ECTE250 Deliverable 2

wasteClassify Detailed Design Report

Team 9

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Executive Summary

This detailed design report is the second deliverable of a two semester course(ECTE250). It contains an **alignment** section, an **introduction** section, a **technical design** section and a **marketing and project management** section. The alignment section will describe how the project aligns with the course requirements, the introduction will be a brief on the project, the technical design section will dive deep into the decided on design for the implementation of the product separating the hardware and software side showing the planned implementation for each and the marketing and project management section will go through the proposed marketing scheme and the plan that is in effect for an efficient mode of delivering the product. The appendix section contains information that may be relevant to the reader to get a better perspective of the report. The references section contains references that were used to determine some of the information that was used in the report. Another section that may be significant to the reader is the budget section(Bill of Materials) which will come under the technical design including a table of costs and a brief description on what each material will be used for in the overall design.

Introduction

The proper recycling of waste could benefit society in both economic terms and in terms of trying to navigate out of a climate crisis. When items like plastic are sent to landfills it can take them numerous years to decompose naturally. When items like these are sent to landfills, it also means there will be a demand to produce more which is terrible for the environment.

It has been found that one of the primary reasons that people do not dispose of waste properly is convenience. If it is not convenient to recycle something(put it in the correct bin), then most people will not[11].

To try and help with this, our team has developed wasteClassify. wasteClassify is an intelligent waste bin which captures an image of the waste that is thrown into it and classifies this waste into the appropriate section. This will increase the rate of materials that are being recycled meaning it will significantly also decrease the amount of recyclable materials being sent to landfills.

wasteClassify will enable office buildings, schools and universities to properly recycle materials and to significantly reduce their carbon footprint. Due to the nature of the sites that wasteClassify is going to be deployed at, it will significantly reduce the amount of items like plastic bottles being sent to landfills.

Alignment

This project aligns well with the course requirements. It meets the reduce, reuse, recycle class. It also incorporates **6 motors** along with a **sensor**, **microcontroller** and **software**. Members of the group executing the project will get a chance to work on different components of the system and will gain very valuable insight into both the engineering and marketing side of projects. There are some constraints that wasteClassify had such as handling a bag of waste or heavier than moderate waste, but it was decided to narrow the targeted customers to meet these requirements.

The product also aligns with **UN SDG goal 12.** This will make it a product that is contributing to global welfare. This will also increase the appetite of the consumers especially those in the hospitality and education sectors.

It will also be seen further in the report that the project falls below the budget set at **900 AED**. Overall, wasteClassify aligns well not only with the course requirements, but also aligns with other initiatives such as the UN SDGs.

Technical Design

Software Architecture for wasteClassify

wasteClassify will consist of a very simple software that will have the following functionalities:

- Interface the camera with the model.
- Keep track of materials recycled.
- Try to estimate when the bin is full and send a notification email to the registered personnel.
- Change the contact of the personnel to be notified when the trash is full.
- Send a signal to the microcontroller when the trash is full.
- Get an update from personnel that trash has been emptied(send update to the hardware).

For these functionalities we will need to have a **REST API**, a **dashboard**(very simple) and ofcourse the **model**. The table below illustrates the technology we will be using for making the specified components.

Components	**Technology For Implementation**
REST API	Flask; MySQL for database
Dashboard	Vue JS
Predictive model(CNN)	Tensorflow/MATLAB(to be decided on)

The endpoints of the REST API can be seen on the table below along with the JSONs they will produce and consume.

Endpoint	**Consumes**	**Produces**
/trashInserted	{ “secretMCCode”: “string” } **[Send image as file with label ‘image’]**	{ “status” : “string”, “full”: int, "typeOfWaste": "string", }
/changeContact	{ “newContactMail”: “string”, “oldContactMail”: “string”}	{ “status” : “string” }
/trashEmptied	None	{ “status” : “string” }
/Login	{ “username”: “string”, “password”: “string}	{ “status” : “string” }

Listed below are brief descriptions for the JSON fields(for each endpoint) mentioned in the table above.

- **typeOfWaste**: Classification of the waste that has been disposed of.
- **secretMCCode:** A string that will be hardcoded both in the REST API and the microcontroller that will be sent by the microcontroller(this is here for security purposes).
- **newContactMail:** Email of the new contact person.
- **oldContactMail:** Previous Email of the responsible personne. This is here for verification purposes.
- **username:** username to use for logging into the dashboard.
- **password:** password to use for logging into the dashboard.
- **status:** Will specify whether or not the operation was successful. This is returned from the API.
- **full:** Either 1 or 0 signifying whether the bin is full or not.

Please note that all of the rows highlighted in **green are protected endpoints**. After the admin inputs the correct username and password on the dashboard, the REST API will return a Json Web Token(**JWT**) and that will be sent in the header of every request to a protected endpoint.

The figure below provides a brief overview of the stack that is going to be used to implement the system mentioned above.

