microcontroller’s lamp could be ping by the user. On each ping request, the lamp will be de-energized for one second. When the locker gets door open command from the broker, the door lock output port will be energized for one second to open the door lock. Furthermore, the microcontroller will send transaction done message when it detects the door is being closed.

Table 3.2 MQTT Topic Name Lists

No	Topic Name	Data Direction	Value
1	[locker_name]/[box_name] /qr	From Server	- “idle” → Inactive - Other → Active, shows the content as QR Code
2	[locker_name]/[box_name] /rssi	To Server	Negative integer showing signal strength
3	[locker_name]/[box_name] /door_feedback	To Server	Boolean indicating the value of digital pin readings of the limit switch
4	[locker_name]/[box_name] /door_command	From Server	Boolean value indicating the value of “on” or ”off”
5	[locker_name]/[box_name] /lamp_ping	From Server	Boolean value indicating the value of “on” or ”off”
6	[locker_name]/[box_name] /transaction_done	To Server	Boolean value indicating the value of “done”

The Table 3.2 above shows the list of MQTT topic name being used by the system to exchange data between the lockers and server. Each locker door has unique identifier in each MQTT subtopic level one and two where the level one subtopic indicates the locker name and the level two subtopic indicates the box or door name. The qr topic from server will be set to be retained to ensure each microcontroller will get the currently set qr code in case of power failure happened.

3.3.6 Web Application for Trial

Web applications or also commonly said as web apps is an application that fully run on top of a web site that only requires web browser to run. The web application is chosen for the implementation of the smart locker system due to its simplicity and familiarity. Web application does not require the user to install or download anything permanent on the user mobile phone which sometimes might be inconvenient for most of the user, especially the online delivery couriers that are not doing pick up regularly in PT. XYZ warehouses. It only requires the user to know the Fully Qualified Domain Name

(FQDN) of the web applications that could be simplified by providing a scannable QR code pointing to the FQDN link. Even though web applications have some limitations especially the hardware access and limited resources, the user side web applications of the smart locker system only require camera access which already supported by web applications.

The web applications that are going to be used for the trial is only a mock-up of the actual system consisting the core parts of the production system. The details of the web applications development will not be covered in this research. The web applications for the smart locker application itself consists of the operator and user part. The operator part is made for the warehouse worker to do the inbound or place the package to specific locker box. The user part is made for the online delivery couriers to claim the package. All of the functionality and performance of the actual and trial web applications are equal.

Due to the camera access requirement, the web application could only run on the outside devices other than localhost via Hypertext Transfer Protocol Secure (HTTPS) method. However, the Secure Socket Layer (SSL) certificate that are being used in this research is a self-signed SSL certificate that are commonly used in development or trial environment. The self-signed and Certificate Authority (CA) signed certificate do not have any different other than the CA-signed certificate could be verified by standard web browsers that tells the authenticity of a web page to prevent fraud. The CA-signed certificate only being used for the production site where the FQDN is already fixed and access without static IP. Using a self-signed certificate might resulting in user need to manually trust the web page on the first-time access and the browser might showed red colour in the link and showing danger sign indicating that the browser could not verify the validity of the server real IP with the FQDN used to access the page. In the production web application, a CA-signed certificate is required to provide security to the user.

