DEVELOPMENT OF AN INTERACTIVE AUTOMATIC SMART BIN SYSTEM

By
Yap Xiang Ying

A REPORT
SUBMITTED TO
Universiti Tunku Abdul Rahman
in partial fulfillment of the requirements
for the degree of
BACHELOR OF INFORMATION TECHNOLOGY (HONOURS)
COMMUNICATIONS AND NETWORKING
Faculty of Information and Communication Technology
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ABSTRACT

The increasing population in Malaysia causes unsustainable waste generation. Malaysia must improve traditional waste management and reduce waste disposal in landfills. Nearly half of Malaysians are aware of environmental issues and recycling, as well as knowing waste segregation. Concurrently, traditional waste collection is low productivity compared to checking and emptying bins individually. The interactive automatic smart bin system is suggested as the solution. The smart bin can increase user engagement and encourage proper waste segregation behaviours, moreover, stays available by remotely monitoring the bin status and sending to the waste collectors. The proposed system classifies the class of waste based on images captured. The bin senses the type of recyclable waste such as paper, plastic, and metal, as well as the trash. Then, automatically sort the waste to dispose of in the appropriate bin. Thus, users don't have to worry about which bins to throw. The system is integrated with Wi-Fi to communicate with the bins. When the bin is full, the system will send a notification to waste collectors. Therefore, the waste collection uses less manpower, fuel cost, and time consumption.

Area of Study: Automation, programming

Keyword: Internet of Things, Arduino, Machine Learning, Computer Vision, Waste Management

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CHAPTER 1

Introduction

This paper aims to develop an interactive smart bin system with automation that is used to improve current waste management. This smart bin system recognizes the type of waste and automatically disposes the waste to the appropriate bin, as well as informs the waste collectors to empty the bins.

1.1 Problem Statement and Motivation

Malaysians lack understanding about recycling, thus misuse the recycling bins, including misplacement of recyclable waste types. Instead of using multiple sensors to classify the types of recyclable waste, they can also be classified using computer vision and machine learning with the captured images. Besides, efficient recyclable waste collection is important for ensuring confidence in recycling. Especially in the frequent collection of recyclable waste, without considering the condition of waste inside the traditional bins, waste collection consumes a longer time and additional manpower.

The goal of the proposed smart bin system is to develop an automated model for identifying, monitoring, and managing recyclable waste. A person without any knowledge of waste segregation and recycling just throws the waste into the smart bin, therefore smart bins will segregate the waste into the correct bins. This system uses the concepts of computer vision and machine learning to address the shortcomings of existing systems, including waste classification based on captured images. Moreover, the traditional waste collection may be improved since the system will notify the waste collector to collect the waste when the bin is full. Real-time bin status monitoring reduces the time, cost, and manpower in waste collection.

1.2 Project Scope

This project will develop an interactive automatic smart bin system, encompassing hardware and software components. This system integrated with image classification to replace the multiple sensors that used to classify the wastes. After the camera captures the images of waste, the trained machine learning model processes the captured image and delivers the results to the smart bin with information on which bin to dispose it correctly according to the types of waste. It will become a solution to address the inefficiencies in current waste management practices, particularly waste segregation by automatically classifying and sorting the waste into recyclable waste and trash. Bin status including fullness of bins and weight of the waste is continuously measured using the load cells and ultrasonic sensors. Rather than check on each bin physically, waste collector optimizes the waste collection since they could monitor each bin's status remotely. When the bin is full, the system also alerts them for collection.

1.3 Project Objectives

The project aims to develop an interactive automatic smart bin system for identifying, segregating and management of recyclable waste and trash.

The first project objective is developing a hardware prototype for the smart bin, with sensors integrated to recognize waste types and precisely track fill level. Construct a multiple-designed waste separation bin to be the hardware prototype. It is composed of four bins arranged in groups, categorized according to categories (plastic, paper, metal, trash). Next, the smart bin is divided into two segments: the upper segment implements a camera sensor for capturing the images of waste; the lower segment includes four bins and a rotary sorter controlled by servo motor to segregate the waste to appropriate bin based on the image classification.

Second, ultrasonic sensors continuously monitor the fullness of bins. When the bin is full, the system will notice waste collectors to pick up the waste. The waste collector will only receive the bin status that required for collection to avoid receiving too many messages. Implementing this system may raise the awareness and willingness of recycling since it optimizes the performance of waste collection.

Third, the proposed system ought to use computer vision and machine learning technologies in waste classification. The camera sensor obtains visual data (images) of waste and categorizes its class through trained machine learning model. The machine learning model of this system will focus on waste classification and train with appropriate dataset that comprises the images of recyclable waste (plastic, paper, metal) and trash.

1.4 Impact, Significance and Contribution

This smart bin system can enhance waste segregation through computer vision and machine learning technologies. Secondly, it also promotes recycling awareness to the public by implementing the smart bins into the recycling programs among communities. Thirdly, enhanced productivity of collecting waste encourage the waste management. Hence, by minimising the amount of waste disposed of in landfills, we can effectively mitigate environmental pollution. Additionally, this approach contributes to the conservation of natural resources and boosts sustainable waste management practices.

1.5 Background Information

As Malaysia’s population rises, it contributes to the growing generation of solid waste. In 2024, about 39,078 tonnes of solid waste were thrown away by Malaysians per day [1]. Additionally, the majority of waste ends up in landfills, including recyclable items. Plastic and paper are the main unmanaged recyclable waste among household waste in certain urban areas [2]. Malaysians’ recycling practice is still low that 33% of respondents will recycle the plastic, but 49% throw it as garbage [2]. For paper, only nearly half of respondents choose to recycle it [2].

Unsustainable waste generation causes environmental pollution and health issues. Most of the residents recruited in study understand that inadequate waste management contributes to the spread of diseases. This also contributes to climate change through methane emissions from landfills.

As a result, waste management needs to be practiced minimizing the direct disposal of solid waste into landfills, thereafter, lessen reliance on landfills. Malaysia must strengthen current waste management to ensure citizens live comfortably. Waste management involves collection, segregation, and recycling. Malaysia's recycling rate is lower than that of developed countries, achieving 30.67% in 2020 [3]. The waste segregation and recycling practice becomes the barrier of the development of waste management. This can be improved with a smart bin system using automation.

In this project, image classification will be used for categorising waste. This section involves computer vision and machine learning. Computer vision will enable smart bin to identify the waste in images through the camera sensor. Next, select an appropriate dataset including images of waste to train a machine learning model. Waste will be classified as recyclable wastes or trash with model. Based on the outcome from the model, the smart bin could sort the waste automatically, thus optimize the waste segregation.