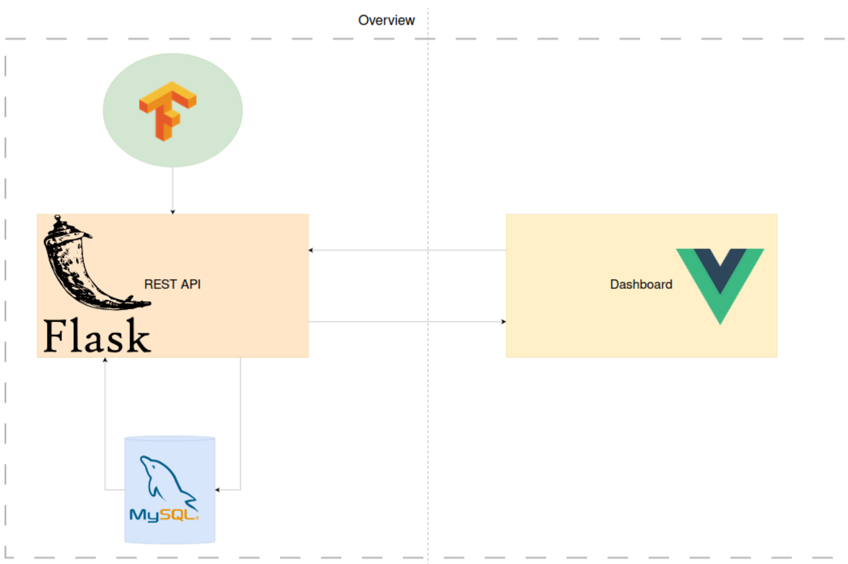

Figure 2.1:Stack Overview

The software for wasteClassify is one of the most integral components of the system. Most of the mentioned functionalities in the flowcharts are contained within the software.

Flowcharts for processes

For this deliverable, we tried to make sure that we represent all of the core processes of the system as flowcharts. We attempted to simplify this and really explain the core processes in detail. The core processes for wasteClassify are the following:

1. The process for handling when trash is dropped.(***Hardware***)
2. The process for handling the received image.(***Software***)

The two sections below explain the above processes including a graphical representation.

Process 1- Trash is dropped(Hardware side logic)

Whenever trash is dropped, the motion sensor will sense this and send a signal to the raspberry pi to take an image. The raspberry pi will then send a signal to the camera to take an image and it(the raspberry pi) will receive that image and send it to the server. Once the endpoint on the server receives that image, it will send it over to the model which will classify the image into one of the categories. In the response, the server will return the status of the API call, the classification of the image, and the status of the waste levels(whether or not the bin is full, this is further explained in the software section).

If the returned confidence level is below 0.5, the trash will be placed in the **general waste** section, if not the raspberry pi will adjust the motors as programmed and place the trash in the respective section. The raspberry pi will also check the status of the waste levels(from API response), and if it turns out that the bin is full, it will blink the LED light.

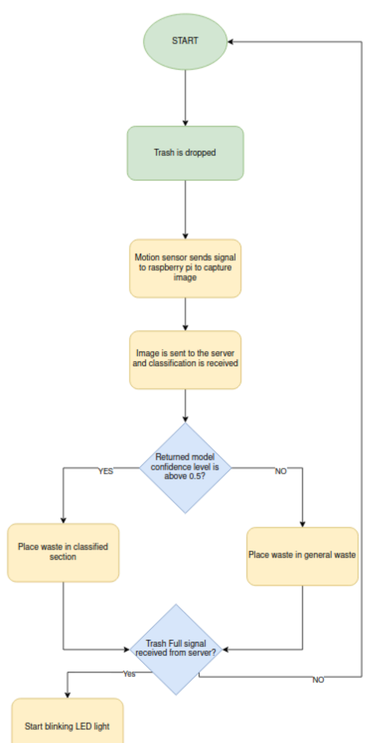

Figure 2.2:Flowchart of Process 1

Process 2- Image is sent to server(API)

The process for receiving the image and processing it is quite a simple one and can be represented by the flowchart below. Once the image is received, sent to the model and classified, there is one more process before returning all of this to the raspberry pi - checking if the bin is full. If the number of materials recycled passes the set threshold, the registered email is queried from the database and an email is sent to the registered personnel regarding this. Then, all of this is incorporated into the response JSON and returned to the raspberry pi(the response is better elaborated in the software architecture section).