3.3.6.1 Operator Side Web Application for Trial

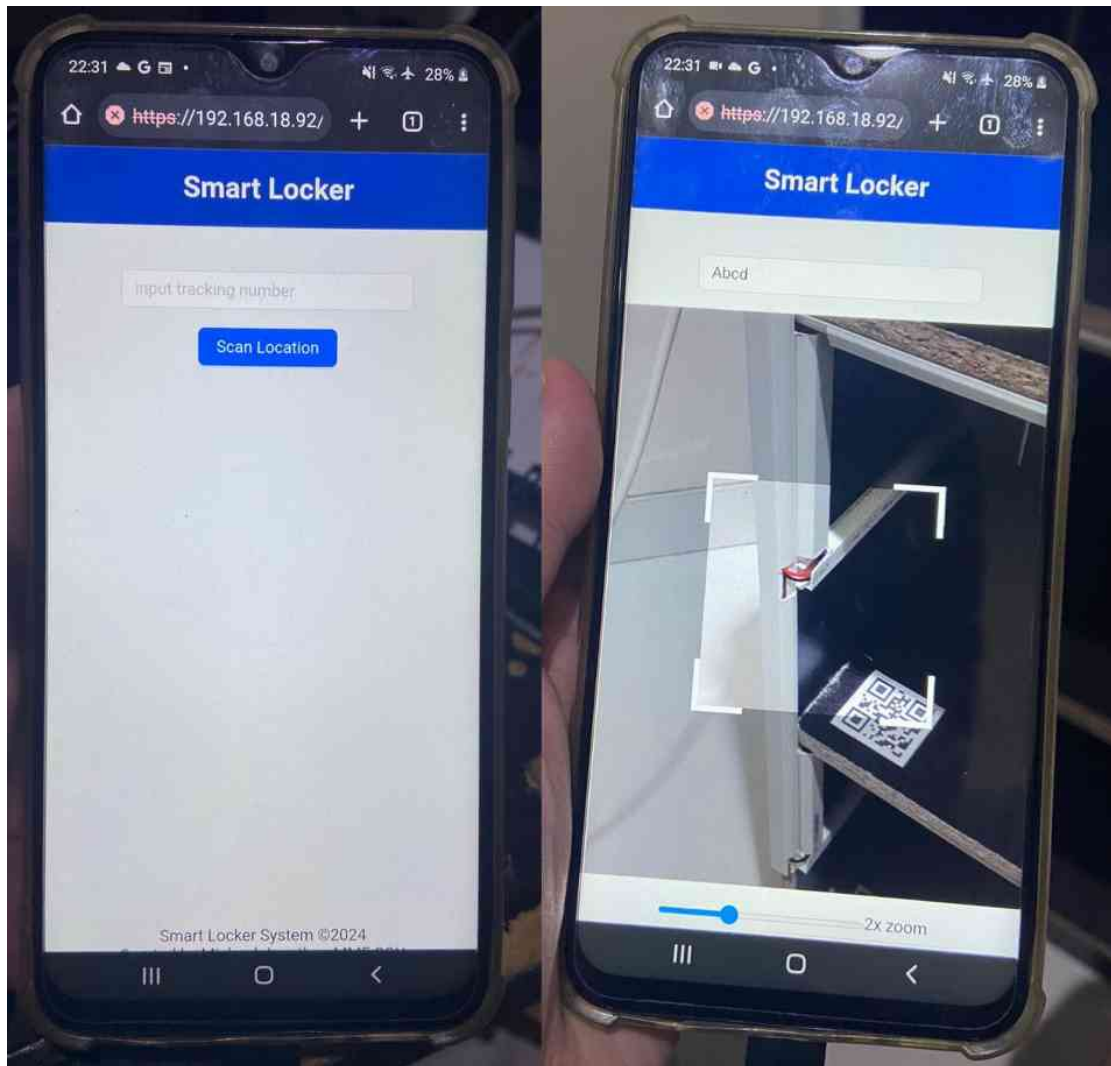


Figure 3.15 Operator Side Web Application for Trial

The Figure 3.15 above shows the operator side web application that will be used for the trial of this research. The operator side web application is intended for the warehouse workers to input the package tracking number or identifier and bind it with the specific locker. As could be seen in the Figure 3.15, there are an input box for the tracking number and a button to trigger the QR code scanner. As could be seen at the right side of the figure, once the scan button is pressed, the web application will show the camera footage including the scanning area for the QR code. The scanning area needs to be limited to reduce the resources needed for the web application to scan the QR code. Once the QR code is scanned and validated, the web application will go back to the initial state as being showed at the left side of the figure.

