977-302 Digital Engineering Project I

Semester 2/2024

Automatic Shuttle Storage

Project Report

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Abstract

This automatic shuttle storage project is designed to study and simulate the use of automatic shuttle storage in homes or small companies because most of automatic shuttle storage is installed in large factories or warehouses. and to make full use of storage space and for safety from climbing stairs to store items, by using automatic shuttle storage, which has shelves on both sides and a robot in the middle to store items. The robot will deliver and store items by controlling them via mobile phone or computer. This project integrates hardware development using ESP32 and stepper motors, software implementation with Node-RED and Arduino IDE, and simulation testing in real environments. Expected outcomes include improved storage organization, increased efficiency, and enhanced safety in small storage spaces.

This project aims to simulate the use of robots for storage and for practical application in home storage rooms.

Keywords: automatic shuttle storage

Acknowledgements

This project was successfully completed. I would like to thank Mr. Wisarut Chantra, the advisor, for his advice on this project. The project creator is very grateful to the examination committee for taking the time to review this project and provide suggestions for improving the project, which will be useful for future projects.

Alif Krohlek

27 April 2025

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LIST OF ABBREVIATIONS

AS/RS	Automated Storage and Retrieval System
CAD	Computer-Aided Design
ESP32	Embedded Serial Peripheral 32-bit Microcontroller
FDM	Fused Deposition Modeling
FYP	Final Year Project
IDE	Integrated Development Environment
IoT	Internet of Things
MQTT	Message Queuing Telemetry Transport
PSU	Prince of Songkla University
SBS/RS	Shuttle-Based Storage and Retrieval System
UI	User Interface
API	Application Programming Interface
CM	Centimeter
CNC	Computer Numerical Control
IR	Infrared

Chapter 1 Introduction

This chapter includes the background, objectives, scope and procedures, expected benefits of the project, locations and tools used in the preparation. This information is the basic information and knowledge of this project.

1.1 Overview

Currently, the Automatic Shuttle Storage system is widely popular in large industrial factories and warehouses because it can help increase storage efficiency and reduce the time it takes to move goods. However, the use of this system in small houses or companies still has many limitations, such as limited space, high budget, and lack of design suitable for household use.

This project was developed to address these problems. The objective is to study and simulate the use of automatic storage systems in small areas to help users use storage space more efficiently and reduce the risk of accidents caused by climbing up high to store items, especially in houses with elderly people or people with physical limitations.

This project presents an automatic storage system with shelves on both sides and a robot that moves in the middle to store and retrieve items, controlled via a mobile phone or computer for convenience, speed, and safety without manual labor. It is particularly useful for small businesses, such as online stores managing inventory in limited spaces or offices improving document and equipment storage. By reducing time and errors in product management, this system enhances efficiency while ensuring safety. Ultimately, it serves as a guideline for integrating automatic storage technology into households and small businesses to improve convenience and productivity.

1.2 Objective

- For organized storage on shelves to make them easier to find
- To make efficient use of space
- To reduce accidents from climbing stairs to collect items
- To reduce the time, it takes to lift items onto shelves

1.3 Scope

- Use ESP32 microcontroller board to control the system and connect to the internet.
- Suitable for households

- The user interface of this project is a mobile application
- The shuttle is moving by lead screw
- The movement of shuttle is in the X,Y,Z axis
    The range of x-axis movement is 35 centimeters
    The range of y-axis movement is 20 centimeters
    The range of z-axis movement is 10 centimeters
- The shelf is 3x2 slot

1.4 Procedures

- Study the equipment required that is used in this project
    - Study about how to using the stepper motor
    - Study how to using the module A4988 (motor driver)
- Test the actual use of all equipment that needs in project
    - Test or real use with the stepper motor
    - Test or real use with module A4988 (motor driver)
- Build a base of the shuttle storage and design parts on shapr3D
    - Buil the base of this project with a wood
    - Design the 3D and print plastic material part of the project
    - Make the electronic circuit that combine with all component include with esp32
- Create the structure of robot shuttle and write code
    - Print a plastic material part for making a shuttle movement
    - Write a code to control the movement of the shuttle
- Develop/improve section of coding and 3D part
    - In some part of plastic part it need to do it many version or improve to make it suitable with this project
- Make the node-red
    - Write a code to make this project to connect to the wifi and can control it via wireless
    - Create the UI with the node-red
- Make report

1.5 Expected Project Results

- To organized storage on shelves to make them easier to find
- Increase efficiency in storage room
- Reduce storage time

1.6 Locations

- PSU Male dormitory

1.7 Development Tools

Hardware

- computer
- ESP32 microcontroller board
- stepper motor
- IR sensor
- board controller for stepper motor
- leader screw

Software

- Arduino IDE
- Sharp 3D
- Node-Red
- Ultimaker Cura

Programming Languages

- C

Chapter 2 Background Knowledge

This chapter explains about hardware and software elements covered in this articles such as the Arduino IDE, Shapr3D, Node-RED, ESP32, stepper motors, and 3D printing offer a solid basis for creating an automated system. Effective smart system design, prototyping, and control are made possible by these tools, especially for automation and Internet of Things applications.

2.1 Application and Hardware

2.1.1 Arduino IDE

Arduino IDE [1] is a "free" program that supports the characteristics of open source. The Arduino IDE will be a program that connects between a Windows, Mac OS X or Linux computer. Start with Arduino that can design the firmware to write code and programs that we write into the Arduino board.