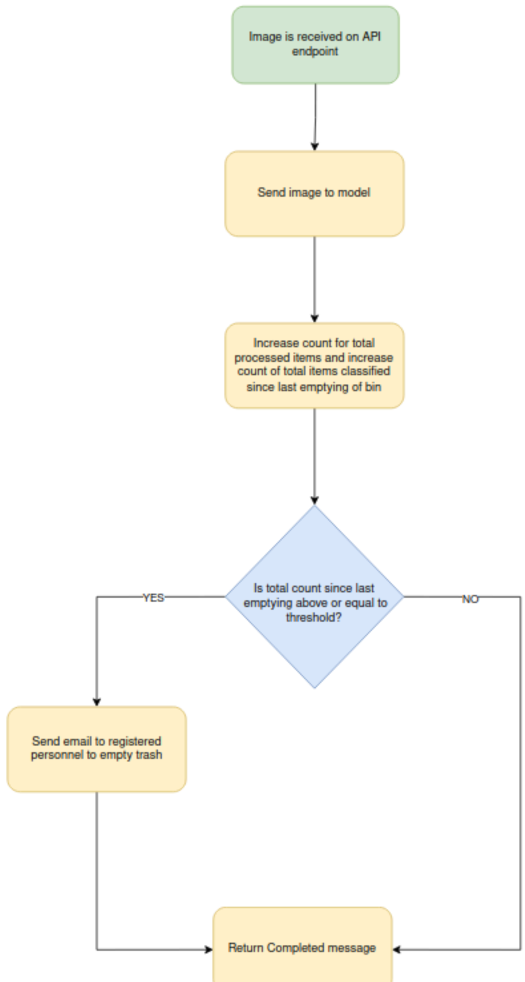

Figure 2.3:Flowchart of Process 2

Block Diagram

Below is the hardware block diagram for wasteClassify. As can be seen from the image, the heart of all of this is the raspberry pi(the microcontroller). The camera, LED light, PIR sensor and the servo motor driver are all connected to and take instructions from the raspberry pi. As can be seen in the block diagram, the servo motor connects all 6 motors to it. This was a design choice we made to **incorporate all of these motors** into the system.Another decision that significantly reduced the amount of components and the complexity of the system was the decision to go from the Arduino microcontroller to the raspberry pi. This decision was made after consulting with the professor and was a wise decision. In the next section of this design(the circuit design), this will be more visible and explained in a more detailed manner.

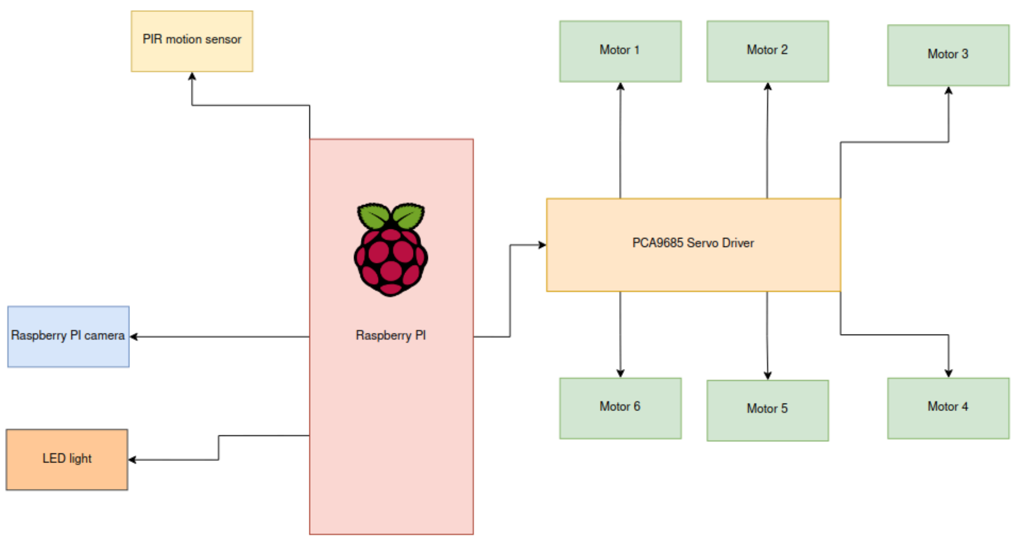

Figure 2.4:Block Diagram

Circuit Design

Below is the design of the circuit. Since **TinkerCAD** does not support the raspberry pi component, **cirkitdesigner**[12] was used for this. The downside of the designer that was used is, it does not support simulating some of the components that were used in the design. All connections and decisions made in the design were made using best practices and recommendations from official documentation. The circuit design can be seen in the figure below.