1.6 Report Organization

This report is structured into seven chapters: Chapter 1 Introduction, Chapter 2 Literature Review, Chapter 3 Methodology, Chapter 4 System Design, Chapter 5 System Implementation, Chapter 6 System Evaluation and Discussion, and Chapter 7 Conclusions and Recommendations. Chapter 1 provides an overview of the project, outlining the problem statements, motivation, objectives, project scope, and key contributions. The second chapter is the literature review related to waste classification and automation of waste sorting. The third chapter is about required component of the system and the interaction between user and system. The fourth chapter consider the comprehensive system design of this project. The fifth chapter explain how to implement the system, including the hardware and software. The sixth chapter involves system testing and the measurement of performance of this system. The seventh chapter concludes this project and provide recommendations.

CHAPTER 2

Literature Reviews

2.1 Previous Works on Waste Classification

2.1.1 Classification without Computer Vision

Scoon designed an embedded recycle sorting system to segregate recyclable wastes in the household [1]. The recyclable wastes were divided into four categories: plastic, glass, paper, and metal. Visual systems and sensors struggle to segregate those recyclable wastes. The proposed system used an inductive proximity sensor to classify metal and sound of recyclable wastes being struck to segregate plastic, glass, and paper. However, paper including cardboard was erroneously categorized as plastic due to the similar sound. Furthermore, paper is the main recyclable waste in household waste. The system also lacked a user interface for user engagement in recycling activities.

Zulkifli and Nasir developed an automatic garbage segregation system. The type of garbage materials included plastic, paper, and aluminium [2]. To segregate the garbage materials automatically, the system implemented the infrared sensor and inductive proximity sensor. The infrared sensor was used to classify plastic and paper; The metal (aluminium) was detected using the inductive proximity sensor. Over 90% of the garbage has been accurately separated.

The design of the system of Scoon, Zulkifli et al. and Agarwal et al. used full automation that automatically classified and segregated the waste [1]-[3]. The bin was divided into two compartments. The compartment within the upper space of the bin was used to classify the recyclable waste. Another compartment with different partitions rotated to corresponding positions and waited for servo to drop the recyclable waste from the upper compartment. The partitions were designated for various categories of recyclable waste.

Hassan et al. presented an recycle bin with sorting automation using an Arduino microcontroller [4]. The bin can sort recyclable wastes including metal, paper, and plastic. The metal (aluminium) was classified using an inductive proximity sensor;

Paper and plastic were segregated using a light dependent resistor to measure light intensity. For example, paper blocked the light and was recognised as paper. All plastic bottles were disposed of in the correct component, paper was 17 out of 20 and aluminium was 15 out of 20. However, plastic bottles used in this paper were transparent. This could not cover all recyclable plastic.

Gupta et. al enhanced waste sorting using intelligent automation techniques [5]. Besides, to enhance system adaptability, the control systems implement machine learning induction algorithms. Regarding classification error, evaluation time, and formulation time, the comparison of learning algorithms (Simple Recursive Splitting, Neural Networks, and instance based) for materials sorting and glass sorting produced inconsistent results. The potential of segregating clear and unclear objects was demonstrated using the data of preliminary sensor obtained from light transmission and acoustic tests. Emitted sound waves were used to classify glass, metal, and plastics. Preliminary metal sorting used electromagnetic sensors.

2.1.2 Classification using Computer Vision

Ramsurrun et al. compared 12 versions of CNN algorithms which perform the identification on solid waste type over SVM Classifier, Sigmoid Classifier and SoftMax Classifier [6]. The Trashnet dataset contained images that were divided into six classes (cardboard, paper, glass, metal, plastic, trash). With a test accuracy of almost 88%, the results indicate that the VGG19 with SoftMax classifier is the most accurate. However, the dataset used images with white background. Thus, when the background is another colour/type, the accuracy doesn't meet expectations.

Machine vision and deep learning were applied to an automatic dry waste segregation system [7]. The aluminium cans, tetra packs and plastic bottles were among the solid dry waste. Researchers performed the waste classification using inception v3, the re-trained CNN model and a higher frame rate camera. The accuracy of classification is 90%. The proposed system sorted around 250 objects per minute.

Narayanswamy et al. aimed at computer vision algorithms for waste segregation [8]. The proposed dustbin was equipped with a camera module. Researchers compared the performance of CNN, YOLO and faster RCNN in detecting the image and classifying the type of waste. The faster RCNN object detection had the best result with 91% accuracy and 16% loss. However, it was the most computationally intensive algorithm, demanding significant computational power and a comprehensive dataset. The research limitation was that the waste images must match with the stored images or caused erroneous results.

2.2 Previous Works on Bin Status Monitoring

The gathered municipal solid waste may release hazardous gas. To prevent hazardous gas leakages, Sreya et al. focused on monitoring the bin level by controlling the lid closing [9]. Ultrasonic sensor was used to detect the fullness of bins. The servo motor opened and closed the lid of the bin. This system used low autonomy that categorized the recyclable waste types and guided users to dispose correctly. The motor with an ultrasonic sensor would not open if the bin was full. Gas sensor with a buzzer alerted officials after detecting hazardous gas. This bin was equipped with automatic light control according to human motion detection using PIR sensor and surroundings light intensity using Ambient Light Sensor.

Touchless recycle bins that automatically control the lid can avoid germs spread. Monitoring waste manually may cause longer waste collection. Implementing a real-time integrated waste management system based on IoT, enabled Internet connection for each recycle bin to send data to the database [10]. Through the use of cloud internet, the study developed connection between a monitoring centre and the recycle bin, which serves as a Remote Terminal Unit (RTU). The monitoring centre's web will be used to display the data, thus enable users to track waste mapping and real-time data about the waste like the volume and weight of waste online. A buzzer was on when the bin was full. In the system design testing, it was found that the weight sensor (ultrasonic sensor) data has an error reading percentage of 1.33%, while the load cell sensor weight readings deviate by 4%.

Mustafa and Ku Azir developed an IoT based system that tracked the level of garbage and alerted the local government [11]. The level of garbage was detected with ultrasonic sensor in the system. Next, ThinkSpeak will handle the data obtained from sensors. Four categories of garbage (paper, plastic, glass and domestic waste) were displayed on the LCD interface in real time. ThingSpeak can be accessed to check the garbage level anytime, anywhere. So, the system alerts the waste management service provider to collect garbage when the bin is full. However, this system didn't have the functionality of identifying the type of garbage.

Ramasamy et al. designed a residential centric waste management system based on IoT called I-Bin system [12]. The I-Bin system was a weight based smart recycling system. It’s hardware prototype consisted of Arduino Uno R3, load cells and bins, integrated with a Wi-Fi module to store the weight of waste on cloud through ThingSpeak. To test the system's performance, a seven-day test was carried out in a residential area in Bandar Puteri 8, Puchong. Recyclable waste was collected from households on average at a rate of 0.996 kg. This indicated that the I-Bin system has the potential to collect roughly 483 kg of waste from 10 similar residential areas. The bins were collected promptly upon reaching their threshold value, boosting efficiency, saving time, and notably reducing operating expenses for recycling companies. In the study, it was also found that residents prefer to dispose of recyclable wastes after office hours. The next study concluded smart trash bins can enhance people's willingness to properly dispose of garbage, leading to changing community attitudes towards waste disposal. The presence of smart trash bins increased the percentage of respondents disposing of trash correctly from 69.2% to 76.6%, indicating a positive perception change. Smart trash bins offer a solution to confront littering habits among the population.