Arduino IDE The IDE is an abbreviation (Integrated Development Environment) is a development extension or various helpers that will help developers or help the development of applications to enhance efficiency, speed, accuracy, and control of the system that can be directly inspected. The development of various tasks soon

In the components and compiled into the board. The Arduino program is mostly AVR code in general because the AVR code is apart from the register directly. But the Arduino code components are accessed through the functions that are written in code in addition to the AVR code or other hardware of Arduino.

Figure2-1 **Logo Arduino IDE**

2.1.2 Application Shapr3D

Shapr3D [2] is a professional CAD (Computer-Aided Design) application primarily designed for iPad, but it also works on macOS and Windows. It's known for its intuitive interface and powerful 3D modeling capabilities, making it a popular choice for engineers, product designers, and architects. This program is used to design the 3D modeling part of this project. It is a free program

***Figure2-2* Logo of Shapr3D**

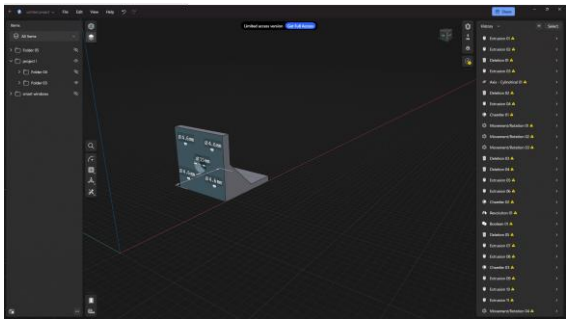

***Figure2-3* Workspace of Shapr3D**

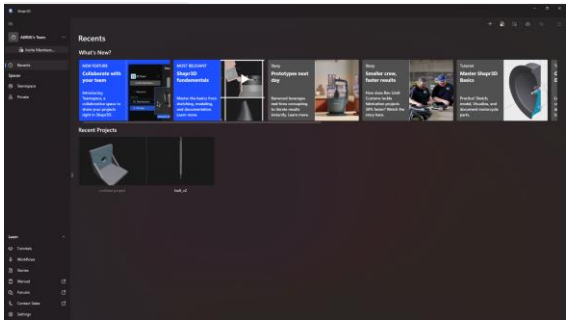

***Figure2-4* Main menu of Shapr3D**

2.1.3 Node-RED

Node-RED [3-4] is an open-source flow-based development tool for visual programming, primarily used for IoT (Internet of Things), automation, and data integration. It runs on Node.js and provides an easy way to connect hardware devices, APIs, and cloud services with minimal coding.

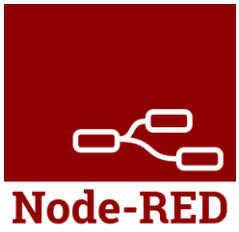

***Figure2-5* Logo of Node-RED**

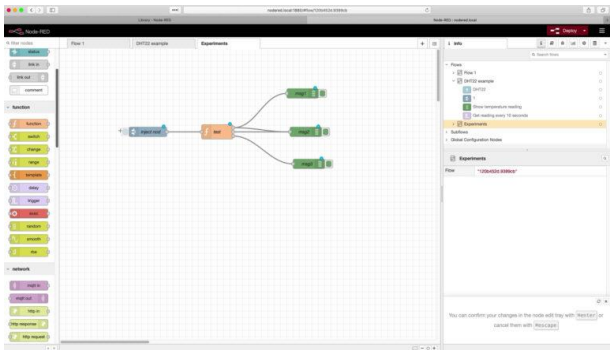

***Figure2-6* Node-RED**

2.1.4 ESP32 Microcontroller Board

The ESP32 [5] is a powerful and versatile microcontroller with built-in Wi-Fi and Bluetooth, developed by Espressif Systems. It is widely used in IoT (Internet of Things) projects, smart devices, robotics, and automation systems due to its low power consumption and high processing capability.

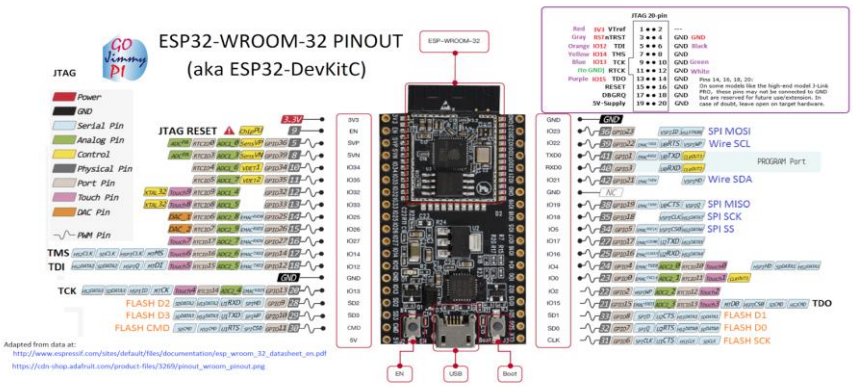

***Figure2-7* ESP32**

2.1.5 Stepper Motor NEMA17

A stepper motor [6] is a type of electric motor that moves in discrete steps rather than continuous rotation. It is widely used in robotics, CNC machines, 3D printers, and automation systems due to its precision and ability to hold a position without needing a feedback system.