3.3.6.2 User Side Web Application for Testing

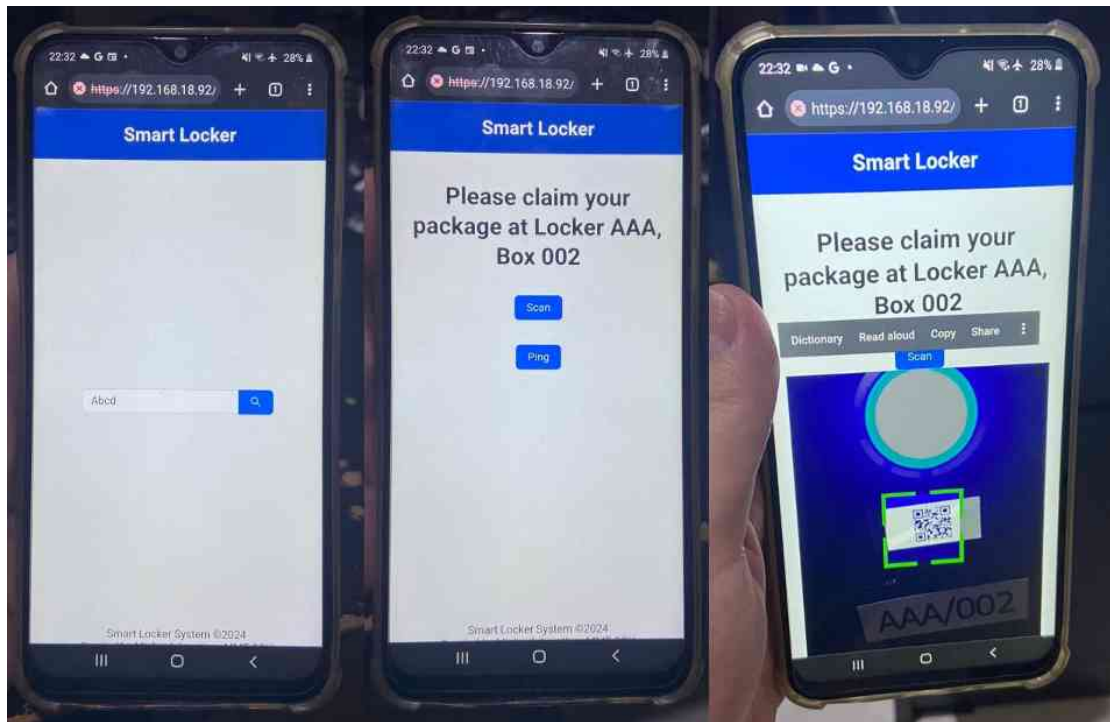


Figure 3.16 User Side Web Application for Testing

The Figure 3.16 above shows the user side web application that is intended to be used by the online delivery courier to claim the packages. As could be seen at the left part, the user will be required to input the tracking number or package identification that the user get from the online delivery platform. If the tracking number is valid and active, the user then will be shown the page shown in the middle part of the figure. In this section, the user will get the access to the package location indicated by the locker name and box name. Furthermore, user will also have access to the ping button and scan button. As could be seen at the right side of the figure, the scanning region is much tighter compare to the operator web application due to the smaller QR code being used for the user. The web-based application is tested and works for both Android based and iOS based mobile phone.

