July 11, 2021
Dr Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

BGreen

Re: ENSC 405W/440 Design Specification for Sort-e

Dear Dr., Scratchley,

This document outlines the design specifications for an add-on accessory, automated waste sorting system for users to make waste sorting more effective and efficient, as outlined in the Project Proposal and Requirements Specification. Our goal is to create an accessible, sustainable system that uses artificial intelligence for image processing to identify and transfer waste material to the designated waste bins. Our automated waste sorting system is adjustable and may attach to existing waste bins to encourage sustainable practices to benefit the environment and to enhance the quality of life.

This document discusses the design specifications for electronic, mechanical and software systems. Each electronic, mechanical and software component will be described separately. Software modules including algorithms and libraries will be outlined.

Our team consists of 4 senior SFU engineering students who strive for environmental sustainability: ChinHo Wan, DongYue Shi, TianXiao Liu, and ChenXi Wang.

We thank you for taking the time in reviewing design specifications documents. If you may have any questions or concerns, please do not hesitate to contact our Chief Communications Officer, DongYue Shi, via email at dongyues@sfu.ca.

Sincerely,

ChinHo Wan
CEO
BGreen Inc.

BGreen

Design Specifications

Sort-e

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Abstract

This document describes design specifications for an add-on accessory, automated waste sorting system, Sort-e. Each component of Sort-e as well as design specifications will be discussed and explored. This document will address and justify design choices made by our team members.

The Sort-e consists of three parts: the controller and the I/O, used for image processing; the camera, to capture images as input; and the mechanical component, to dispose of waste which includes a frame for waste bin attachment. A user-friendly display will be installed on the product which provides feedback to the user regarding the status of the system as well as capacity status of the bins.

The design specification for Sort-e provides justification for design choices made in the electronic, mechanical and software systems. This document will also include several subdocuments in the appendix that detail our final proof-of-concept test plan and our user interface design.

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Glossary

Term	Definition
Artificial Intelligence	Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and imitate their behavior.
CSA	Standards organization; Canadian Standard Association.
Microcontroller	Microcontroller is a small computer that used for automatically controlling in a device.
Raspberry Pi 4	Raspberry Pi 4 a specific model of microcontroller.
TensorFlow	TensorFlow is an open-source platform for machine learning

1 Introduction

Using artificial intelligence technology Sort-e is able to identify and transfer waste material to their designated waste bins. This system allows users to sort waste materials effectively and efficiently, pursuing a zero-waste future. Sort-e provides users with guidance in classification of waste materials; thus, promoting recycling education.

The Sort-e machine is composed of three subsystems: First, the raspberry pi will be used as a controller for the input/output (I/O) and for image capturing. Second, the software system will perform image classification using the TensorFlow library. Third, the mechanical component will perform waste disposal, featuring a frame for waste bin attachment. Details regarding the technical details of the design requirements for each subsystem will be discussed in this document.

1.1 Background

One of the greatest challenges waste experts have yet to resolve is the high contamination of recyclable materials [1]. One contaminated bin may lead to multiple bins to end up in the landfill. Once a certain percentage of recyclable material is contaminated, the entire batch is considered not usable. In 2018, British Columbians disposed of an average of 505kg of municipal solid waste per person, excluding reused and recycled waste [2]. The amount of waste could be reduced through composting, repurposing, or recycling.

Our company's goal is to advocate for a sustainable future by addressing contamination of recyclable materials and increasing waste literacy. Sort-e aims to educate users, emphasizing on newcomers and students regarding waste classification and promoting recycling education. Sort-e fosters sustainable and positive behavior changes towards building a zero-waste future.

1.2 Scope

This document is supported by the requirement specification document for BGreen. The document outlines the design specification for each subsystem. This document also explores and justifies design choices. The Proof-of-Concept Test Plan will be found in Appendix A, the User Interface requirements will be found in Appendix B.

1.3 Intended Audience

The intended audience of Sort-e's design specification includes: BGreen Inc. members, potential customers, corporate partners, teaching assistants and professors. The design specification guidelines will provide detailed justifications in regards for design choices. Future development will be referred to this document.

1.4 Design Classification

The following convention will be used to label the design specifications in this document:

Des {Section}.{Subsection}.{Requirement Number} {Stage of Development}

The different phases of development are shown in the table below:

Table 1.4 - Development Phase Encoding

Encoding	**Phase of Development**	**Deadline**
C	Proof of Concept	End of ENSC 405W
P	Prototype	End of ENSC 440
F	Final Product	In production

2 System Overview

The Sort-e is an adjustable, attachable, waste sorting device that is designed to identify and transfer waste material to their corresponding waste bins. A discreet camera will be installed into the device to capture images of waste materials for the system to process the image. Using the mechanical parts of the system, Sort-e will sort the waste material according to the result produced from the image classification. A general system overview will be shown in Figure 2.1., and the 3D appearance of Sort-e will be demonstrated in Figure 2.2 and Figure 2.3.

Adaptations and modifications are also available for users to allows the device to satisfy different standards. Examples include, different size of the waste bins and the type of the waste required to sort.