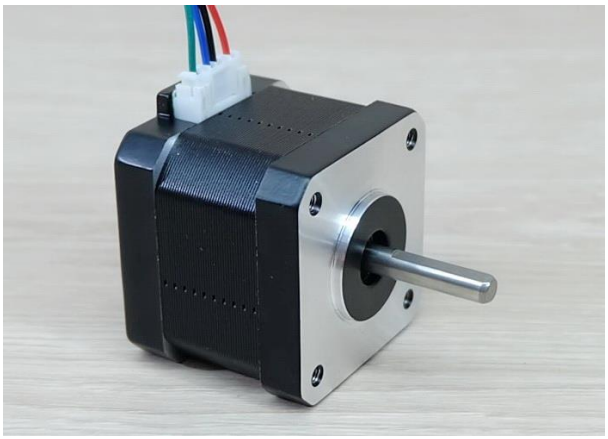

***Figure2-8* Stepper motor Nema17**

2.1.6 DC Gear Motor

A DC gear motor [7] is a combination of a DC motor and a gearbox. It works on the principle of electromagnetic induction, where a current-carrying conductor placed in magnetic fields, experiences a force and causes the rotation of the motor.

***Figure2- 9* DC gear motor**

2.1.7 A4988 Stepper Motor Driver Module

A4988 [8] is a module board specifically for controlling stepper motors and is a very popular module. It can control bipolar stepper motors, which are basic stepper motors that are also very popular. It can be applied in many forms, such as robotics, CNC machines, or 3D printers, etc. As for stepper motors that use voltage lower than 8 V, A4988 can also be used. The module will adjust the voltage to the motor as appropriate, referring to the adjustment of the current limit so that the motor does not receive too much voltage.

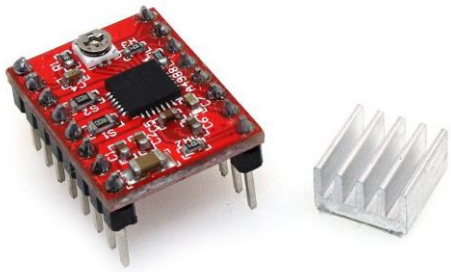

***Figure2- 10* A4988 module driver**

2.1.8 IR Infrared Photoelectric Sensor Module

The Infrared Obstacle Detection Sensor [9] and Black and White Line IR Infrared Obstacle Detection Sensor operate on the principle of light reflection when hitting objects, allowing for adjustable sensitivity and detection of objects within a range of 2–30 cm. Utilizing infrared LEDs to emit light and a phototransistor to receive it, these sensors can effectively distinguish between black and white surfaces. They function with an operating voltage of 3V - 5.5V and incorporate the LM393 voltage comparator IC for accurate detection.

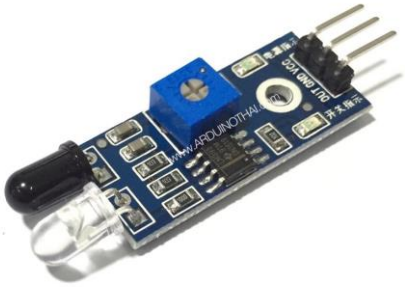

***Figure2- 11* IR sensor**

2.1.9 Limit Switch

A limit switch [10] is an electrical device that opens or closes an electrical circuit by contacting the mechanical parts inside the switch. It is used to limit distance, cut/connect electrical circuits, check the position of objects, send signals, and control the operation in automatic systems. Therefore, it is widely used in various industries, such as passenger elevators, freight elevators, conveyor systems, automatic production systems, machinery systems, etc.

***Figure2- 12* Limit switch**

2.1.10 Filament 3D Printer

FDM 3D Printing [11] is the best choice for fast and cheap prototypes. It can be used for a wide range of applications. In addition to being the cheapest system, there are also many materials and colors to choose from. FDM 3D printers use plastic filament as a raw material to mold the workpiece. Currently, there are many types of plastic materials for 3D printing, such as high-strength materials, conductive materials, and rubber-like flexible materials. This makes 3D printers able to meet more applications.

***Figure2- 13* 3d Printer**

2.2 Related Works/Research Review

The article: "A design framework for shuttle-based automated storage systems" [12] presents a conceptual framework for designing Shuttle-Based Automated Storage Systems (SBS/RS), an automated warehouse system that uses shuttles to move goods, improving storage efficiency and retrieval. This system offers high storage density, flexibility, and shorter operation time compared to traditional warehouse systems. The structure consists of racks, material handling vehicles, and buffer areas, each affecting storage capacity, product movement, and storage space management. However, there is a lack of common standards for defining SBS/RS system structure and gaps in research, such as asymmetric system design and variable lane depth strategy. The article proposes a conceptual framework for designing and developing SBS/RS systems for modern logistics industries.

The article: "A reinforcement learning approach for transaction scheduling in a shuttle-based storage and retrieval system" [13] discusses the use of reinforcement learning, specifically Q-learning, in enhancing the efficiency of a shuttle-based storage and retrieval system. The Tier-to-Tier design allows shuttles to move between shelves, reducing the load on the elevator. Q-learning can help shuttles select appropriate transactions more efficiently, especially when there are many orders, reducing the average time per transaction. This research highlights the potential of AI and Machine Learning in developing automated warehouse systems that operate faster and more efficiently, potentially benefiting the logistics and automation industries.