2.3 Previous Works on Wireless Connection

2.3.1 GSM Module

GSM module enables Internet access through a cellular network that has coverage over a wide area, even poor Wi-Fi connection. Chand et al. and Wahab et al. developed a GSM-based notification system for smart bins [13]-[14]. Wahab et al. provided features that location tagging using GPS was contained within the message [14]. So, Google Maps application was used to find the location of a specific recycle bin received through SMS. Ghongane et al. discovered that a garbage collection system with a GSM module helps in collecting garbage on time [15]. Its advantages included less time delays and less response time. Jalani et al. deployed a GSM module on an Automatic Recycle Dustbin System [16]. The accuracy of the proposed system in sorting recyclable waste, which included wet, metal, and paper, was 95%. The GSM module sent a message that showed the distance between waste and ultrasonic sensors. Meanwhile, an LCD also displayed the status of bins such as ‘full’ or ‘50% full’. However, the cost of sending notifications through SMS was higher than the Wi-Fi network. For instance, a SIM card and data plan is required for the GSM module.

Researchers designed a smart monitoring and collection system for solid waste to replace the manual waste collection [17]. When the bin was full or more than half-full, the system allowed the Radio Frequency (RF) transmitter transferr signal to the control centre. Next, a message (SMS) was sent to garbage collection vehicles through GSM/GPRS. If the vehicle didn't empty the bin, this message will be sent to another vehicle after one hour. However, the improvement for the message is required if all vehicle drivers got off work or were unavailable. The system also showed the collected data in the GLCD screen.

2.3.2 Wi-Fi Module

Haque et al. proposed an IoT based waste collection system with three sub-systems: smart bin system, real-time monitoring system and navigation system [18]. This proposed system was equipped with a Wi-Fi transceiver to communicate with the server and use Google API as well as the IoT cloud. It allowed users to monitor the smart bins in defined areas, including temperature, fill level, fill status, humidity and level of surrounding Volatile Organic Compounds. Data collected from sensors was stored and processed on the cloud. The real-time monitoring system continuously updated which bins needed to be cleaned in any waste collection route. In addition, stored cloud data in graphical interface enabled users monitoring real-time data anytime, anywhere. The navigation system presented the most optimal route for collecting waste from selected bins. The decreased travel distance of garbage collection vehicles contributed to reducing manpower and fuel cost. However, the system must use IoT communication protocols (Wi-Fi/LTE/3G) as the bins were located in random places in the city of Michigan, but this can be solved using Routing Protocol for Low Power and Lossy Networks.

Smart systems using Wi-Fi and IoT were suggested for solid waste management [19]. This system used DeviceBit as a monitoring platform to remotely monitor the operation of bins. The real time data can be shown on the mobile phone, tablet, or PC. The information of bins included company name, house number, street number and number of bins. To improve the current system, GPS can be added to find the location of bins. However, these systems were limited for areas with a poor Wi-Fi connection.

2.4 Previous Works on Automatic Lid Mechanism

Bacteria got into hand by touching. Trash bins may be contaminated with bacteria. Abidin introduced the smart trash bin to prevent contact with bins [20]. The lid of the bin opened automatically when disposing of trash; and it closed automatically after collecting trash. The ultrasonic sensor detected someone within 50 cm, the lid will automatically open for 7 seconds. This bin was equipped with automatic sorting of organic and inorganic waste. Based on the data gathered by the capacitive proximity sensor, the servo motor rotated the waste sorter, separating the organic and inorganic waste. Carelessness of cleaning the full trash bins was a common problem in waste management, yet it contributed to bad odour. There was an LCD screen that presented the type of disposed waste.

2.5 Previous Works on Notification

The notification was sent using SMS via GSM module when the dustbin meets the requirement to collect the waste. Integrated Wi-Fi module, system informed waste collectors through email [18]. In addition, DeviceBit or Blynk or Telegram application sent notification in real time if the bin is full [2], [19]-[20].

CHAPTER 3

Methodology

3.1 System Design Diagram

3.1.1 System Architecture Diagram

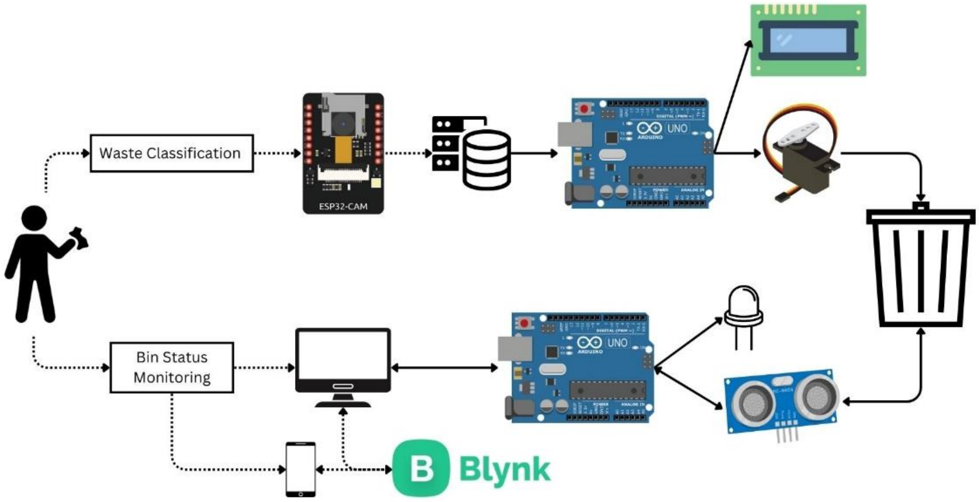

Figure 3.1 System Architecture Diagram

This project was conducted in order to develop an interactive automatic smart bin system, that involves Computer Vision and Machine Learning. The embedded system is divided into two parts: Waste Classification and Bin Status Monitoring. In waste classification, this system utilizes ESP32-CAM with USB base to capture and send images to laptop that turn into a local server. Next, the captured images are used to detect whether there are any waste items within the captured images. If waste items are detected, algorithms perform the waste classification. After receiving the result from classification model, server sent this result to microcontroller that is Arduino UNO. According to the results, Arduino UNO control the servo motor to sort the waste items to appropriate bin. Meanwhile, the LCD screen display the result and sorting process.

The fullness of the bin is monitored continuously. It is crucial for waste management which saves time and effort to check bins one by one. The smart bin uses four ultrasonic sensors to measure the distance as its bin level. These distances consistently send to the local server, as well as local server update the real time data to

Blynk. User could review the bin level through website and application on computer or mobile phone. If the bin is full, the system activates the corresponding red LED of that bin to indicate users surrounding stop using that bin and alert waste collectors to empty the bin as soon as possible.