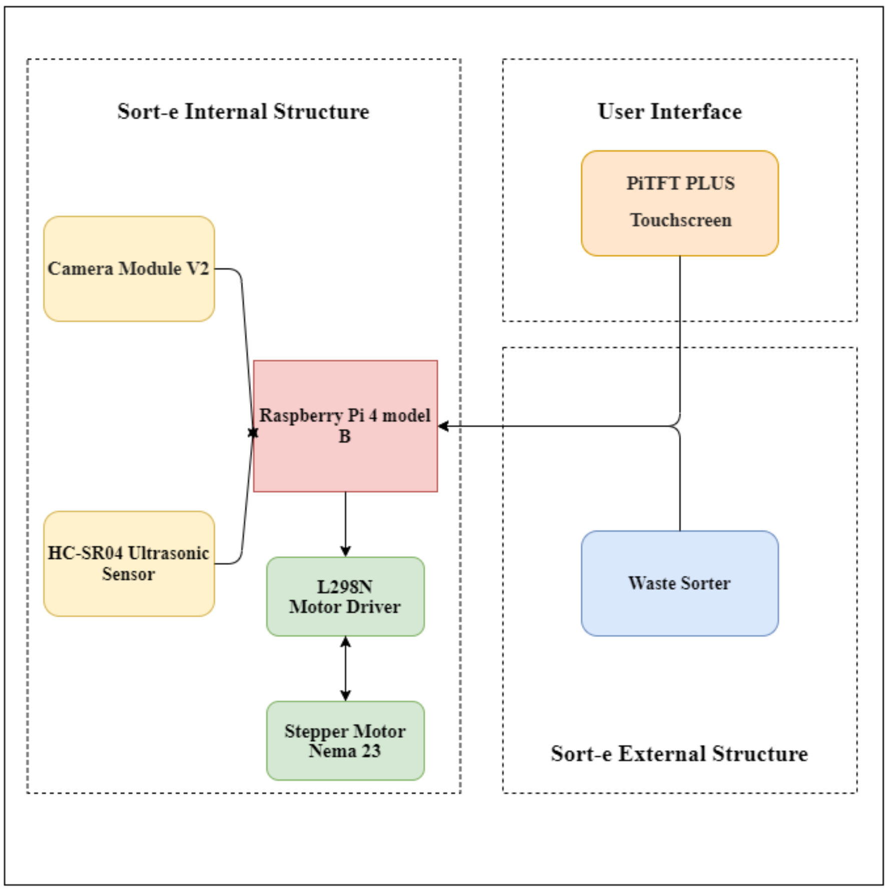


Figure 2.1 Sort-e System Overview

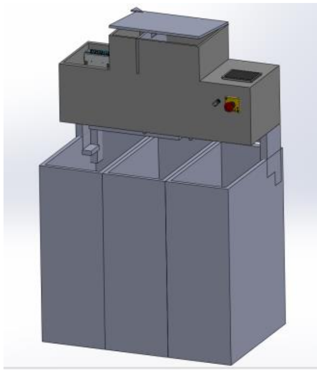


Figure 2.2- Sort-e Concept 3D Model

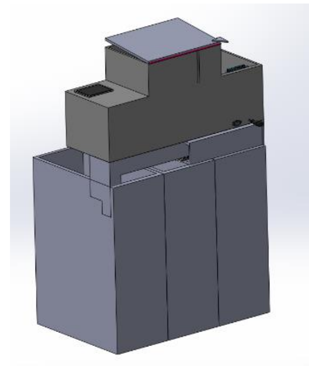


Figure 2.3 - Sort-e Concept 3D Model (Back view)

Table 2.1 – System Overview Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 2.1.1 C	The device will sort three categories of waste: Food scraps & compostable, recyclables and landfill waste.	Req 3.1.3 P Req 3.2.1 C Req 4.2.1 P Req 5.3.1 C
Des 2.1.2 C	The device will display the level of fullness of the waste bin.	Req 3.1.8 P Req 3.2.5 P Req 5.1.3 P
Des 2.1.3 F	The device will operate normally when it is powered on.	Req 3.1.11 F
Des 2.1.4 F	The device will use waterproof material to adapt to outdoor environments and to prevent liquid from the food waste from damaging the device.	Req 3.1.12 F Req 5.1.6 F
Des 2.1.5 P	The weight of device will range from 8 kg -10 kg, with a maximum length of 120 cm.	Req 3.1.13 P Req 3.1.14 P
Des 2.1.6 P	The device will allocate space to give the option for users to manually dispose waste materials	Req 3.1.15 P

3 Software Design

3.1 Image classification

Sort-e's software system is compacted with the TensorFlow machine learning platform. TensorFlow has a comprehensive and flexible ecosystem of tools and libraries [3]. This allows building an artificial intelligence (AI) model with ease.

TensorFlow may be used for both training and inference: the main platform for creating AI model and dataset training. In terms of programming on Raspberry Pi, the TensorFlow Lite library is a suitable option as it optimizes execution of the AI model for developers running the models on mobile, embedded and IoT devices [7]. Compared with TensorFlow, TensorFlow Lite is smaller in size, has less latency, and has a more efficient inference.

The convolutional neural network (CNN) will be implemented for AI training. CNN is commonly used as a deep learning network model for image classification. It may be used to extract a higher-level representation of an image (Figure 1). Rather than to preprocess data to derive features such textures and shapes, a CNN acquires the image's raw pixel as input data and "learns" how to extract these features; ultimately, determining the classification of the object [9].

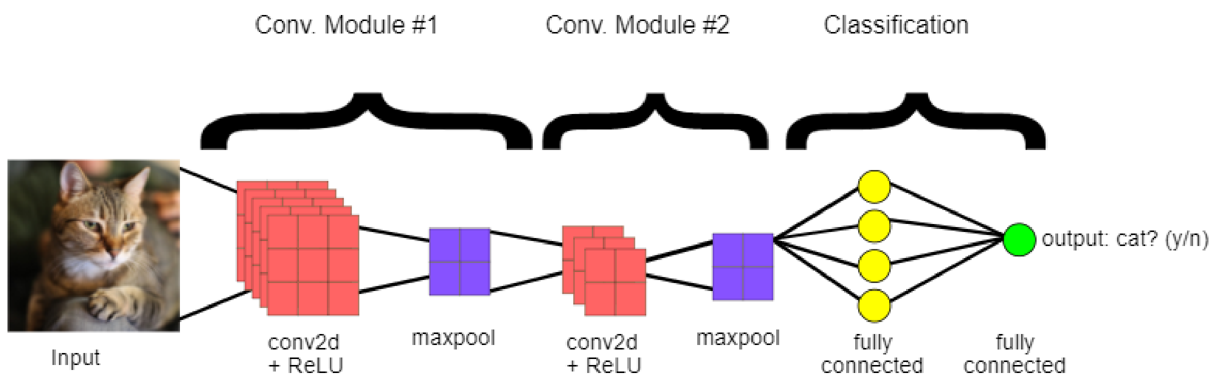


Figure 3.1 – End-to-end Structure of a Convolutional Neural Network (CNN) [9]

Table 3.1 - Image Classification Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 3.1.1 C	The waste classification program will run the TensorFlow Lite library with Python3.	Req 4.1.1 C
Des 3.1.1 C	The program runs the AI model according to the image that is taken from the camera module, which includes: output prediction with the rate of correctness and the label.	Req 3.1.3 P Req 3.1.5 P Req 3.2.1 C Req 4.1.2 C Req 4.1.3 C
Des 3.1.4 C	The program sends a signal to the Raspberry Pi to control the motor movement based on the predicted result using the AI model.	Req 4.1.4 P Req 4.1.5 P
Des 3.1.1 P	The program has a status variable to represent the status of the system which includes: ready, processing, and out of order.	Req 3.2.4 P Req 4.1.4 P Req 4.1.5 P
Des 3.1.4 P	The system will be in ready/sleep mode if there is no given input over a period.	Req 4.1.4 P Req 4.1.5 P Req 4.2.2 F

3.2 AI Training

There are 3 steps for AI training: building a model, training the model with training datasets and using the model to predict unknown data [6]. Three convolution blocks will be created for the model with a maxpool layer between them [8].