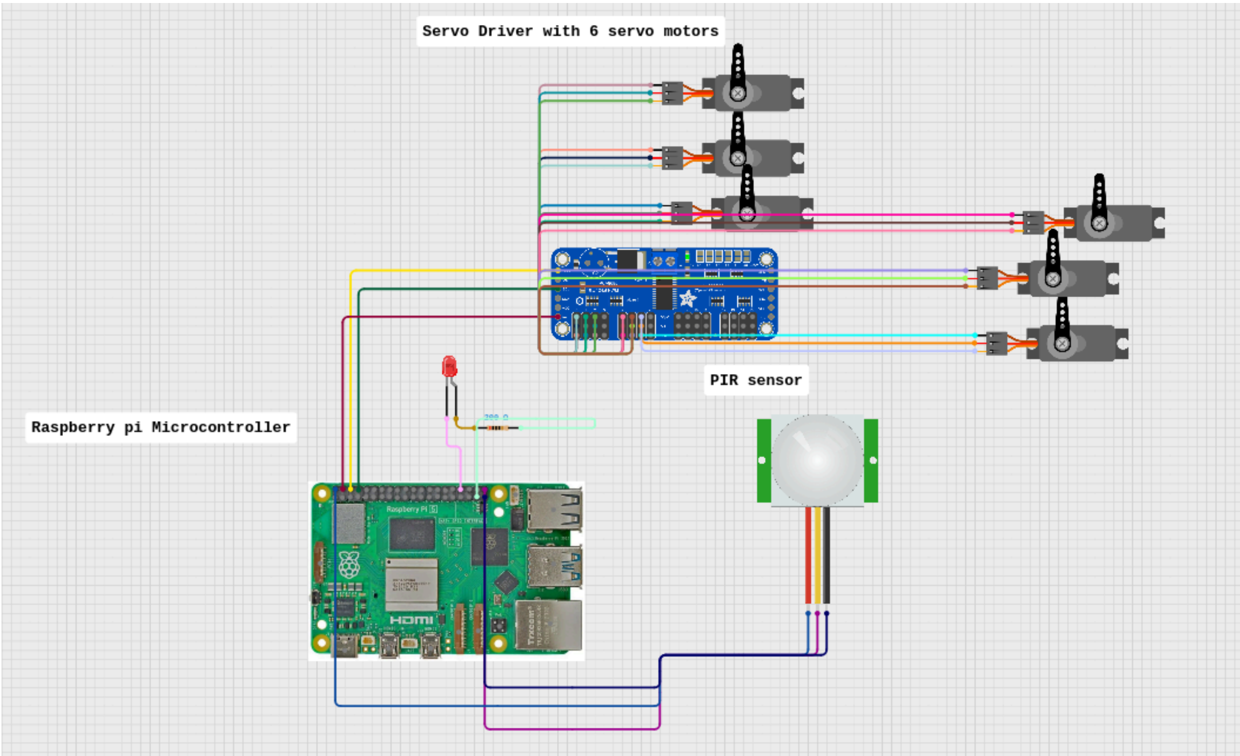

Figure 2.5:Circuit design

A brief description of the working of the circuit

It can be seen that the raspberry pi is connected to a servo driver which is then connected to 6 different servo motors. This ensures that the raspberry pi can send out instructions to the 6 motors without overloading its GPIO pins. The PIR sensor is directly connected to the raspberry pi and sends signals that the raspberry pi will analyze. The LED light for indicating performance issues and the status of the waste will also be connected directly to the raspberry pi(there will be a resistor in between). As for the raspberry pi camera(not included in the diagram), it will be connected to the raspberry pi using a BUS cable. The raspberry pi supports BUS cable connections through its built-in ports.

Image Recognition Model

Model Architecture

After reading the introduction and other technical aspects of wasteClassify, it can be seen that the most essential component of the system is the **machine learning model**. The model will be an image classification model trained on openly available data from **kaggle**[1]. The model will need to return two things after being fed an image, the **classification** and the **confidence level**. The confidence level of a model is just how "sure" the model is that the image belongs to the respective class it has classified it into[2]. Once a classification of an image is received from the model, the raspberry pi will handle the logic of where to place the trash(this is further explained in the flowcharts section).

The plan for the implementation is to develop two different models and compare their accuracies. The first implementation will be made using tensorflow. **Tensorflow** is an open-source machine learning library made and maintained by Google[3]. **Keras** will also be used in the implementation to speed up the process. The second implementation will be made using **MATLAB** which is gaining significant popularity for its **deep learning toolbox**[4]. Since the pipelines already exist for making these image classification models, most of the work will be in **data engineering**. This is what enables us to train two separate models using two different technical stacks and compare their accuracies.

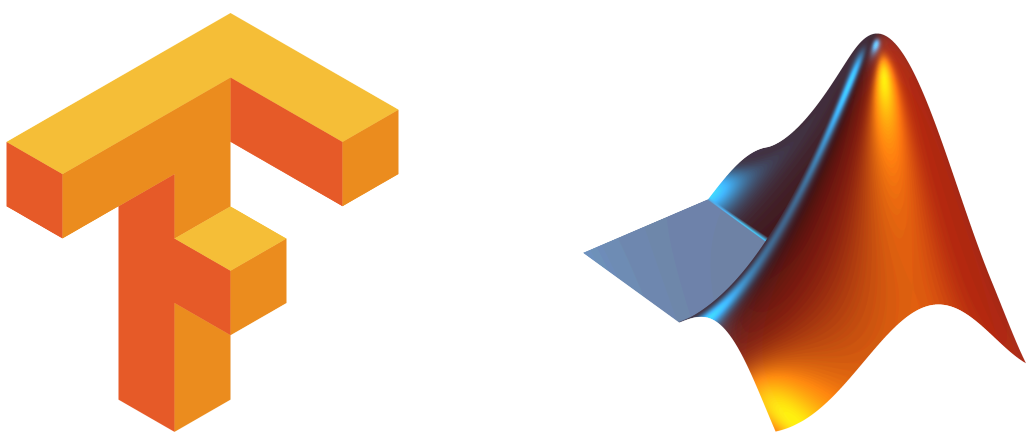

Figure 2.6:Tensorflow and Matlab

The Dataset

As mentioned above, the model will only be as good as the data that it is trained on. The dataset that is going to be used for training the model will consist of the following classes:

1. **Plastic**
2. **Paper**
3. **Glasses and Cans**

The dataset containing images with the following classes has been found. But, it excludes the third class meaning the set of images of glasses and cans needs to be sourced. Even though the product will also classify some images as general waste, this classification will be done based on the confidence level. The dataset, available on kaggle[5], contains 12 classes, but we will only use two.

It is to be noted that the model will be trained separately and then called in the REST API.

Power Requirements

Since power is one of the most essential components of the system, the requirement needed to be carefully evaluated. After consulting with people in the field and doing thorough research online, we came to find some very important information. The specific components and their respective power requirements can be seen in the table below.

Component	Power Requirement
Raspberry pi	5V[6]
Raspberry pi Camera	3.3V[7]
LED	1.2-3V
PIR sensor	5V[8]
PCA9685	6V[9]

For the specified components to run optimally with no interruptions or performance issues, the power supply needs to be constant. Also, it will be quite optimal to have a light option(weight wise) to avoid having to come up with a structure to support a heavy power supply.

After going through the available options, it was decided to power the system using a **27W USB-C power supply** which will be used to power the raspberry pi. Then, the raspberry pi will be used to power the rest of the components of the system mentioned above in the table. The power supply will be connected to the raspberry pi's USB-C port. The power supply has an output of approximately 5.1V[10]. The block diagram below displays how the system will be powered.