3.1.2 Use Case Diagram and Description

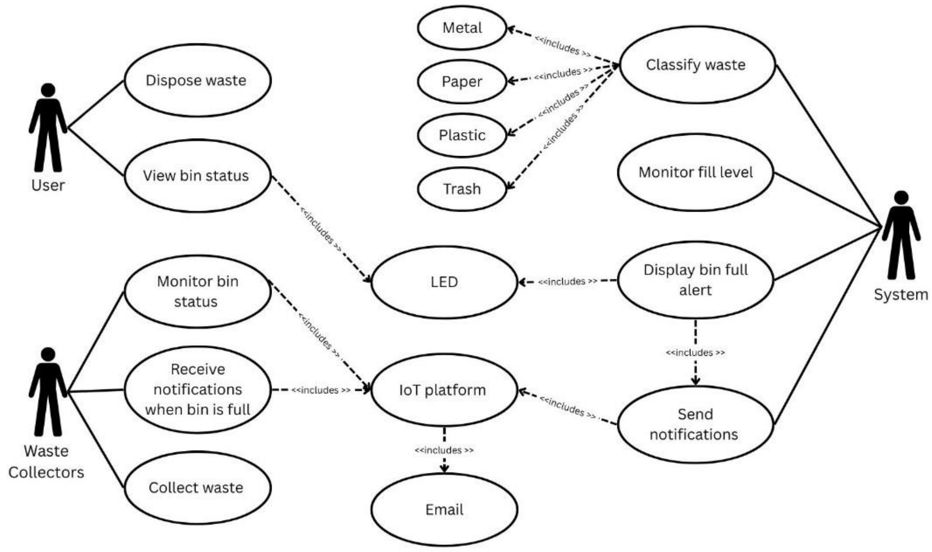

Figure 3.2 Use Case Diagram

Based on Figure 3.2, this diagram illustrates the interaction between the user, waste collector and the system, performing the system's main functionalities. The first actor is the user, who dispose the waste to this smart bin. Meanwhile, they could realize the availability of bin for each waste type (paper, plastic, metal, trash) through LED.

The second actor in this use case is waste collector. Optimizing waste collection routes by obtaining the real-time information from bins. They remotely monitor the bin status through IoT platform. Thus, they arrange waste collection after receiving the alert of full bin.

The third actor is system that process waste classification and monitor bin status in the backend. When the bin is full, microcontroller turn on appropriate LED, as well as IoT platform automatically notice the waste collector via email.

3.1.3 Activity Diagram

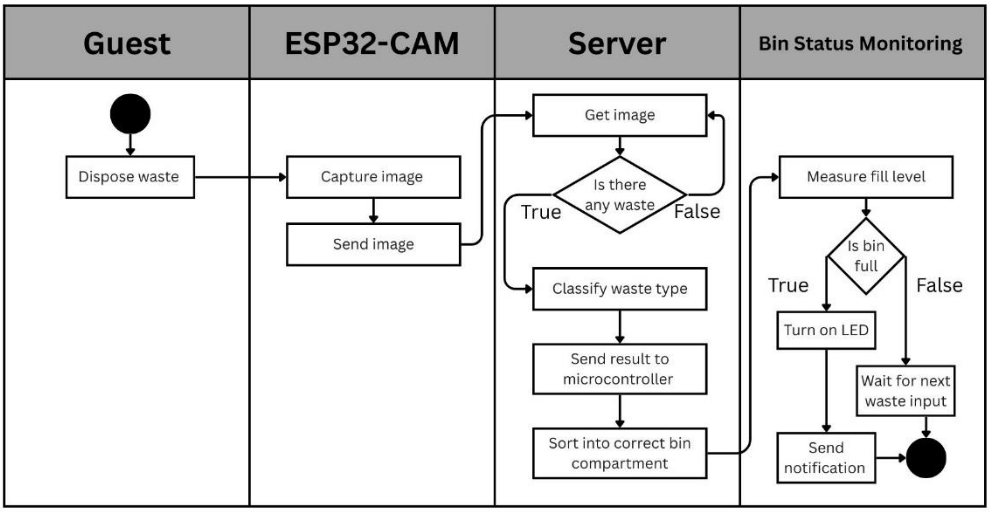

Figure 3.3 Activity Diagram

According to Figure 3.3, Activity Diagram represents the workflow of this system. First of all, a guest disposes the waste to this smart bin. Next, the ESP32-CAM capture images continuously and send it to the server. When server receiving the image, it firstly determines if the captured images contain any waste items. If contain the waste items, server categorize its waste type and send the result of classification to microcontroller to sort the waste to correct bin compartment. If there is no waste item within the image, server will ignore this image and wait for next image. Besides that, each bin's fill level is continuously monitored. When the bin is full, microcontroller turn on the LED of related bin, meanwhile a notification is sent via email, else this system will wait for next waste input.

CHAPTER 4

System Design

4.1 System Block Diagram

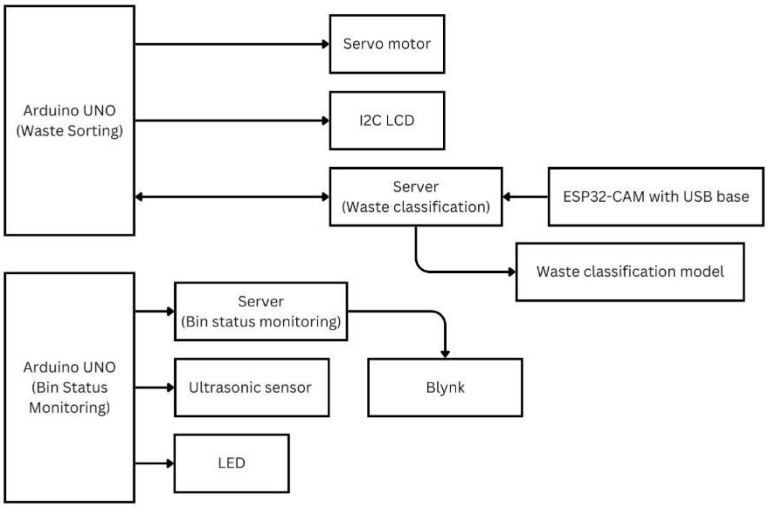

Figure 4.1 System Block Diagram

According to Figure 4.1, this diagram presents the system block of this project. The three main microcontrollers are two Arduino UNOs and a ESP32-CAM with USB base. In this system, one of the Arduino UNO is used for waste sorting, integrated with servo motor that sort the waste items and I2C LCD that display classification result and sorting process. It also communicates with a server to receive the classification results and transmit the sorting process. Another one is used for bin status monitoring, interfaced with ultrasonic sensor that measure the fill level and LED. It also updates the data to Blynk through server. Lastly, the ESP32-CAM consistently capture and send the images to server.