From the student project under the course MECH4412 (Design and Manufacturing) of the Department of Mechanical Engineering, The University of Hong Kong (HKU) [14], a project was organized that focused on developing students' practical skills and problem-solving. The topic was "Automated Storage and Retrieval System," which is a computer-controlled system for storing and retrieving goods from a specified location. The benefits of AS/RS systems include reduced labor in transporting goods in and out of the warehouse, reduced inventory levels, more accurate tracking of goods, and space savings.

The main challenges of the project include high production costs, reliance on ready-made, non-modifiable equipment, large device sizes unsuitable for small spaces, and the need for specific programs to operate. However, by studying existing solutions, it is possible to adapt the technology for smaller spaces and enable mobile phone operation. This approach allows for the creation of a more flexible, affordable, and scalable automated system, ideal for tasks like small-scale storage.

Chapter 3 Detail of System

This chapter presents the system architecture and system design of the Automatic Shuttle Storage System.

3.1 Software & Hardware Specification

The Automatic Shuttle Storage System requires software components to control the robotic mechanism, manage inventory, and provide an intuitive user interface. The system integrates both hardware control and cloud-based monitoring, ensuring efficient and real-time operations.

3.1.1 Embedded Software

- Platform: ESP32 microcontroller
- Development Environment: Arduino IDE
- Programming Language: C
- Functionality:
    - Controls stepper motors for precise movement along the XYZ axis
    - Communicate with sensors for obstacle detection and item positioning
    - Connects to Wi-Fi for remote operation

3.1.2 User Interface & Control

- Platform: Web-based control system (Node-RED)
- Development Tools:
    - Node-RED for visual programming and system monitoring
    - Web-based UI (hosted locally or on a server)
- Functionality:
    - Allows users to send storage/retrieval commands
    - Displays the system's status and storage layout
    - Logs retrieval history for inventory tracking

3.1.3 3D Modeling & Design Software

- Shapr3D (used for designing the storage system structure)
- Ultimaker Cura (for slicing 3D-printable components)

3.1.4 Cloud & Data Processing

- MQTT or HTTP communication for real-time updates

3.1.5 Movement of the shuttle

- Use the stepper motor for move the shuttle
- Use dc gear motor

3.1.6 Sensor and microcontroller board

- Use IR sensor for detecting the box
- Use limit switch for getting the position of shuttle and limit of rotation
- Use Esp 32 for control the systems

3.2 System Architecture

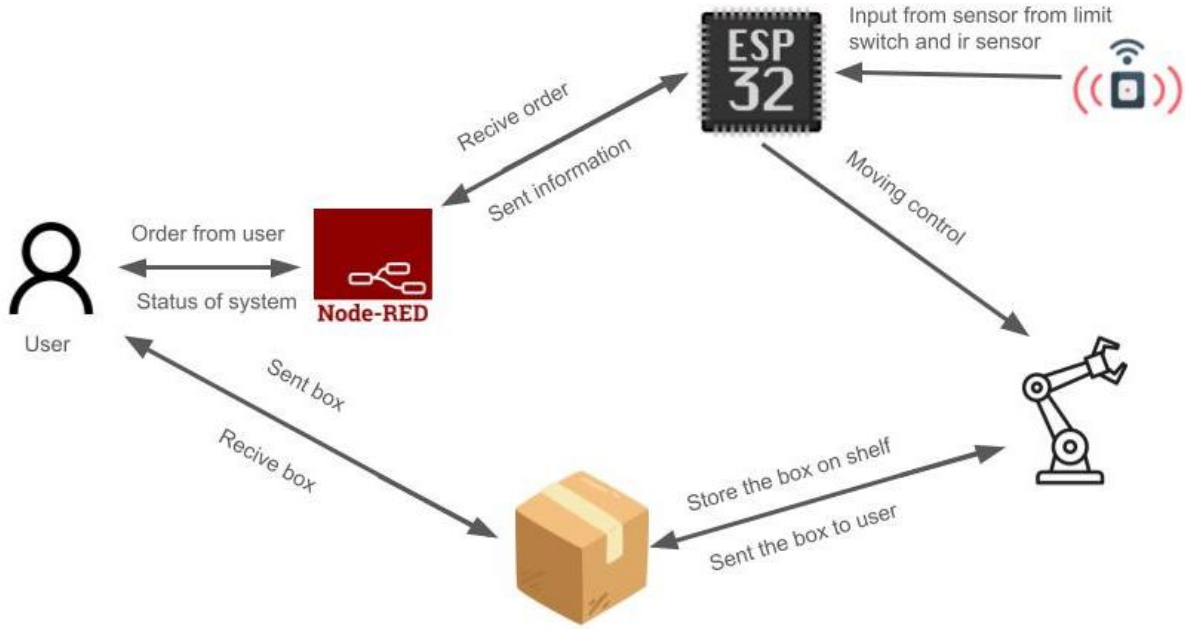

Figure3-1 System Architecture

From the figure 3-1 The user can give commands through Node-RED, then Node-RED sends commands to esp32 via the internet. The sensor part is used to check the position of the robot receiving the box and check the presence of the box, and the user can choose whether to send or receive the box, then the Shuttle will receive and send the box in the specified location. The esp32 is used to control the movement of the stepper motor, read the sensor values, and receive and send commands from Node-RED.