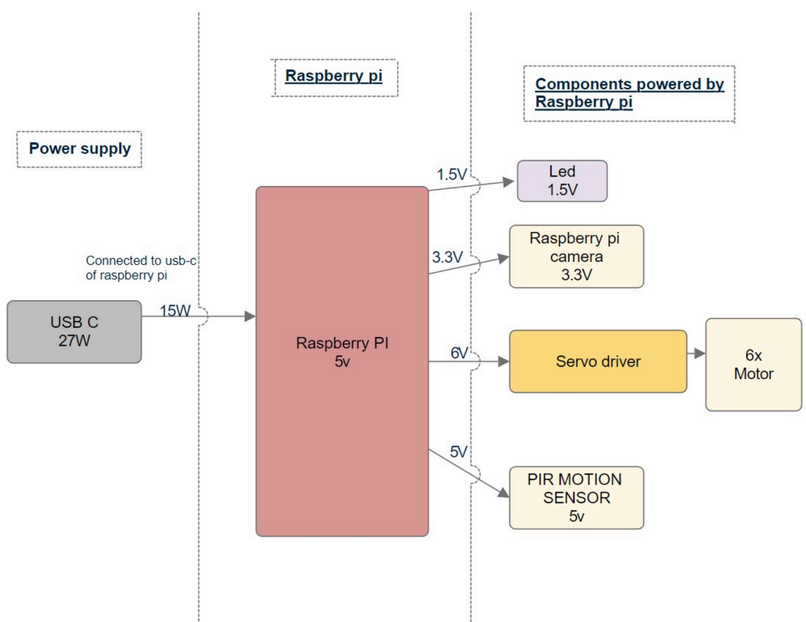

Figure 2.7:Power Requirements

Motor and plate movement

The plates(controlled by the servo motors) need to move in a certain sequence to be able to place trash in the desired compartment. A preliminary handmade design was made to show how the motors will move in specific scenarios.

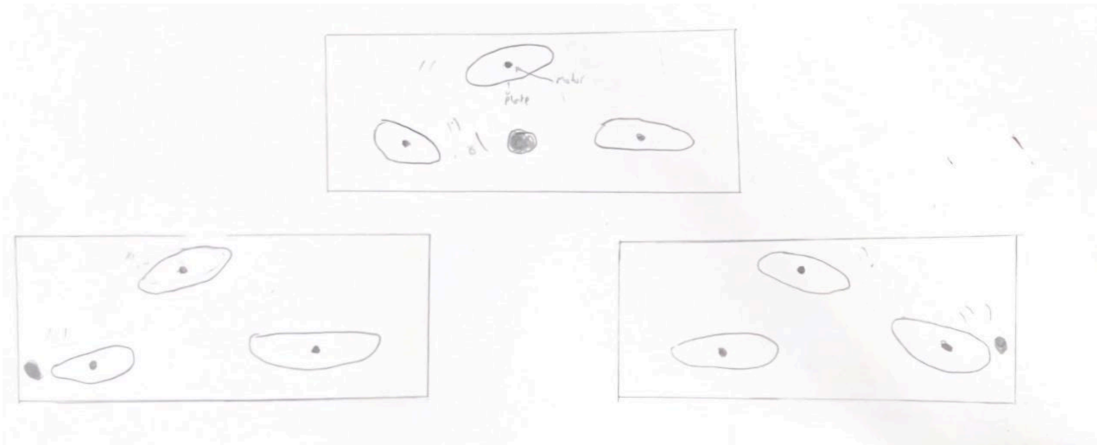

Figure 2.8:Plate movement scenario

The case in the middle on top shows what would be done for the thrown object to land in the middle section. The bottom left plate is slanted to the right while the top plate slants to the left so that the object falls on the top plate, slides down to the left side, and slides off the bottom left plate to land in the centre zone.

Bottom left case shows when the object is needed in the left zone. Identical to before but this time both plates are slanted to the left. **The motors will be attached to the plates in the front and back.**

Testing Methodology

After making each component, there needs to be robust testing to ensure all of the components of the system works. To ensure efficient testing, we have laid out the following plan to test the separate components and the system as a whole.

PIR Sensor Testing

- We need a PIR sensor for sensing motion. It is going to be used to detect when the trash is dropped in the bin. After we add the connection between the PIR sensor and the Raspberry Pi and we write the necessary logic on the Raspberry pi, we will start testing if it properly senses the required motion(throwing trash). We will need to place the sensor vertically during this phase as this will be it's position in the final implementation

Servo Motor Testing

- First, we will check that the servo motors work properly after connecting them to the driver. If they work properly, we will test their movement in different directions through the software(on the raspberry pi). The servos should turn correctly to direct specific trash types into their designated compartments. **Each scenario will be tested to make sure correctness before proceeding**.

LED Testing

- Lastly, the LED light will be tested. We will check whether it **blinks** when it needs to blink and **turns red** at the appropriate times. This ensures it supplies the correct feedback to the users.

Final System Testing

- After individual component testing, we will combine all components and test their features as a complete system. This part will be confirmed by comparing the system's functionality based on its description.

Please note that the software components will undergo standard unit tests before deployment.