4.2 System Components Specifications

Table 4.1 System Component Specification

System Components	Description
Server	• Laptop: Hosts two Python scripts • Waste classification: Performs on-device classification of waste images into

	categories and send it to Arduino UNO via serial. • Bin status monitoring: Receives real-time data of fill level from Arduino UNO via serial and transmit it to Blynk
Arduino UNO	Serial Communication between Arduino UNO and Python
ESP32-CAM with USB base	Capture and send real-time images to server via Wi-Fi
Servo motor	Rotate to sort the waste items to appropriate bin
I2C LCD	Display message including classification result and sorting process
Ultrasonic sensor	Measure the fill level of bin

Table 4.1 shows partial component and their specification in this system. Each component has its own functionality in this project.

4.3 Circuit and Components Design

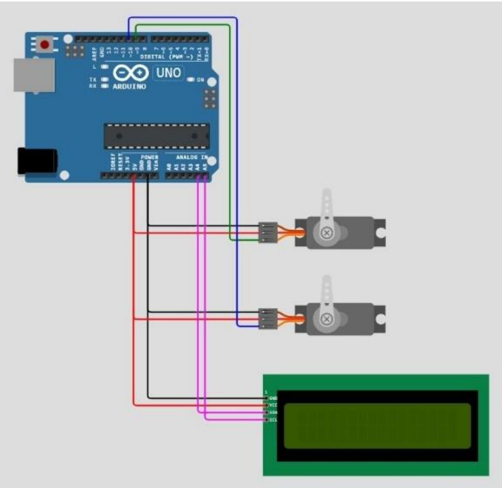

Figure 4.2 Circuit for Waste Sorting

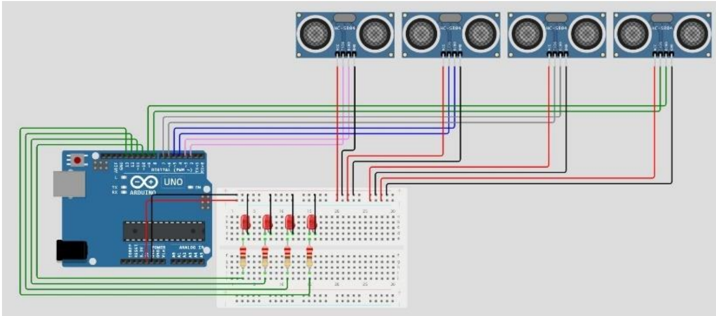

Figure 4.3 Circuit for Bin Status Monitoring

Figure 4.4 ESP32-CAM with USB Base

Figure 4.2 and 4.3 show the circuit diagram of this project, which is Arduino for waste sorting and bin status monitoring. In Figure 4.2, two servo motors and an I2C LCD are wired to Arduino UNO. Additionally, servo motors and I2C LCD require at least 5V to function. On this Arduino board, each servo motor uses a digital pin, as well as I2C LCD uses two analog pins. In Figure 4.3, this circuit contains four ultrasonic sensors and four red LEDs. Each ultrasonic sensor needs 5V and two digital pins to provide distance measurement. Plus, each LED uses a digital pin and a 220-ohm resistor. Figure 4.4 shows the ESP32-CAM with USB base. Thus, this component does not need extra wiring, except a cable for power supply.

4.4 System Component Interaction Operation

4.4.1 ESP32-CAM

ESP32-CAM with USB base simplifies the step of wiring, it just needs a USB base and a cable. This also lets ESP32-CAM focus on Computer Vision. A wireless connection is established between the ESP32-CAM and the server using laptop's mobile hotspot. It ensures the ESP32-CAM and the server is on the same Local Area Network. While ESP32-CAM captures images, it transmits the images to server through direct IP address access.

4.4.2 Waste Classification Model

The dataset contains about 2,400 waste images that are selected from Kaggle. The categories of waste include cardboard, glass, metal, paper, plastic and trash. In this project, the cardboard is sorted into paper bin and glass is sorted into trash bin. Thus, this system delivers 6 categories of waste item and sorts them into 4 bins (metal, paper, plastic, trash). I trained a classification model using Jupyter Notebook, leveraging a Kaggle dataset and a pretrained ResNet50 model. Next, the model is converted from Jupyter Notebook to ONNX, then converted to TensorFlow Lite. Furthermore, I created a Python script to load TensorFlow Lite model. Additionally, it looks for images of waste stored in the laptop then perform image classification inference.

4.4.3 Waste Sorting

After receiving classification result from server via serial, Arduino UNO control servo motor turn to four direction that placing different bin then threw it into the bin. While sorting, the I2C LCD screen also shows the classification result and sorting process,

4.4.4 Bin Status Monitoring

The ultrasonic sensors are placed on the top of bins. It is used to measure the distance between waste and the top of bins. Arduini UNO collect the fill level of bin using ultrasonic sensor. If the percentage of bin level is larger than 80%, Arduino UNO will turn on the red LED of corresponding bin. This data also transmits to server that host another Python script that used for uploading data to Blynk. Thus, user could monitor bin status remotely through Blynk. This system also implements the Automation in Blynk to send email notification when the percentage of bin level is larger than 80%.

CHAPTER 5

System Implementation

5.1 Hardware Setup

Table 5.1 Hardware Setup

Hardware	Description	Connection/ Interface	Purpose/Function
ESP32-CAM	Wi-Fi-enabled microcontroller with built-in camera	Wi-Fi (same LAN as laptop)	Captures images of waste and sends them to the server
Laptop (Server)	Local server running Python, PHP and XAMPP	Wi-Fi + USB to Arduino (Serial COM)	Stores image, performs classification using TFLite, upload data toBlynk
Arduino Uno	Microcontroller board	USB to laptop	Receives classification result and drives the servo motor; Collect data from ultrasonic sensor and activate LED
Servo Motor (180° & 360°)	Actuator that rotates to specific angles	Connected to Arduino PWM pin	Directs waste into the appropriate bin based on classification
I2C LCD Display	16x2 LCD with I2C interface module	I2C	Display messages like classification and sorting process
Ultrasonic Sensor	HC-SR04	Trigger & Echo pins to Arduino	Detect the fill level of bin

LED	Red	Digital output pin	Indicates fill level

Table 5.1 introduces hardware required for this project and setup. It explains how to connect some of them wirelessly and interface with other hardware. It also provide each hardware's functionality in this project.

5.2 Software Setup

Table 5.2 Software Setup

Software	Description
Arduino IDE	Used to write, compile, and upload code to the Arduino Uno and ESP32-CAM
Waste Classification Model (TFLite)	Hosts the classification script and handles serial communication with Arduino
PHP (XAMPP Server)	Accepts image uploads from ESP32-CAM and stores them in the folder
Python	Hosts the classification script, handles serial communication with Arduino and upload real-time data of bin status to Blynk
Blynk	Display real-time bin status

Table 5.2 shows the software needed to build the smart bin system and its functionality.