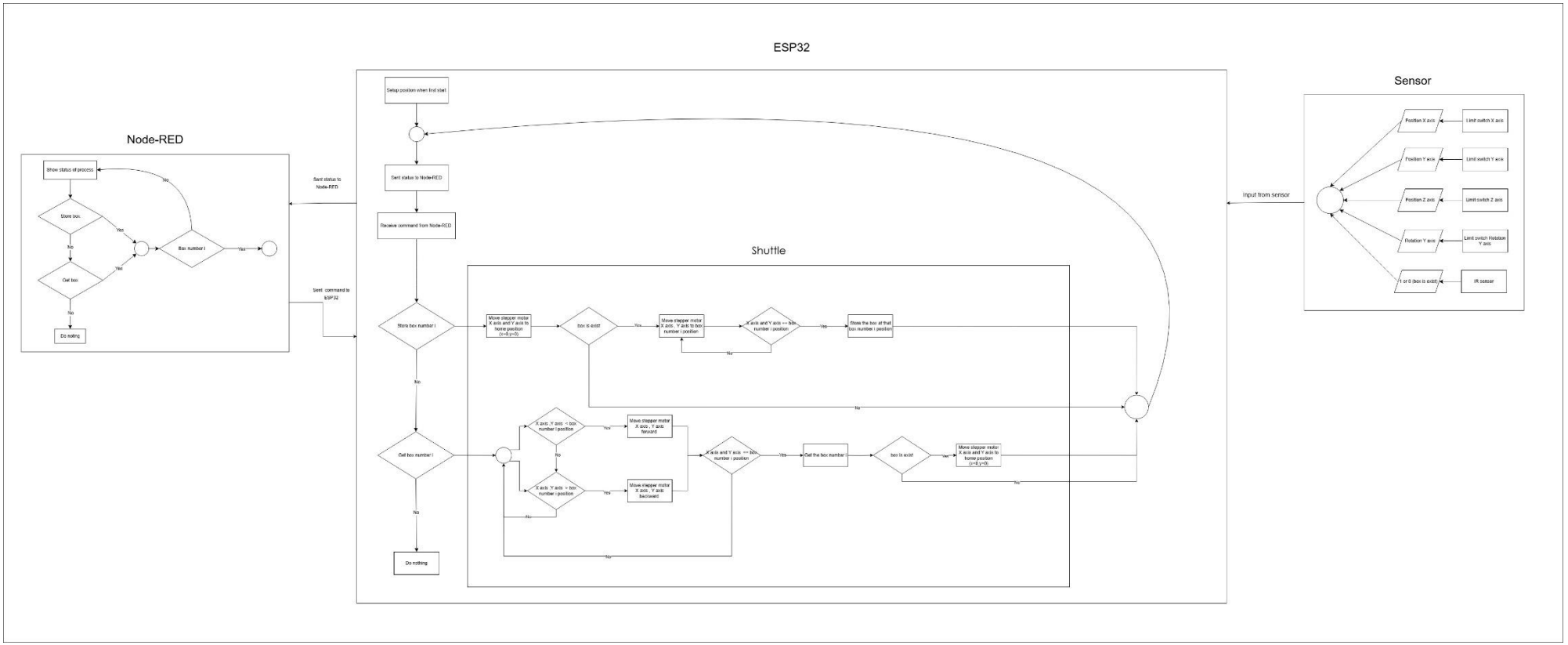

***Figure3-2* All System Architectur**

3.3 System Design

3.3.1 User Interaction

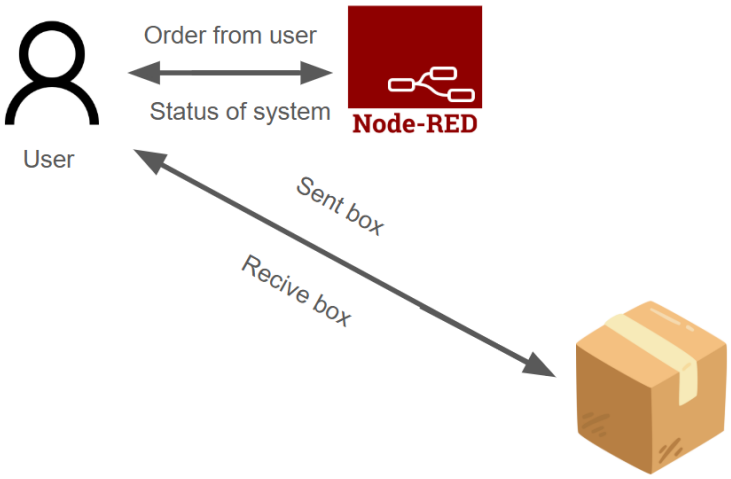

Figure3-3 User System

From the figure 3-3 users can send boxes to store or get box in fixed position after user do with the box user need to control by using Node-RED.