State Diagram

For better comprehension, this description depicts the system's workflow as a state machine even though we do not have one and is based on the figure below. While it waits for motion detection the system starts in the IDLE (000) state. The Trash Detected (001) state is activated upon motion detection signifying the existence of waste. Taking a picture (010) and processing it (011) to identify the type of waste is the next step. If the system determines a high classification confidence level (greater than 0. 5) the waste is categorized as Classified Waste (101). It falls into the General Waste (100) category if the confidence level is less than 0. 5. Unless the bin fills up in which case it moves into the Full Bin (110) state the system keeps working after sorting. If there is a problem like a detection or sorting error the system enters the Error (111) state which needs to be fixed before it can continue. The system returns to the idle state and is prepared for the subsequent detection and classification cycle after errors have been corrected or the bin has been emptied.

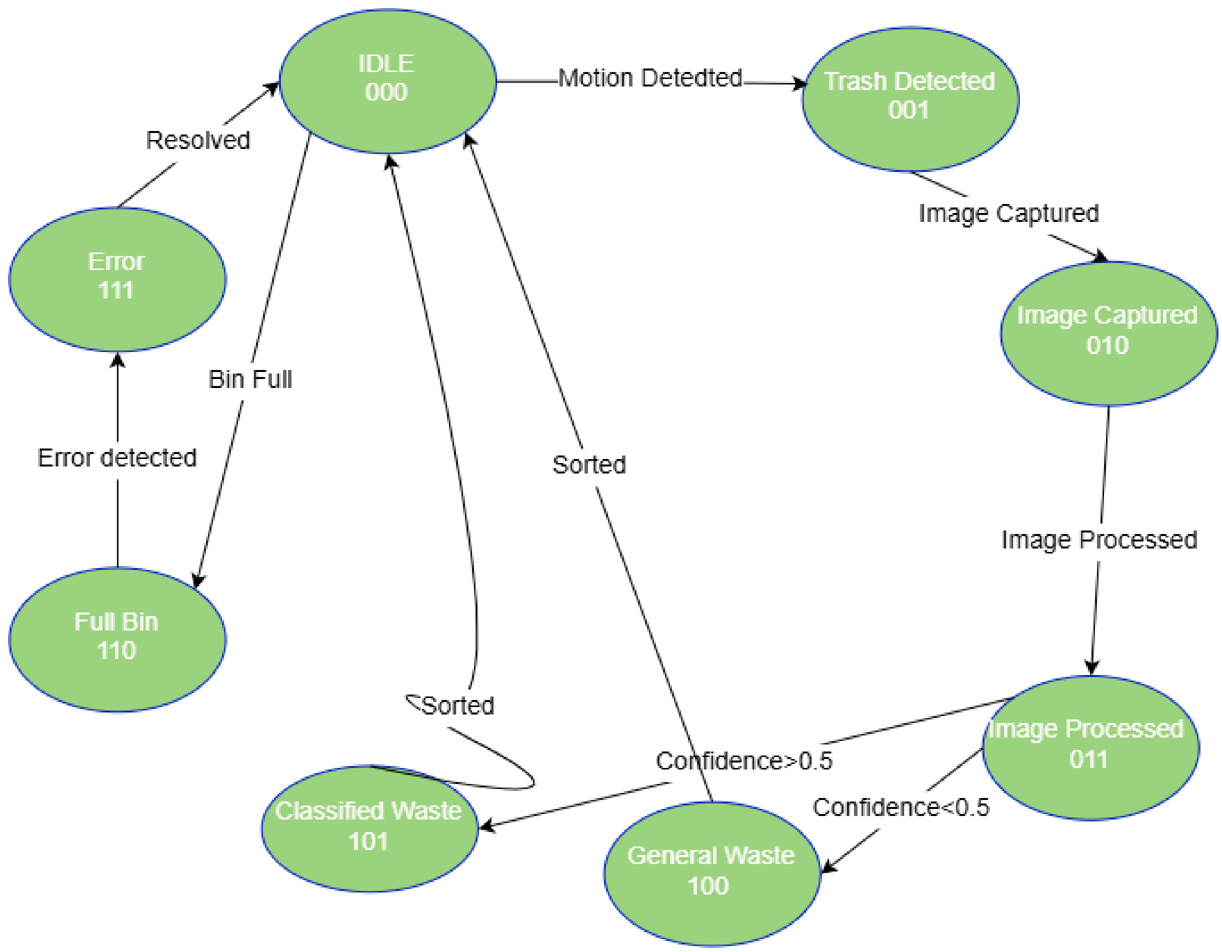

Figure 2.9:State Diagram

Risks

There are risks that are associated with the implementation of this project. From a health and safety perspective, there are risks associated with building the hardware that could occur during the soldering process or even during the process where we combine all separate components. All of these risks can be minimized by following the necessary precautions during implementation. From a project management perspective, there is a risk that we will not be able to deliver on time. This risk can be easily minimized by adhering to the internal deadlines set and ensuring that we consult with the necessary professionals when feeling stuck.

Bill Of Materials

The table below represents our BOM(bill of materials) and contains each element we will use for implementation along with the price, quantity and source of the price.