5.3 Setting and Configuration

Table 5.3 Setting and Configuration

Item	Details
ESP32-CAM Wi-Fi	Use the laptop's mobile hotspot; Configure with local network SSID and password in the Arduino code; Network band must be 2.4 GHz

ESP32-CAM (Arduino IDE)	Include the IP address of server computer to transmit image
PHP (XAMPP Server)	Start Apache and MySQL module service in XAMPP Control Panel
onnx2tflite	• Download this module from GitHub • Create a virtual environment with Python 3.10 in Command Prompt and install below module: o TensorFlow 2.12 o onnxruntime o onnx_simplifier • Follow its instructions to install and convert the ONNX file
Serial Communication	Identify correct COM port for Arduino
Arduino Baud Rate	Match baud rate in Arduino and Python (e.g., 115200)
Blynk Virtual Pin and Automations	• Set up Virtual Pin for each waste type • Unit is percentage • Ensure it turns on Expose to Automations including condition and action o Automation type is sensor
Blynk Authentication	Configure correct Blynk token in Python script

Table 5.3 mentions the setting and configuration, especially for the software required. This table includes wireless connection, local server environment setup, convert the format of model, serial communication between Arduino and server, as well as remotely monitor data from sensors.

5.4 System Operation (with Screenshot)

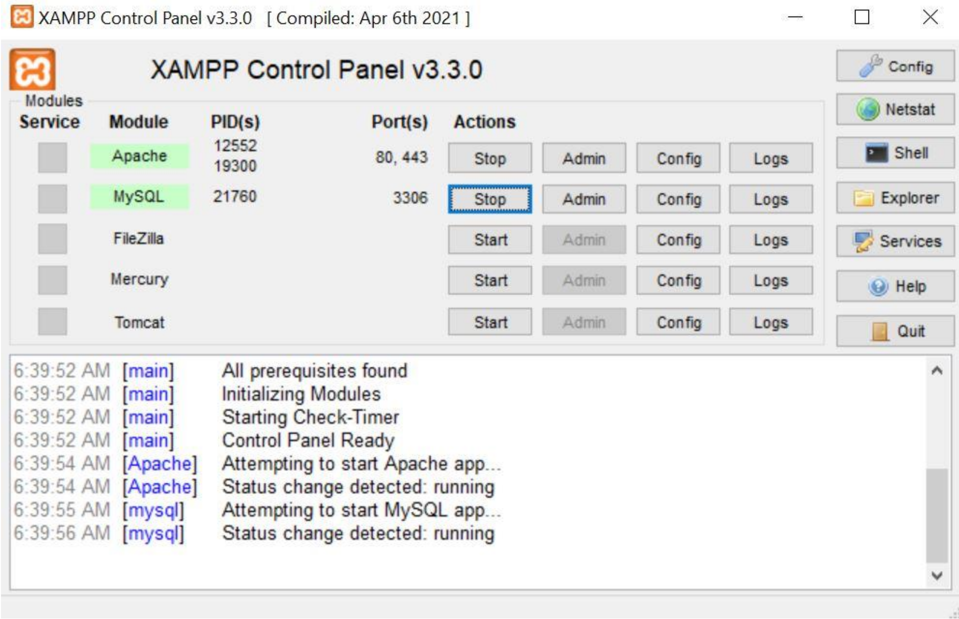

Figure 5.1 XAMPP

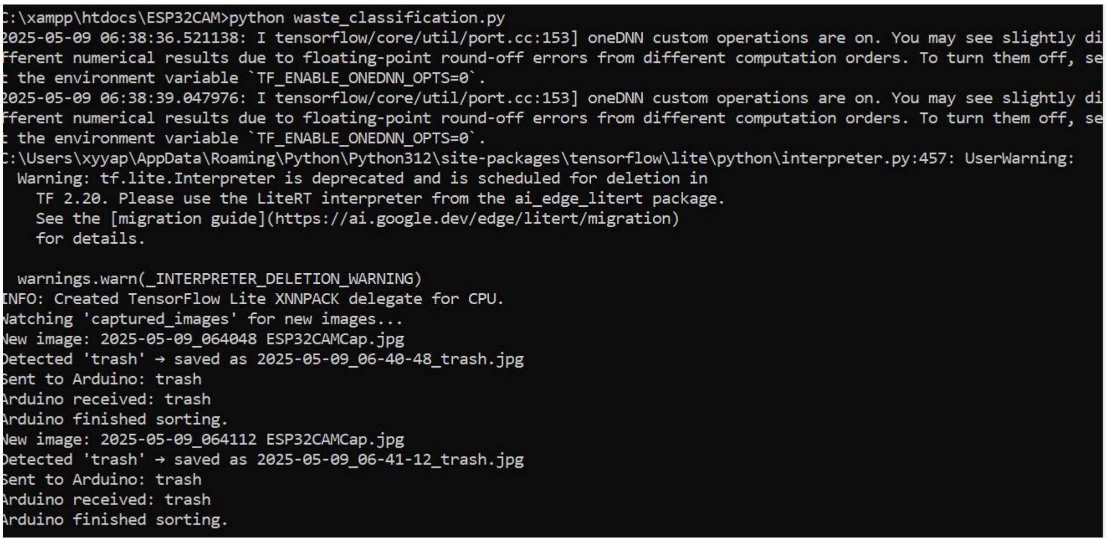

Figure 5.2 Python Script of Waste Classification

Figure 5.1 shows the operation of transmitting image captured, in addition, XAMPP host the PHP file that used to receive and store images. Figure 5.2 shows how the Python script works on getting image captured from laptop (server), waste detection, waste classification and serial communication with Arduino.