3.3.2 Node-RED System/User Interface

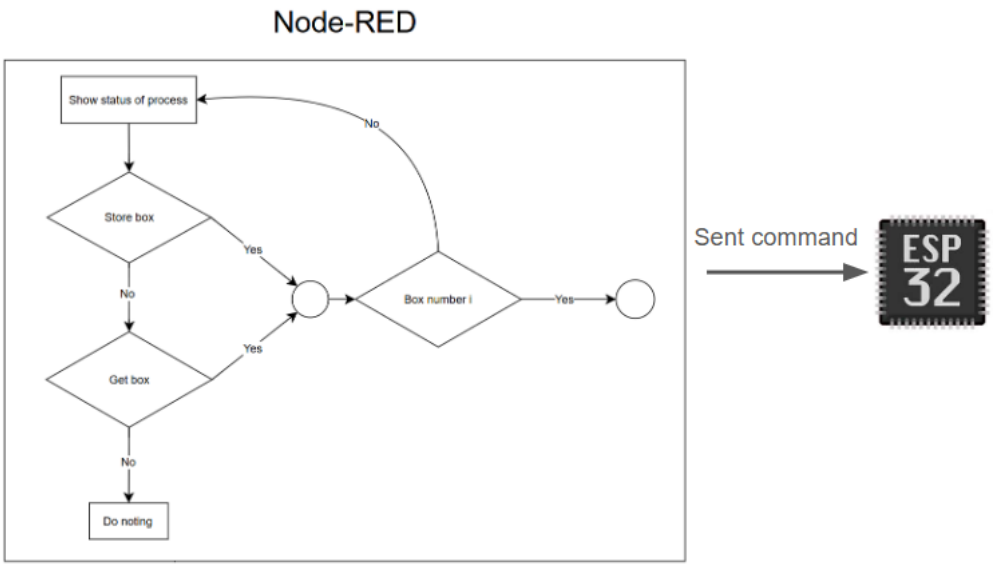

***Figure3-4* Node-RED System**

In Node-RED it will show the status of the process of working and have two buttons to choose to store box or get box after that it need to choose number of box and that send command to ESP32.

3.3.3 ESP32 System

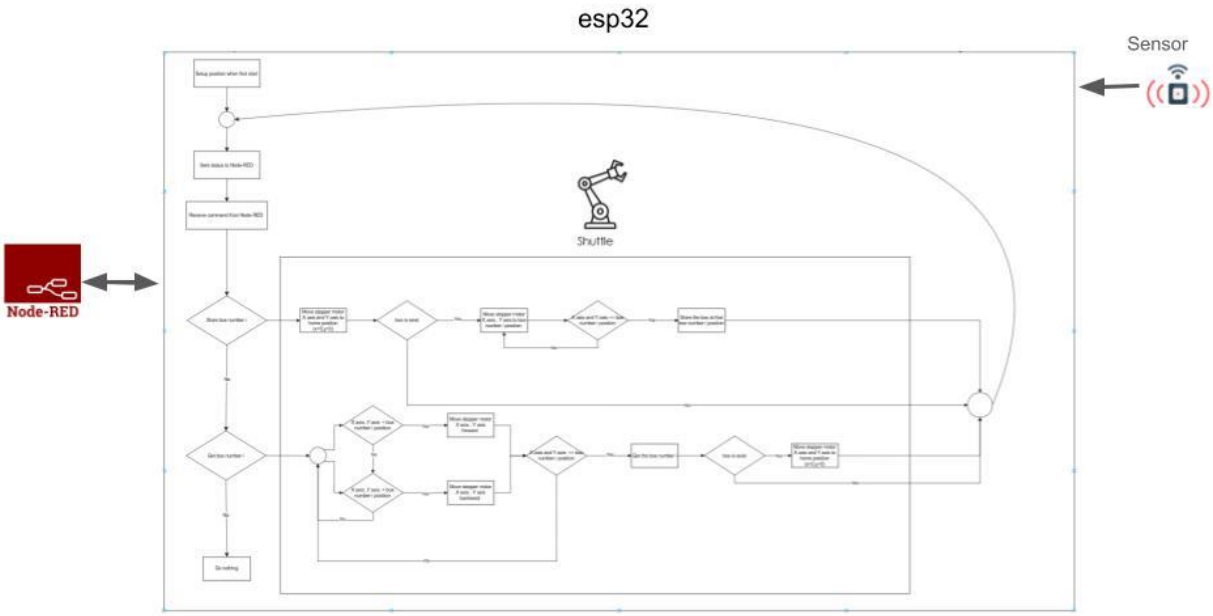

Figure3-5 ESP32 System

From figure 3-5 EPS32 will send the information to Node-RED and get command from Node-RED and get value from sensor and then ESP32 control the shuttle.

3.3.4 Shuttle Storage System

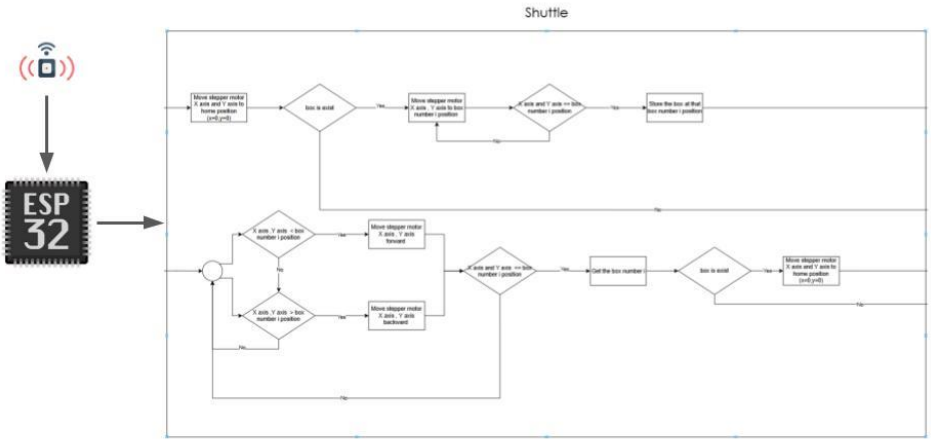

***Figure3-6* Shuttle Storage System**

Shuttle controlled by ESP32 it will go in each box position, at the same time ESP32 will read value from sensor.