Item Name	**Price(AED)**	**Quantity**	**Source**	**URL**	**Total Price(AED)**
Raspberry pi 5	294.25	1	Amazon	https://goto.now/CgY50	394.25
Raspberry pi Cam	84.16	1	Amazon	https://goto.now/jqsB0	84.16
Servo Motor	16	8	Amazon	https://goto.now/Oeh07	128
PCA9685	30	1	BLUE PCB	https://goto.now/OQQjC	30
PIR Sensor	24.99	1	Amazon	https://goto.now/3u2eU	24.99
LED	5	1	BLUE PCB	https://goto.now/I8B1H	5
Raspberry Pi 27W USB-C Power Supply (Black)	59.99	1	Amazon	https://shorturl.at/g7ve5	59.99
Plastic Slabs	36.49	1	Amazon	https://shorturl.at/mCHXG	36.49
Total					**762.88**

Below is a brief description of what each material is planned to be used for in the system.

1. Raspberry Pi 5

- Acting as the brain of the entire system, the raspberry pi will be controlling the logic of the hardware and will be a bridge between the software(including the model) and the hardware.

2. Raspberry Pi Camera

- This camera will be used for capturing the waste being disposed of and sending that data back to the server for it to be classified.

3. Servo Motor

- The servo motor will enable the system to be able to properly place trash in their respective compartments after the trash has been classified.

4. PCA9685 (PWM Driver)

- Since we need to control almost 6 servos, this driver will control all six using logic instructions from the raspberry pi.

5. PIR Sensor (Passive Infrared Sensor)

- The PIR motion detects motion and lets the system know when trash has been disposed of.

6. LEDs

- The LED is used to provide visual feedback to the user. It shows if the system is ready or if there's an issue. For example, the LED will show red if there is trash not yet processed, show nothing when there is no trash that hasn't been processed, and will blink continuously if full.

It is to be noted that the prices for some of these components fluctuate and the prices put up were the prices effective on February 20 2025.

Marketing and Project Management

Project plan

So far for the implementation of the design phase of wasteClassify, we have used a modular approach to classifying the tasks and compiling them for the submission of the deliverable. This ensures that all members of the group are participating and that there is check and balance in the final review stage.

It can be seen from our planning diagram below that almost all of the tasks for each deliverable consist of an initial listing of tasks, a subdivision of those tasks and a review. This approach has worked quite well for deliverables one and two. For the actual hardware and software implementation phase(s) of the project, it can be seen on the diagram below that these deliverables have relatively more tasks as compared to those in the design phase. We plan to rotationally divide the tasks to ensure that all members get to work equally on both aspects.

To ensure that the rotational division of tasks is successful, we plan to further subdivide the software and hardware parts to be completed by a specific member. For instance, in the software implementation there is a REST API to be implemented and there is a frontend dashboard, we plan to claim each task as a pair. So, if member A and member B claim the task for the REST API, then member A can work on half of the endpoints whereas member B can work on the other half.

We believe that completing each deliverable in a modular manner would ensure that the deliverable is complete and that each member has gotten the opportunity to work on something and learn from it equally.

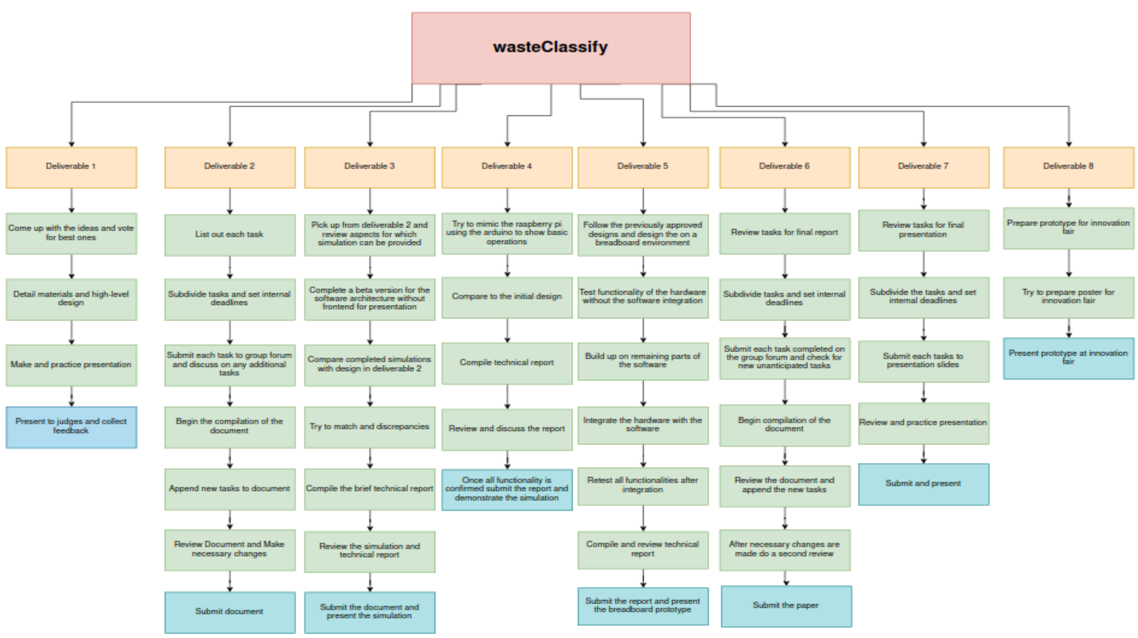

Figure 2.10:Project Plan

During the phase of the hardware and software implementations, due to the nature of the modular approach we are taking, there will be many cases where the completion of one task affects the beginning of another. This means that the **internal deadlines we set will need to be much stricter** in that phase as the delay of one module could cause a lot of havoc.

After each module is completed it has been agreed to upload them on the team forum which will ensure that there is visibility if one member is causing a lot of havoc. The forum will also be used as a central storage of our files and documents.