The data set will be separated into several image folders, where each folder has the same name as the label name. In our case, the file names will represent the type of waste. Image files will be compressed into a zip file and will be uploaded to a cloud storage (i.e. Google Cloud).

Training this model with the dataset consists of downloading the dataset that is stored in cloud storage, which includes the images captured by the team or random sample images obtained from online. The ‘model.fit’ function will iterate all downloaded images as training data to train the AI model [8].

Table 3.2 - AI Training Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 3.2.1 C	The image set for training the AI model must have the same resolution for reducing the model's training time.	Req 3.2.2 C Req 3.2.6 F
Des 3.2.2 C	The image set file include three folders which represent three categories which labels for model training.	Req 3.2.2 C Req 3.2.6 F
Des 3.2.3 P	During the training process, set epochs (number of training time) to 10, the model will iterate the image set 10 times.	Req 3.2.6 F Req 4.2.1 P

3.3 Accuracy

Overfitting is a common problem that will affect the model accuracy. Overfitting occurs when there are a small number of training dataset. In this case, the model may take noises or unwanted details from the sample images [8]. To solve this problem, data augmentation method will make a difference when a large amount of dataset is not imported. Data augmentation is a technique that generates additional training data from existing examples by augmenting them with a random rotational transformation. This allows the model to learn from more aspects of the data [8].

In Figure 3.3.1, the blue line represents the training accuracy with different numbers of epochs. The training accuracy was tested using 80% of the images from the dataset, these images were also used in model training. The orange line represents validation accuracy with different numbers of epochs. The validation accuracy was tested using the remaining 20% (not used for training) of the images from the dataset. The validation accuracy does not increase as the epochs increases (Figure 3.3.1). This indicates that overfitting occurs when there are small number of samples used for training.

As Figure 3.3.2 shows the accuracy between training and validation using data augmentation. The validation accuracy increases significantly with more epochs. This indicates that the data augmentation method improves the accuracy of the model with a small training dataset.

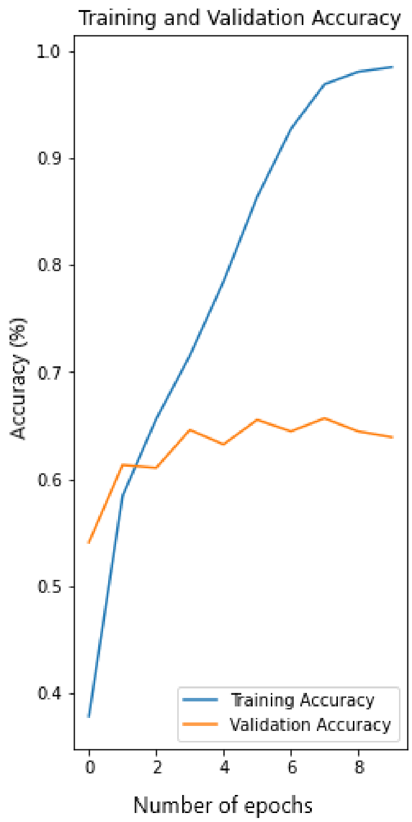


Figure 3.3.1 Accuracy without Data Augmentation [8]

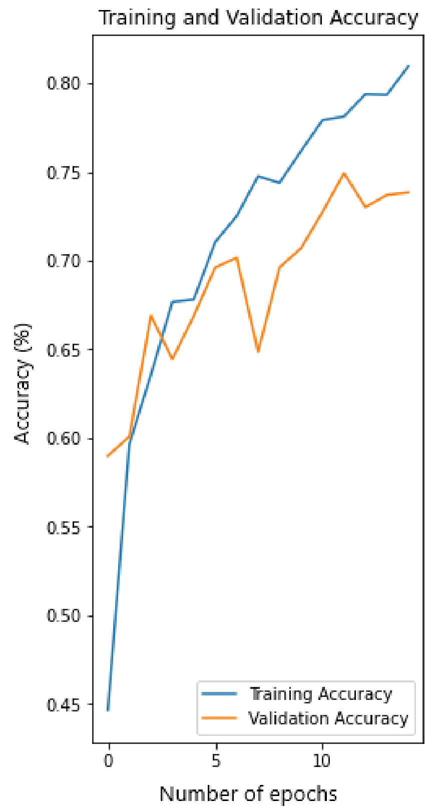


Figure 3.3.2 Accuracy with Data Augmentation [8]

Table 3.3 - Model Accuracy Design Specification

Design ID	**Design Specification Description**	**Corresponding Requirements**
Des 3.3.1 P	Before training the AI model, the data set will go through a data augmentation function for generating an image set that will be randomly transformed.	Req 3.2.2 C Req 3.2.6 F
Des 3.3.2 P	The accuracy of model after training may increase the correction prediction rate to 80%.	Req 4.2.1 P

3.4 Processing Speed Optimizer

To classify the waste precisely and efficiently, the following methods are going to commit in the system, accelerated linear algebra (XLA), and latency reduction.

Accelerated linear algebra is a domain-specific compiler used for matrix operations. It may accelerate the TensorFlow models without changing the source code. This allows the TensorFlow program an alternative running mode which is more efficient [4].

Latency is the time required to process an input image using a specific model. Latency reduction also relates to model quantization. In other words, reducing the model size decrease the latency, but may lower the accuracy. TensorFlow Lite provides different types of quantization model (Figure 3.4.1).

Technique	Data requirements	Size reduction	Accuracy	Supported hardware
Post-training float16 quantization	No data	Up to 50%	Insignificant accuracy loss	CPU, GPU
Post-training dynamic range quantization	No data	Up to 75%	Accuracy loss	CPU, GPU (Android)
Post-training integer quantization	Unlabelled representative sample	Up to 75%	Smaller accuracy loss	CPU, GPU (Android), EdgeTPU, Hexagon DSP
Quantization-aware training	Labelled training data	Up to 75%	Smallest accuracy loss	CPU, GPU (Android), EdgeTPU, Hexagon DSP

Figure 3.4.1 - Types of Quantization in TensorFlow Lite [5]

Our software system aims to use quantization-aware training as a/the quantization model. Quantization-aware training may result in the smallest accuracy loss of; however, it may reduce up to 75% of the model's size and reduce a significant small amount of latency compare with other quantization models. The Figure 3.4.2 compares different quantization models and the models with quantization-aware training [5].