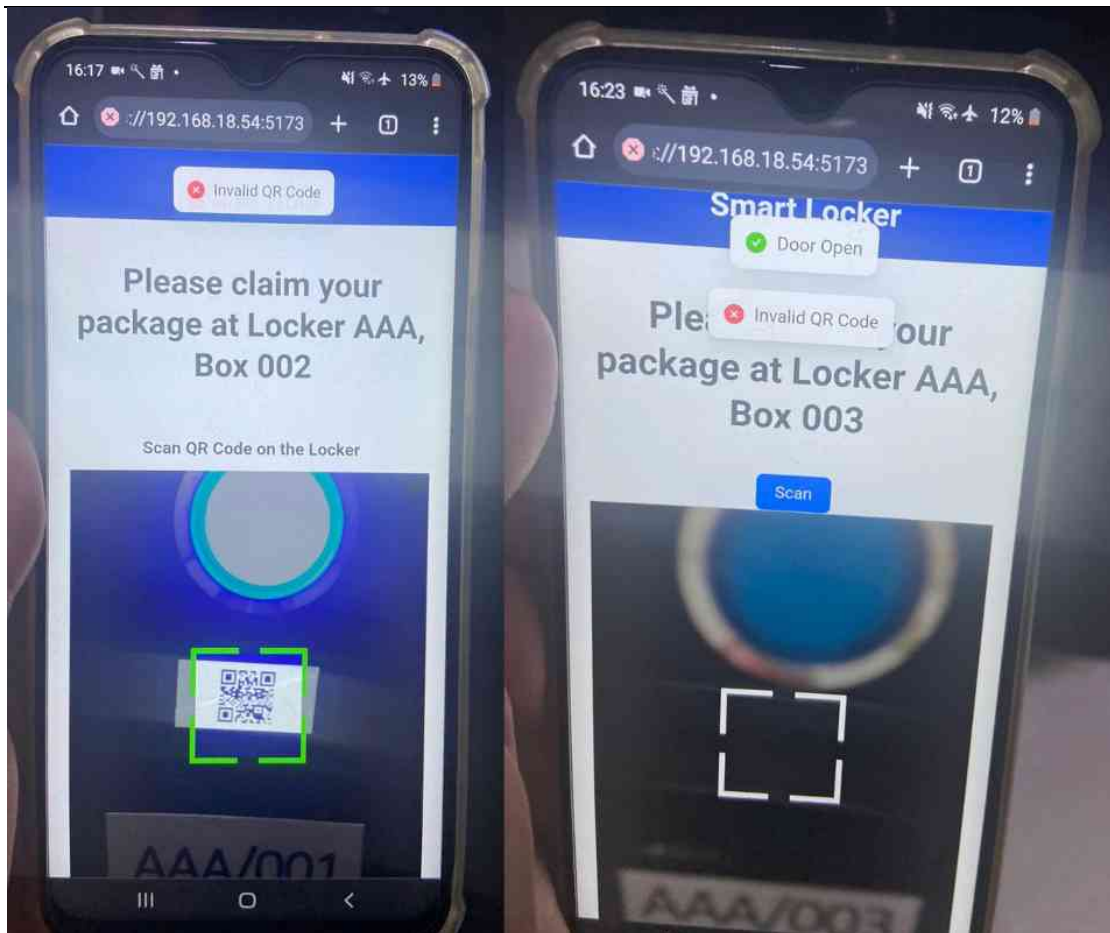


Figure 3.17 Web Applications Error and Success Messages

The Figure 3.17 above shows the error and success message displayed by the web applications as feedback to the user. The web application has visual and audio form notification which are the push notification on top of the web page and an audio played on failure or success. As could be seen at the left side of the figure, the push notification with red icon with the error message appear on error scanning invalid QR Code. At the same time the push notification being showed, an error indicating audio also being played. On the other hand, at the right side of the figure, on success event where the scanned QR Code is correct and the door is open, a push notification with green icon with the success message are being shown on top of the web page. At the same time also, the success indicating audio also being played at the moment the push notification is being shown.

3.3.7 Performance Tests and Data Takings

This section will focus on the performance tests and data takings need to be done in this research. As being mentioned in the previous parts, the performance tests and data takings will focus on evaluating the smart locker system assembly and its integration with the core main server functionality.

3.3.7.1 Preliminary Data Taking

To begin the research, a preliminary data taking needs to be done to know current situation before the implementation of the smart locker system. The data taking will be done in one of the largest PT. XYZ warehouse during the handover time between warehouse and online courier delivery. The aim of this data taking is to gather the average waiting time of the online courier delivery as the user.

3.3.7.2 Assembly and Fittings

This section will focus on the discussion of the execution result of the fabricated part for this research ranging from the enclosure, PCB, and overall assembly. Any adjustment needed during the assembly and fitting process will also be discussed in this section.

3.3.7.3 Locking Mechanism Actuation Test

This section will focus on evaluating the actuation robustness and time of the smart locker door locking mechanism. The test will be done by continuously open and close the door. The open actuation will be triggered by the microcontrollers and the time needed from the microcontroller starts the current flow until the limit switch detect the door is opened will be measured. To measure the robustness, the number of doors really opens (could be open by relatively small forces) will be count.

3.3.7.4 QR Code Display Accuracy

This section will focus on evaluating the generated QR code accuracy displayed on the OLED screen. The QR code content will be blasted from the MQTT broker via the QR code topic template mentioned in the Table 3.2 above. The content then will be evaluated by using standard mobile phone with various operating system (Android and IOS) to be evaluated whether if the content scanned by the mobile phone is matched or not.

3.3.7.5 Ping Test

This section will focus on testing the ping feature reliability. The ping feature is made to help the user find the assigned lockers. If the ping feature itself is not reliable enough, the user could be confused instead of being helped by the ping feature. The repeatability and the response time for the ping feature will be evaluated in this part.

3.3.7.6 Signal Strength

This section will focus on testing the signal strength of the microcontrollers inside the enclosure. The signal strength received by each locker microcontrollers is important for smooth operations. Having weak signal could leads into frequent data losses, delays in the response, or event total inactivity. The test will be done by logging the Received Signal Strength Indicator (RSSI) feedback send by the microcontrollers over MQTT protocols. The signal test is important to evaluate the enclosure design. Where the onboard antenna of the ESP32-CAM is blocked by the enclosure materials and quite close to the metallic insert nuts and bolts that could affect the signal strength. Only with adequate signal strength, IoT devices could run as it supposed to be. Having the ability to look at the RSSI logs could be useful for the future troubleshooting.

3.3.7.7 User Test

This section will act as the final test where the overall performance of the device will be evaluated. The test will be done by simulating the actual conditions occurs in PT. XYZ warehouse with various kind of mobile phone. The time needed by the user to claim their package then will be measured to compare the effectivity of the smart locker system implementation.

3.3.7.8 Power Failure Situation

This section will act as an additional test to check the system robustness during power failure. The test will be done by cut the power to all microcontrollers since the Wi-Fi network and server being used by PT. XYZ warehouse are all enterprise grade with redundancy and auto switchover feature. All microcontrollers are all expected to reconnected to the broker as soon as the power source connected and continue its previous state whether if it is active and showing QR code or idling.