3.3.5 Sensor Part

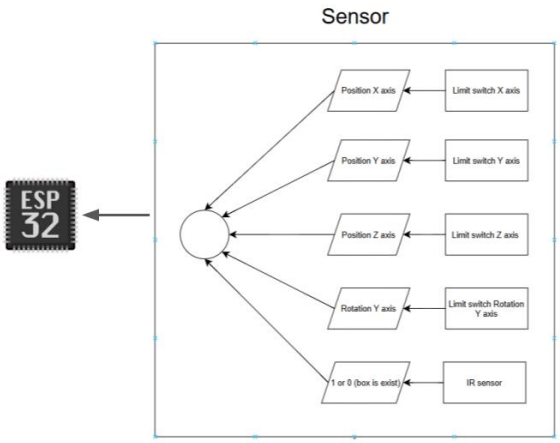

Figure3-7 Sensor System

From Figure 3-7 IR sensors are used for checking the box exists or not and for the limit switches it uses for check position of shuttle then send value of all sensors to ESP32.

3.5 Project Plan

Table3-1 Project plan

TASK	2025																			
	January				February				March				April				May			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Study the equipment required																				
Study the usage of the device																				
Test the actual use																				
Build a base and design the project																				
Create structure and write code																				
Develop/improve of code and 3d part																				
Do the node-red																				
Make report																				
Preparing for presentation																				
Presentation																				

Chapter 4 Results and Conclusion

In this chapter, is talking about the results of working with equipment like the ESP32 board, stepper motor, and A4988 module, and the obstacles of doing this project or the problem of this project and finding the solution to solve the problem for the future to make this project even better.

4.1 Operating Result

Study and experiment with devices such as esp32, stepper motor, A4988 module, limit switch and study basic information that is important for creating projects, write code to make stepper motor work and receive values from limit switch to bring the obtained values to control stepper motor and make some structures from 3d printer which are as follows.

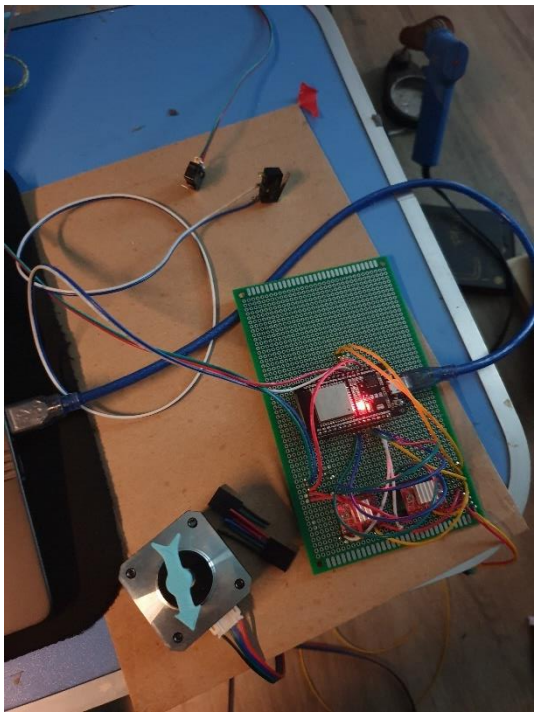

***Figure4- 1* Circuit board**

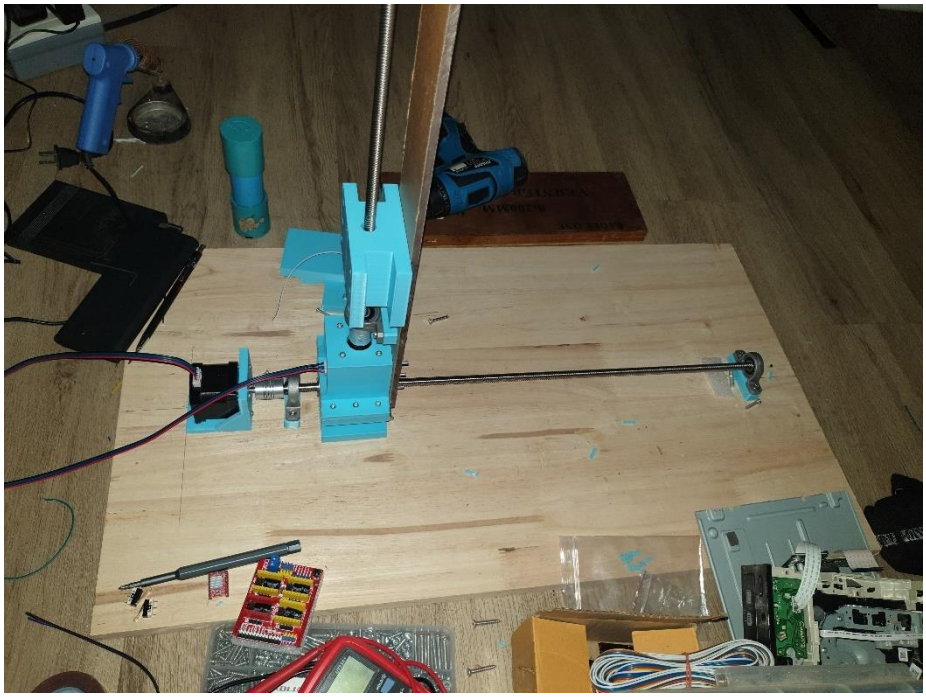

Figure4-2 Structure of shuttle storage

4.1.1 Working of Stepper Motor and Limit Switch

The code makes the stepper motor rotate in a counterclockwise or clockwise direction and reads the value from the limit switch to stop the stepper motor.