Model	Top-1 Accuracy (Original)	Top-1 Accuracy (Post Training Quantized)	Top-1 Accuracy (Quantization Aware Training)	Latency (Original) (ms)	Latency (Post Training Quantized) (ms)	Latency (Quantization Aware Training) (ms)	Size (Original) (MB)	Size (Optimized) (MB)
Mobilenet-v1-1-224	0.709	0.657	0.70	124	112	64	16.9	4.3
Mobilenet-v2-1-224	0.719	0.637	0.709	89	98	54	14	3.6
Inception_v3	0.78	0.772	0.775	1130	845	543	95.7	23.9
Resnet_v2_101	0.770	0.768	N/A	3973	2868	N/A	178.3	44.9

Figure 3.4.2 - Quantization-Aware Training Model vs Others [5]

Table 3.4 - Processing Speed Optimizer Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 3.4.1 P	To enable accelerated linear algebra (XLA), run python code 'tf.config.optimizer.set_jit(True)' at beginning of the program. The processing time is expected to decrease by approximately 15% [2].	Req 3.2.2 C Req 4.2.1 P
Des 3.4.2 P	To use Quantization-Aware Training, import the AI model. Then run quantization function 'tfmot.quantization.keras.quantize_model(model)'. The output of this function is the quantized model. The expected size reduction is up to 75%. Accuracy loss will be less than 1%.	Req 3.2.2 C Req 4.2.1 P

3.5 Device Interface

The device interface functions to communicate between the software system and the hardware system. The device interface can control and respond to users or components' input/output (I/O) at different statuses. To minimize risk of classifying waste incorrectly, the system will ensure that prediction of the type of waste must have a minimum accuracy of 80%. If the prediction does not satisfy this requirement, the waste will not be identified as a recyclable, and will be transferred to the landfill bin. The following flow chart (Figure 3.5.1) displays the overview for the operation of the system

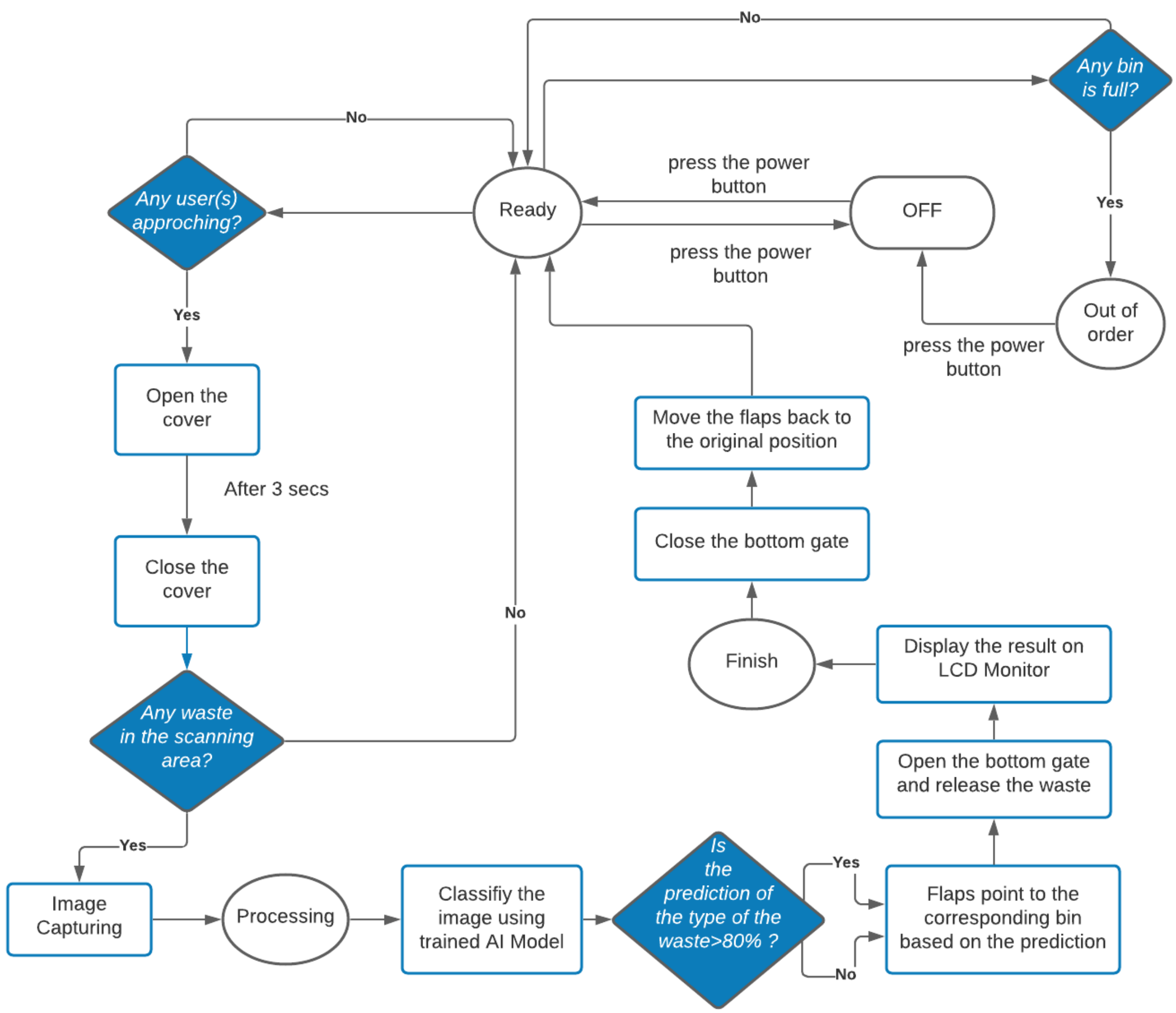


Figure 3.5.1 – Device Flowchart

The device interface also includes: a power button, an LED, and an LCD monitor. LED is used for indicating the power state of this system. The LED will light up while system powers on. The LCD monitor is used for displaying the system's status and important information. There are 4 possible statuses when the system is on, these include: processing, ready, finish and out of order.