To ensure that we fix our weaknesses, at the end of each deliverable(before beginning the next one), there will be an online meeting to look at what caused the most discomfort in the last deliverable and to try and mitigate the cause and ensure a smoother implementation and submission for the next deliverable. Below is a GANTT chart displaying the anticipated beginning and delivery times for each deliverable.

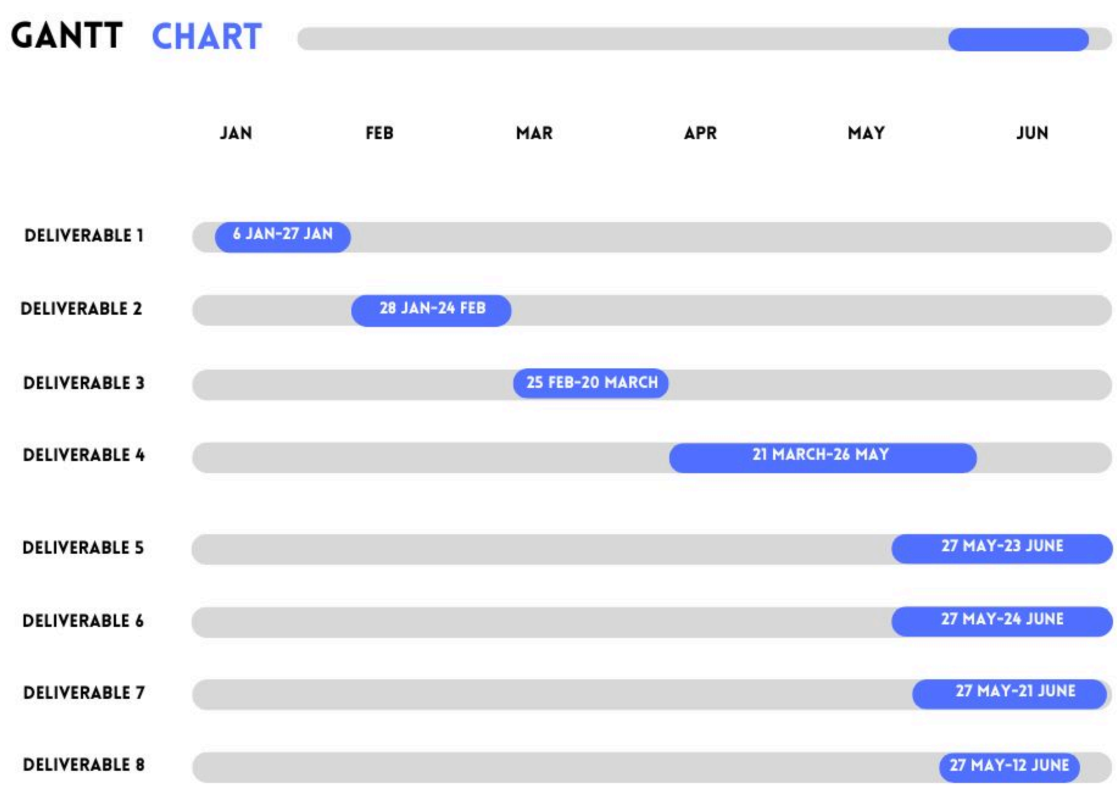

Figure 2.11:Gantt Chart

Marketing Scheme

Our target customers are mainly **schools**, **offices** and the **hospitality** sector. A lot of schools and hotels get different rankings based on sustainability and reduced carbon footprints. If deployed at their sites, wasteClassify will have a significant effect on these. The fact that wasteClassify is also beneficial for the plastic bottles industry will also make it an attractive product for the companies in the industry to invest in.

In terms of actually selling the product, it will be quite easy once an initiative is made by a significant customer. Especially in the university domain, if wasteClassify is deployed not only will it show to the students and faculty that the school is becoming eco-friendly, but it will also show that the school is open to more innovative and high-end products. The same can be said for customers in the hospitality sector. Creating a more high-tech scene has shown to play a significant part in customer attraction.

There may be some competition to wasteClassify, but after the prototype a cheaper design can be implemented using a more basic microcontroller and maybe implementing a pipeline to convert all images to base64 before sending to the server significantly reducing computing time. This will give it an edge over competition and will also give a cost effective product to the target customers mentioned above.

Appendix

Appendix A

There is not much to model for this particular project as it is essentially just a box, but the model below tries to illustrate how the camera will be positioned and how it will be able to efficiently view the trash.

Figure 2.12:Model

Appendix B

Other than the costs mentioned in the BOM section above, there will be costs that will arise due to labor. This was covered in the first deliverable. This includes the cost for the consultation and professional labor. The table below is an estimated breakdown of these costs. The first table is a breakdown of the labor costs per deliverable and the second one is the breakdown of the consultation costs based on the estimated amount of hours needed for consultation.

Deliverable	Hours	Cost (AED)
1: Proposal Presentations	4	1200
2: Detailed Design Report Submission	12	3600
3: Design Simulation Presentation	7	2100
4: Breadboard Prototype	10	3000
5: Perfboard Prototype	20	6000
6: Final Design Report Submission	25	7500
7: Final Project Presentation	5	1500
Total		24,900

Consulting Personnel	Number of hours	Cost
Lecturer	4	2000
Lab engineers	4	2000
Total		4000

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