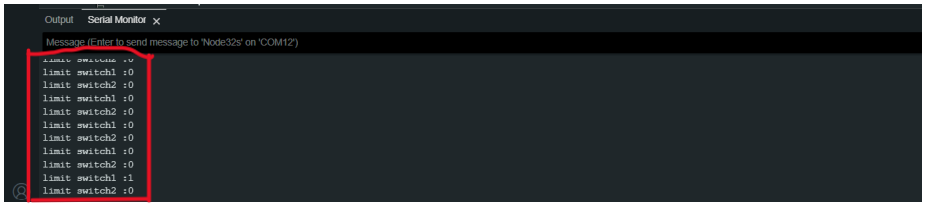

Figure4-3 Code of reding value from limit switch

From figure 4-3 it is about reading value from limit switch and log value by printing it in Serial to check it work or not and make if function to break when limit switch is 1 or high to stop stepper motor.

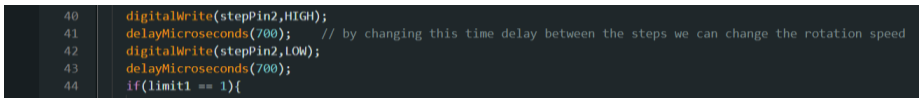

Figure4-4 Code of working of stepper motor

From figure 4-4 is about controlling the moving of stepper motor and controlling speed.

4.1.2 Working on node-red

This is the flow on node-red to make the project connect to wifi and to control it via wireless to make friendly with user

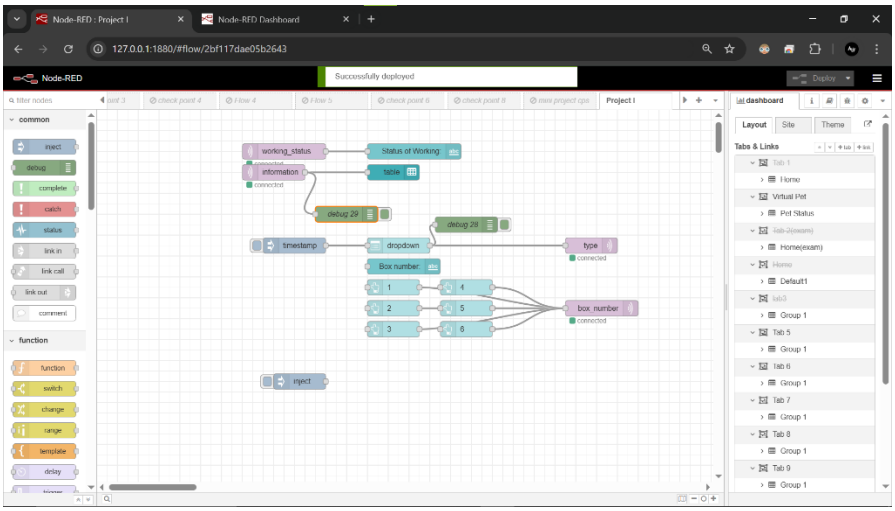

Figure4- 5 flow on node-red

From figure 4-5 it receive the command from esp32 2 node to get working status and information of the box and send the command 2 node to esp32 to control sending or receiving the box of each box number.

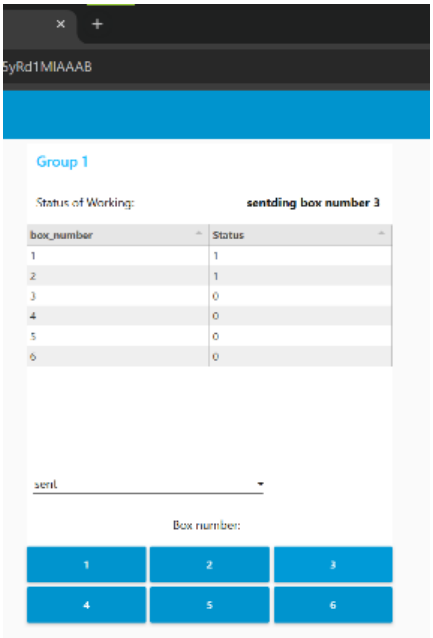

Figure4- 6 UI

From figure 4-6 on UI users can see the current working status, the existing of each box on the shelves and user can choose box number to send or receive.

4.2 Result

- Code
    - Read value from limit switch
    - Control stepper motor
- Structure of shuttle storage
    - Base of structure and 2 axis of shuttle storage

4.3 Problems and Obstacles

- The structure is not stable when moving in a horizontal direction
- It takes quite a long time to make 3D printed parts

4.4 Suggestions / Guidelines for further development

4.4.1 Suggestions

- Should study the use or related knowledge of stepper motor
- Should study the principle of robot arm movement
- Should study the adjustment in 3D printer use

4.4.1 Guidelines for further development

- Write code to make it more manageable
- Making web applications
- Improve structural components to be more stable
- Design and test the box gripper

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[1] The Invention, "**Arduino IDE** คืออะไร มีวิธีการติดตั้งโปรแกรมอย่างไร และการใช้โปรแกรมยังไงกันนะ" Available at: https://www.ai-corporation.net/2021/11/18/what-is-arduino-ide/ [Accessed: 20 Fabruary 2025].

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