The 'ready' status indicates that system is waiting for the user to dispose the waste into the scanning area, and 'processing' indicates that the system is undergoing scanning, classifying, or delivering waste material to the designated bin prior to intake of new waste material. 'Finish' indicates that system has successfully classified the waste material, where the result of classification will be displayed on the LCD monitor. Given certain circumstances, the system may be 'out of order'. Once the system senses that a waste bin is full, the system will stop operating, indicate that it is 'out of order', and display related information on the LCD monitor.

Table 3.5 - Device Interface Design Specification

Design ID	**Design Specification Description**	**Corresponding Requirements**
Des 3.5.1 C	The system will have a power button for system on and off	Req 3.1.4 P Req 7.2.3 P
Des 3.5.2 C	The system will have an LED to inform the user the current power state. If LED lights up, power is on.	Req 3.1.2 C
Des 3.5.3 P	The system will have an LCD screen to inform the user of the current state of system: including ready, processing.	Req 3.2.4 P Req 3.2.5 P
Des 3.5.4 P	LCD will display the level of fullness of each waste bin and inform the user when the waste bin is full.	Req 3.1.8 P Req 3.2.5 P

4 Electrical Design

The Sort-e will use Raspberry Pi 4 model B as its motherboard. The system must receive images as input data from the camera module and analyze the data which will give the prediction using our trained AI model. Based on the result of the photographs taken during the analysis process, Raspberry Pi will send control signals to the motor driver, which will control and drive stepper motors to perform mechanical movement such as the system's waste sorter, gate for waste release, etc. Further information will be mentioned in the Mechanical Design section.

4.1 System Controller

The control unit (Raspberry Pi 4 Model B) is the core of this device, which may connect to other mechanical parts of the device to achieve various functions of the device (Figure 4.1.1). Compared to other control units, Raspberry Pi 4 has a more suitable processor for image processing. The processing speed is 1.5 GHz and has an 8 GB memory. Raspberry Pi 4 was selected as it is more cost-effective. Raspberry Pi 4 operates with only a 5V supply and draws 3A, which allows the board to be powered with ease [13]. In Figure 4.1.2, the pin layout for Raspberry Pi 4 is listed for their different purposes.

Figure 4.1.1 - Raspberry Pi 4 Model B [13]

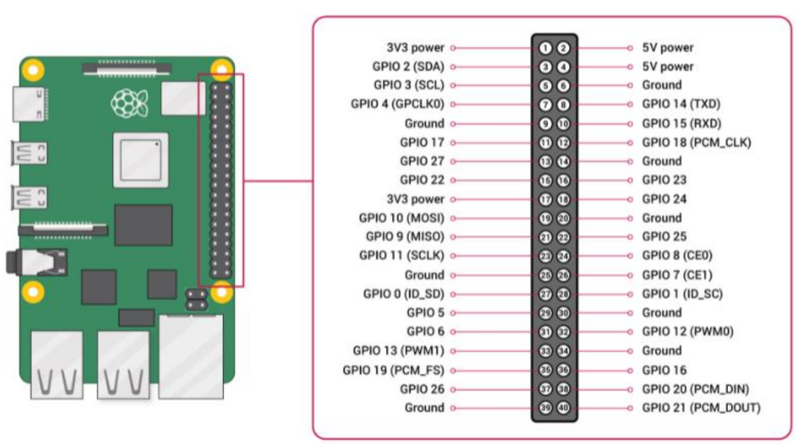


Figure 4.1.2 - Raspberry Pi 4 Model B Pin Layout [14]

Table 4.1 - Control Unit Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.1.1 C	Raspberry Pi 4 must be able to smoothly run complex processing image software; processing time will be less than 2 seconds.	Req 3.1.3 P
Des 4.1.2 C	Raspberry Pi 4 must be able to run trained AI models for image predictions	Req 3.1.3 P
Des 4.1.3 C	The captured images will be saved to local folders in Raspberry Pi 4's caches with camera module V2.	Req 3.1.1 C Req 5.1.1 C
Des 4.1.4 C	The LED light will be connected to Raspberry Pi 4 as the power indicator.	Req 3.1.2 C
Des 4.1.5 P	PiTFT PLUS Touchscreen will be connected to Raspberry Pi 4 as an UI display.	Req 3.2.4 P

4.2 Camera Module

Camera Module V2 will be connected to the Raspberry Pi 4 (Figure 4.2.1). This camera module allows for image capturing for system input. To perform image classification with machine learning, captured images must meet the standard quality and resolution, for clarity to be guaranteed when it is compressed.

To meet size requirements, Camera Module V2 is most suitable for the device. The size of the camera module is relatively small, which allows the camera to fit in the designated area built to be hidden in the scanning area without occupying too much space. Moreover, the response time for image capturing with this camera module is relatively short. This allows the total processing time of the system to be reduced. Camera Module V2 runs with 3280*2464 sensor pixels which guarantees quality images to be captured for further operations.

Working mode	H-bridge drive (two-way)
Main control chip	L298N
Logic voltage	5V
Driving voltage	5V-35V
Logic current	0mA-36mA
Drive current	2A (MAX single bridge)
Storage temperature	-20 to +135
Maximum power	25W

Figure 4.2.1 - Camera Module V2 Specification [15]

Table 4.2 - Camera Module Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.2.1 C	The Camera Module is capable of capturing images up to 1080P; the color will be composed of red, green, blue (RGB).	Req 3.2.1 C Req 5.2.1 C
Des 4.2.2 C	The image processing time for each image transfer to the system controller will be less than 0.1 second.	Req 3.2.2 C Req 3.2.6 F
Des 4.2.3 C	The power supply must be supply minimum 5V for both Raspberry Pi and Camera Module to operate.	Req 5.2.3 C
Des 4.2.4 P	The size of the camera module will be 3cm by 3 cm; small enough to fit into the designated space.	Req 5.1.4 P

4.3 Motor driver

The L298N motor driver will be connected to multiple stepper motors (Figure 4.3.1). An additional power source will be connected to this driver because the voltage required by the stepper motor is 12V, and the voltage for the Raspberry Pi is only 5V.

The L298N motor driver module has an H-bridge with back-EMF protection; this converts the low-power digital output from the microcontroller to the required high-power signal motor.

The L298N is commonly used as a motor driver. The L298N can be easily integrated with Raspberry Pi. This motor driver meets all conditions and has an independent protection system. After receiving data from Raspberry Pi, it will drive the stepper motor and complete the designed task.