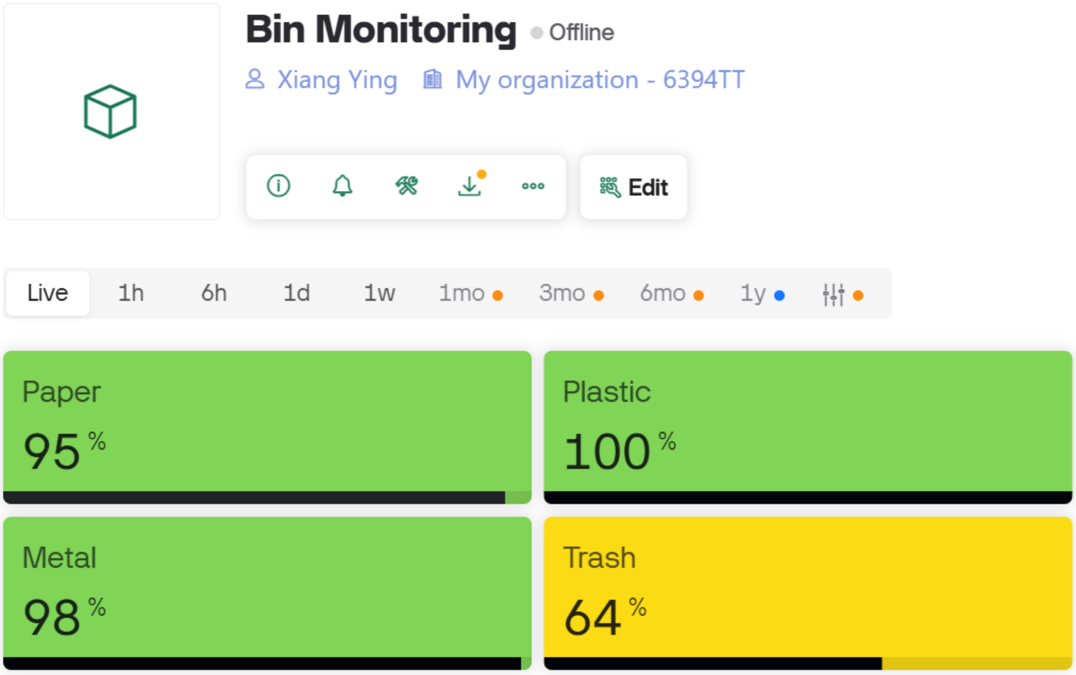

Figure 5.3 Blynk Dashboard

```
C:\Users\xyyap\Documents>python distance_blynk.py
Raw: Paper:10,Plastic:0,Metal:2,Trash:35
Sent Bin Paper: 92 % full to V1
Sent Bin Plastic: 100 % full to V2
Sent Bin Metal: 100 % full to V3
Sent Bin Trash: 66 % full to V4
Raw: Paper:10,Plastic:3,Metal:2,Trash:32
Sent Bin Paper: 92 % full to V1
Sent Bin Plastic: 99 % full to V2
Sent Bin Metal: 100 % full to V3
Sent Bin Trash: 69 % full to V4
Raw: Paper:10,Plastic:3,Metal:2,Trash:35
Sent Bin Paper: 92 % full to V1
Sent Bin Plastic: 99 % full to V2
Sent Bin Metal: 100 % full to V3
Sent Bin Trash: 66 % full to V4
```

Figure 5.4 Python Script of Bin Status Monitoring

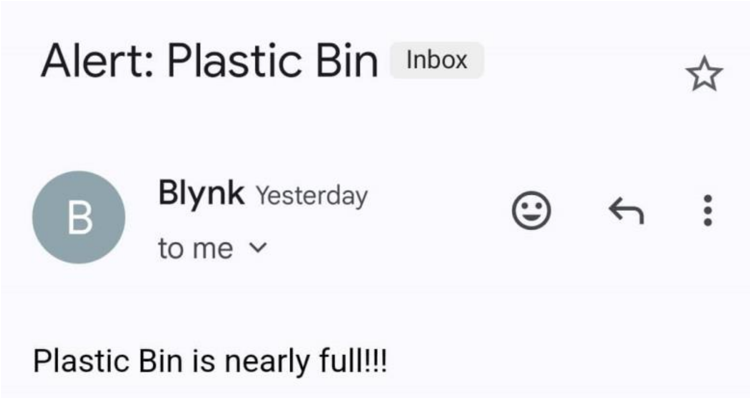

Figure 5.5 Email Notification

As Figure 5.3 shows, bin status could be monitored remotely through Blynk. The Blynk dashboard displays the fill level of each bin, additionally modifying the color of widget according to fill level. Figure 5.4 shows the Python scripts that used to receive data of bin status from Arduino via serial, then send data to Blynk Virtual Pins (V1, V2, V3, V4) that assigned to each sensor. In Figure 5.5, when a bin is full, Blynk Automation send an email notification to specific email addresses.

5.5 Implementation Issue and Challenges

One of the issues and challenges for this system is stable wireless connectivity. During development, I cost several time on connecting ESP32-CAM with Wi-Fi due to it cannot connect to home Wi-Fi or mobile phone's hotspot. Finally, I found that it can connect to my laptop's hotspot. In real environments, we also could not ensure that the location where the smart bin has stable wireless connection since this system needs to transmit the images and upload real-time data to Blynk. These features require stable wireless connection.

Moreover, another one is the limited number of messages in Blynk. This message is used to upload data from Arduino. However, there is a limitation on message used that is 30,000 messages per 30 days. This can be solved by limiting the number of messages used, but this system wouldn't show real-time data.

5.6 Concluding Remark

This chapter mentions the hardware and software setup, how to configure this system and the implementation issues and challenges. This system is divided into two parts:

waste classification and sorting, as well as bin status monitoring. This system's main features contain image capture, waste classification, waste sorting and bin status monitoring.

CHAPTER 6

System Evaluation and Discussion

6.1 System Testing and Performance Metrics

Table 6.1 System Testing

Test Case	Expected Result
ESP32-CAM Wi-Fi Connectivity	ESP32-CAM connects to local network
Image Capture Test	ESP32-CAM captures and uploads image via PHP
TFLite Classification Test	Model classifies waste correctly
Serial Communication with Arduino	Arduino receives full string message via serial
Servo Movement Test	Servo rotates correctly to specific angles
Blynk Update Test	Blynk app displays correct fill level remotely

Table 6.2 Performance Metrics

Metric	Measured Value	Description
Classification Accuracy	~90%	Percentage of correct predictions made by the TFLite model

6.2 Testing Setup and Result

Table 6.3 Testing Setup

Component	Description
Laptop (Server)	Running Python script, PHP server (XAMPP)
Wi-Fi	Local area network used by both ESP32-CAM and the server for file transfer

Test Objects	Sample waste items (paper, plastic, metal, trash) used for classification testing
Software	Arduino IDE, Python, , XAMPP, Blynk

```
num_epochs = 8
opt_func = torch.optim.Adam
lr = 5.5e-5

history = fit(num_epochs, lr, model, train_dl, val_dl, opt_func)
```

```
Epoch 1: train_loss: 1.0700, val_loss: 1.1201, val_acc: 0.9171
Epoch 2: train_loss: 1.0652, val_loss: 1.1385, val_acc: 0.9034
Epoch 3: train_loss: 1.0562, val_loss: 1.1198, val_acc: 0.9229
Epoch 4: train_loss: 1.0524, val_loss: 1.1257, val_acc: 0.9127
Epoch 5: train_loss: 1.0593, val_loss: 1.1154, val_acc: 0.9190
Epoch 6: train_loss: 1.0563, val_loss: 1.1130, val_acc: 0.9322
Epoch 7: train_loss: 1.0530, val_loss: 1.1295, val_acc: 0.9156
Epoch 8: train_loss: 1.0566, val_loss: 1.1069, val_acc: 0.9390
```