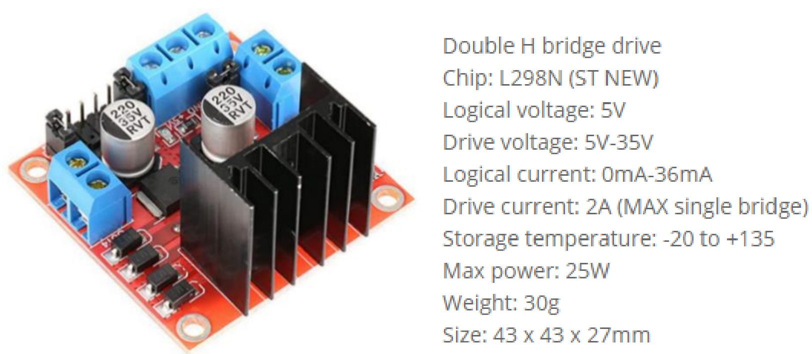


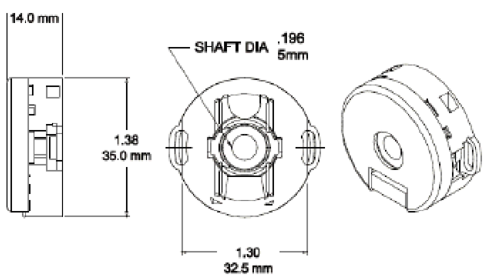
Figure 4.3.1 - Motor Driver Specification [16]

Table 4.3 - Motor Driver Design Specification

Design ID	**Design Specification Description**	**Corresponding Requirements**
Des 4.3.1 - C	The L298N motor driver shall withstand voltages up to 20V and current draws up to 3A.	Req 5.2.2 C
Des 4.3.2 - P	The L298N motor driver supports two types of motors independently as well as communicating with the microcontroller which can be able to rotate with the weight of the waste.	Req 5.2.7 P

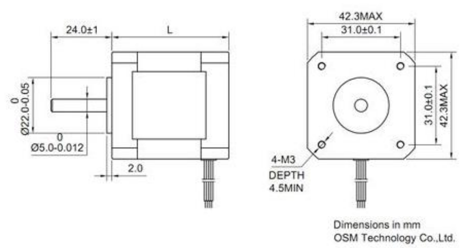
4.4 Stepper Motor

The Nema23 Stepper Motor will be used to transfer the waste by releasing the waste to its designated waste bin (Figure 4.4.1). Nema17 Stepper Motor will be used to open or close the cover for the scanning area (Figure 4.4.2). The gate is comparatively lighter than other mechanical parts within the device, therefore Nema17 with 44 N-cm torque will be enough to perform opening and closing of the cover.



Motor Specifications						
Part	Length	Torque	Series	Parallel	Rotor	Weight
	L				Inertia	Weight
Number	mm	N-cm	Amp	Amp	g-cm²	g
HT23-552	43.43	59.6	0.71	1.41	120	470
				Part Numbers		
Winding	Winging	Phase	Phase	Motor	Encoder	
Resistance	Inductanc	Current	Voltage	Part	Part	
OHM±10%	mH±20%	Amp	VDC	Number	Number	
6.2	7.6	1	5.6	HT23-552D	-ZAA	

Figure 4.4.1 - Nema23 Stepper Motor Specification [17]



The most used stepper motors in Reprap–based 3D printers are the Kysan 1124090/42BYGH4803, Rattm 17HS8401, and Wantai 42BYGHW609.

However, motors close to NEMA 17 size, with approximately the following specifications, can also work:

- 1.5A to 1.8A current per phase
- 1-4 volts
- 3 to 8 MH inductance per phase
- 44 N·cm (62oz·in, 4.5kg·cm) or more holding torque.
- 1.8 or 0.9 degrees per step (200/400 steps/rev respectively)

Figure 4.4.2 - Nema17 Stepper Motor Specification [17]

Table 4.4 - Stepper Motor Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.4.1 P	The motor will be single directional to rotate with the weight of waste and flaps.	Req 5.2.7 P
Des 4.4.2 P	The motor will have at least 3.5 N-m rated torque to move the gate or the flaps. The rated power will be at least 45W [18].	Req 5.2.7 P Req 5.3.4 P
Des 4.4.3 P	The motor will generate insignificant noise levels while working. Each motor is replaceable.	Req 7.2.6 F

4.5 Ultrasonic sensor

Sort-e requires five sensors to complete given tasks. Three ultrasonic sensors will be used to determine the level of fullness of the three waste bins by calculating the distance between the system and the waste. One ultrasonic sensor will be used to open the cover by determining whether waste is approaching the scanning area. Another ultrasonic sensor will be used to determine whether waste remains in the scanning area once the cover is closed.

The HC-SR04 ultrasonic sensors adapt to the sensor requirements of the device (Figure 4.5.1). This device will carry at least five ultrasonic sensors. The ultrasonic sensor detection ranges from 2cm up to 4m. This allows proper indicators to perform given tasks. This ultrasonic sensor is specially designed for Raspberry Pi, allowing data to be accurately transmitted and collected [19].

The HC-SR04 Ultrasonic Range Sensor Features:

- **Input Voltage: 5V**
- **Current Draw: 20mA (Max)**
- **Digital Output: 5V**
- **Digital Output: 0V (Low)**
- **Working Temperature: -15°C to 70°C**
- **Sensing Angle: 30° Cone**
- **Angle of Effect: 15° Cone**
- **Ultrasonic Frequency: 40kHz**
- **Range: 2cm - 400cm**

- **Dimensions**
  - **Length: 43mm**
  - **Width: 20mm**
  - **Height (with transmitters): 15mm**
  - **Centre screw hole distance: 40mm x 15mm**
  - **Screw hole diameter: 1mm (M1)**
  - **Transmitter diameter: 8mm**

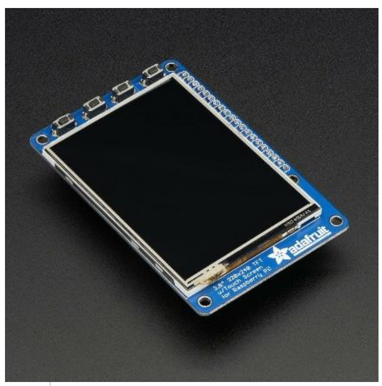
Figure 4.5.1- HC-SR04 Ultrasonic Sensors Specification [20]

Table 4.5 - Ultrasonic Sensor Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.5.1 C	The ultrasonic sensor shall be able to communicate to Raspberry Pi, the lid of the scanning area must be able to open when user approach.	Req 5.3.3 P
Des 4.5.2 C	The ultrasonic sensor has a range of 5cm for detection.	Req 5.2.3 P Req 5.3.3 P

4.6 UI System (LCD Monitor)

An LCD monitor is required to display the user interface (UI) for system feedback and status. The LCD monitor will be able to display messages and information, including: the status of the system, the level of fullness of the waste bins, the result of the prediction, date, and time.



Screen Dimensions	50mm x 69mm x 4mm / 2" x 2.7" x 0.16"
PCB Dimensions	56mm x 85mm x 11mm / 2.2" x 3.3" x 0.4"
Weight	42g
Datasheets, EagleCAD	and Fritzing objects available from the Downloads page

Figure 4.6.1 – LCD Monitor Specification [21]

Table 4.6: UI System Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.7.2 - P	The LCD monitor will display the status and progress of the system operation.	Req 3.2.4 P
Des 4.7.3 - P	The LCD monitor will display the level of fullness of the waste bin for users.	Req 3.2.5 P

4.7 Power Supply

All electronic components of Sort-e require a power supply to operate. The device will use a wired power supply which will be connected to an outlet.

The model CY-0530 USB adapter will be used to power Raspberry Pi (Figure 4.7.1). The camera, ultrasonic sensors, and the LCD monitor all will be driven by the Raspberry Pi. Sort-e also requires an additional power supply to drive the motors. The additional power supply will provide a minimum of 6V and 1.5A, based on the motors' specification. For instance, Nema17 motors require 4V to operate and Nema23 requires 5.6V to operate. A battery set of 6V and 1.5A must be provided to the motor driver to power the different motors among the system.

Figure 4.7.1 – USB Adapter Specification [22]

Table 4.7: Power Supply Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 4.7.1 C	The power supply shall provide up to 3 amps.	Req 5.2.3 C
Des 4.7.2 C	The external power supply shall provide enough voltage and current to drive the motor driver, controlling the stepper motors.	Req 5.2.3 C Req 5.2.4 P

5 Mechanical Design

The mechanical part of Sort-e is responsible for physically sorting the waste by controlling various gates and protecting the internal components of the machine from the external environment. Mechanical components for the proof-of-concept (POC) device will be divided into different sections for clarification for each component.

5.1 External Body Structure

5.1.1 Body structure Overview

The proof-of-concept version of Sort-e's body will be constructed by sturdy and lightweight wood beams and plastic panels. The main structure of Sort-e is formed with the combination of two rectangular parallelepipeds, as shown in Figure 5.1.1. The small cuboid (scanning area) is located and built directly above the large cuboid (the base of Sort-e). The size of the small cuboid is approximately one-third of the large cuboid. The small cuboid is divided into two units: one unit for the storage of electrical component, one unit for scanning and photographing waste items.

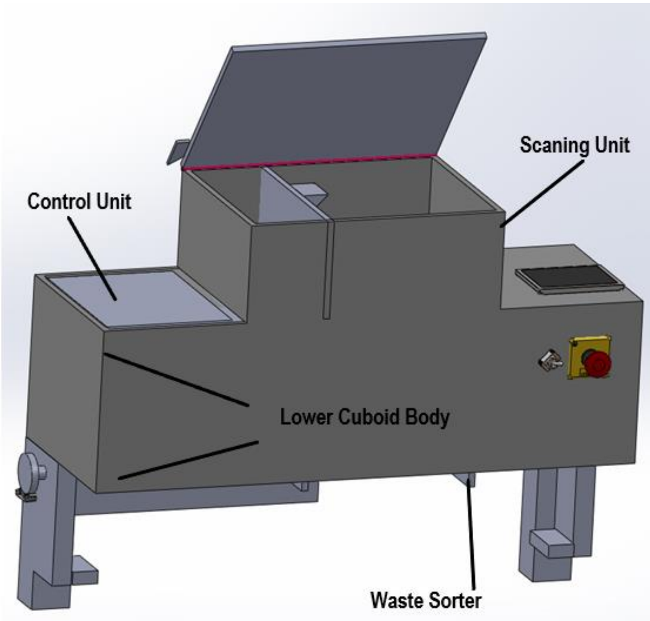


Figure 5.1.1 - Structure of POC Version of Sort-e

5.1.2 System Attachment Structure

As shown in Figure 5.1.2, an attachment piece will be placed under at the bottom of the device. This attachment piece will be attached onto a set of three waste bins. The material of the attachment piece will be made from aluminum alloy. To minimize damage to the human body, the L-shaped corners will be smoothened to rounded corners. The length of this bracket may be adjusted for attachment over waste bins of different sizes.

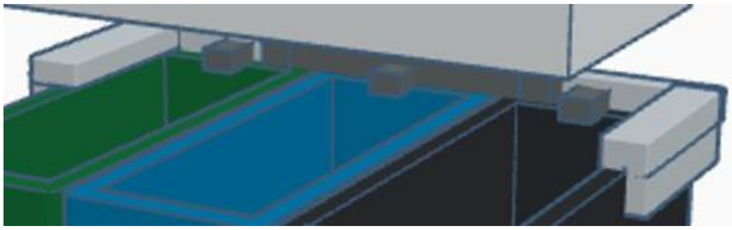


Figure 5.1.2 Structure of the Attachment Piece

From Figure 5.1.3 below, that the attachment piece may support waste bins of different shapes and sizes. Adjustment of the attachment piece will be adjusted using a rounded knob, which is located on the left side. When the knob is twisted in the clockwise direction, the adjustment piece will extend its length. To shorten the length of the attachment piece, twist the knob counterclockwise. In order to adjust the length of adjustment piece, an extra piece of wood cover will be placed above the original bracket to cover its original length. From the Figure 5.1.4, Ball-Bearing Slide is placed between two wood beams to allow them to move freely.