Figure 6.1 Accuracy When Training

Figure 6.2 Test Object

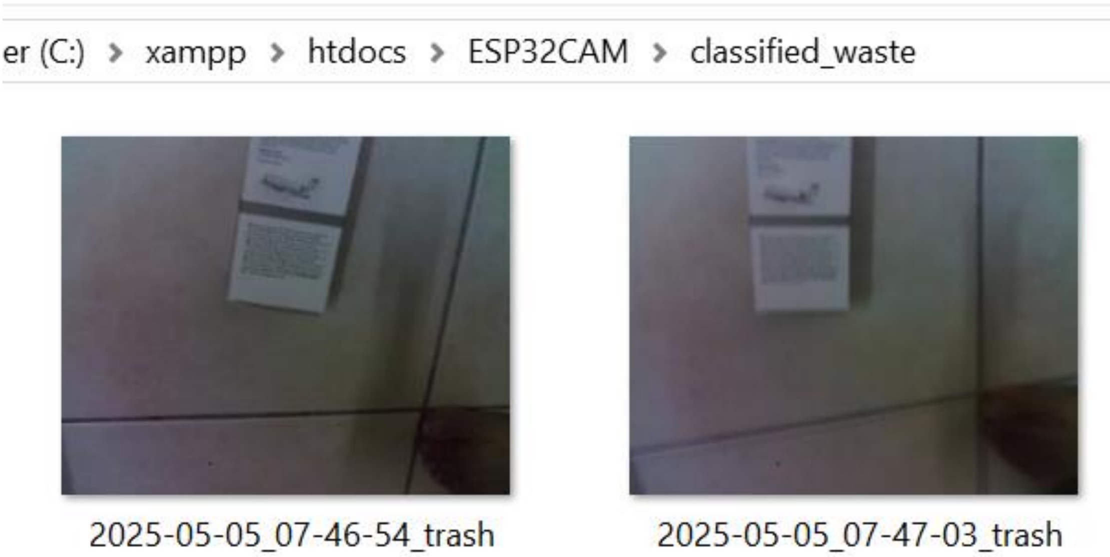

Figure 6.3 Result of Waste Classification

Table 6.3 shows the component that required for system testing and how to setup them. Based on Figure 6.3, Python script renames the image with date, time and categorized waste type after classifying, but the waste type does not match with the test object. However, the accuracy is greater than 90% during training, which means the classification accuracy in real environment was observed to be lower than expected.

6.3 Project Challenges

The largest challenge of this project is low classification accuracy in real environments. This may be due to limited or unbalanced training data, poor image quality, or similar visual features between categories. These inaccuracies could affect the sorting instruction, leading to incorrect waste allocation. Thus, it will increase the cost of manpower and time on categorizing.

Besides, I have tried to connect ESP32 with Blynk for directly updating the fill level. On the other hand, ESP32 always keeps reset the connection, causes offline every few seconds. Fortunately, I find that I could update the data to Blynk through Python script, as well as it is easier to upload code to Arduino compared with ESP32.

Thirdly, the format convert of classification model from ONNX to TFLite costs me lots of time due to misleading. Common method for this converting that I searched on the internet is from ONNX to TensorFlow, then from TensorFlow to TensorFlow Lite. However, required module for this method stop updating since 2023 as well as cannot download. Thus, this method is unusable. The final method I used is directly convert ONNX to TFLite. Aside from that, I excessively focused on convert ONNX to TensorFlow.

Next, the size of waste classification in TFLite format is 89MB. However, even the TFLite Micro model file is too large for ESP32-CAM, due to its flash memory only has 4MB. Thus, I require to modify the feature of ESP32-CAM, looking for new method other than directly classifying. Then, the solution is using ESP32-CAM for capturing image only, just consider where to send and store these images. Additionally, Python script can check images that stored in specific folder and run the classification model.

6.4 Objective Evaluation

The goal of the project was to develop an interactive automatic smart bin system for waste management including waste classification and sorting plus bin status monitoring.

The hardware prototype includes ultrasonic sensors, a camera sensor and servo motor. The system successfully captured images every few seconds using camera sensor and store it to specific folder. The ultrasonic sensor continuously measures the fill level of bin. Furthermore, rotary sorter controlled by servo motor is used to segregate the waste.

While consistently collecting data from ultrasonic sensor, Arduino also turn on the LED to inform user the unavailability of bin, meanwhile send the data to Blynk via Python. In Blynk Automation, when the bin level access more than a specific value, it will send an email notification.

Camera sensor works well in capturing images. However, in real situations, the waste items were occasionally misclassified. This may confuse the waste sorting, additionally bin status monitoring.

6.5 Concluding Remark

Most of the component within this system function well such as image capturing and bin status monitoring. However, the accuracy of waste classification is too low to implement in this project.

CHAPTER 7

Conclusion and Recommendations

7.1 Conclusion

Waste segregation plays a crucial role in waste management. The mixture of recyclable waste and trash not only increase the difficulty in recycling practice but also reduce the number of recyclable wastes such as polluted paper. Lack of understanding about recycling leading to various problems including misuse of recycling bin. Recycling bin unable to perform its original function, that provide multiple bins for storing different types of recyclable wastes. In addition, waste collectors consume additional time and effort on segregating the waste, thus reducing the productivity of waste management. Besides, waste collection on time is emphasized in order to improve current waste management. Intergrading with waste segregation, which consist of four bins (paper, plastic, aluminium can and trash), these bins may have different usage frequency, as well as require different collecting frequency. In current waste management, waste collector needs to collect the waste regardless of the bin status.

This project aims to develop a smart bin system involving classifying, segregating and monitoring the waste (recyclable waste and trash). The smart bin offers bins for both recyclable waste and trash, which means it is not limited to hold the recyclable waste only. Although user confused about the recycling or ignore the waste's type they are throwing in, smart bin will automatically categorize the waste and sort it into the correct bin. The automation in waste segregation led to ease and convenience of recycling. Even though users are unaware that their waste can be recycled or not, the waste they thrown will be segregated appropriately. To optimize the waste collection, when the bin's fullness reaches a threshold, the system will inform the waste collector to collect the waste timely. Remotely monitoring the bin status result in the reducing cost of waste collection, since the waste collector just collect the waste from bins fulfilled the requirements. It may reduce the time and effort compared to the current waste collection. The waste collection on time also encourages willingness to participate in recycling practices, seeing that the residents could make effective use of the bin.

This smart bin implements image classification to categorize the waste. Additionally, a Machine Learning model is trained for image classification focusing on waste. After classification, the sorter controlled by servo motor will segregate the waste into the correct bin. Inside the bin, there is ultrasonic sensor detect the fullness of the bin. When the bin is full, system will send the information of the selected bin to the waste collector.

7.2 Recommendations

To improve the waste classification's accuracy, augment the training dataset with more diverse and representative images of underperforming waste categories. For example, choosing certain waste are more commonly found in Malaysia. Following with retrain the classification model, then improve the image capture quality.

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APPENDIX

POSTER