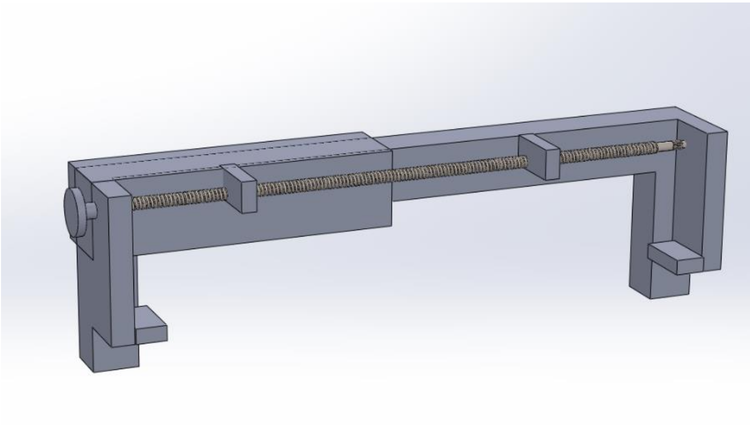


Figure 5.1.3 Structure of Bracket

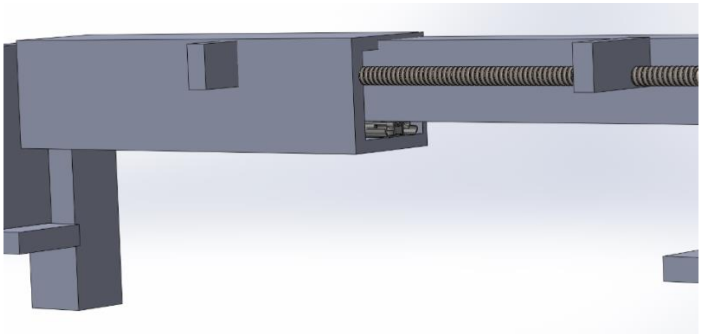


Figure 5.1.4 Ball-Bearing Slide between two Wood Beams

5.1.3 Emergency Button

In Figure 5.1.5, the emergency button is implemented to ensure the safety of users. The emergency button in place functions as an immediate control for the system to shut down. The red emergency button will be installed at the front corner of the device for higher visibility.

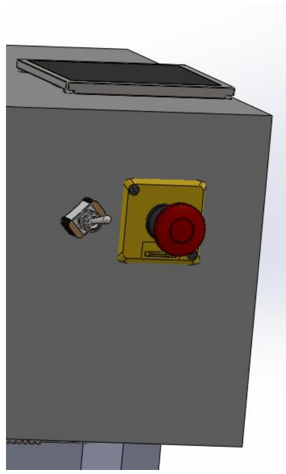


Figure 5.1.5 Placement of the Emergency Button

Table 5.1: External Body Structure Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 5.1.1 P	The material of the external body structure will be built using wood, and the attachment piece will be built using a stainless-steel material.	Req 3.1.9 F Req 3.1.12 F Req 3.1.13 P Req 7.1.5 F Req 7.1.8 P Req 7.2.6 F Req 7.2.7 F
Des 5.1.2 P	The emergency button and the power button will be located on the right corner of the exterior, approximately 5 cm from the edge of the lower cuboid.	Req 7.2.3 P
Des 5.1.3 P	The length of this attachment piece is greater than the total width of three standard waste bins. The shortest length is 90 cm and may be extended up to 120cm. In order to attach and support Sort-e onto the waste bins, an L-shaped corner.	Req 3.1.7 P Req 3.1.14 P Req 3.1.15 P Req 5.3.5 P Req 5.3.6 P Req 7.1.2 P Req 7.1.3 P Req 7.1.4 F Req 7.2.5 F Req 7.2.7 F

5.2 Scanning Unit Structure

The purpose of the division piece in the small cuboid is to isolate the electric stepper motor, for lifting the cover, from the scanning area. From Figures 5.2.1 and 5.2.2 below, the lid has two states: opened and closed. The user may place their hand in front of the ultrasonic senor in order to set the cover to its opened state.

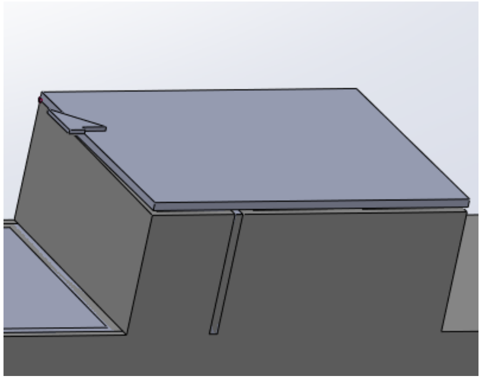


Figure 5.2.1- Mechanical Structure of Cover Opener (Open)

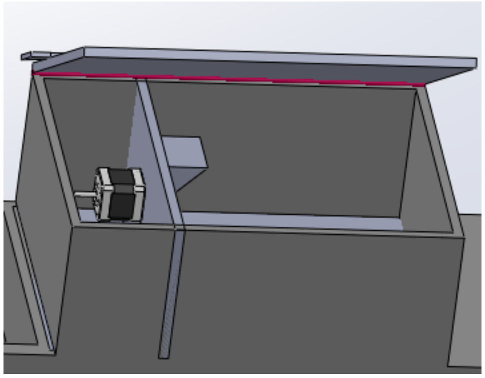


Figure 5.2.2 - Mechanical Structure of Cover Opener (Close)

Figures 5.2.3 displays the principle of the mechanical arm known as the Four Bars Mechanism. For the lid to be fully opened or closed, the motor must rotate 180 degrees. Given that the initial position is when the cover is fully closed, the motor needs to rotate 180 degrees to fully open the cover.

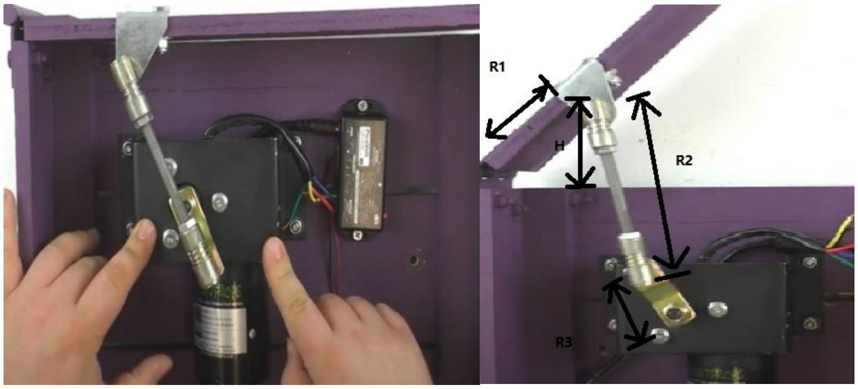


Figure 5.2.3 - Mechanical Schematic Diagram of Cover Opener [10]

To avoid interference when scanning waste products, the cover opening system will be separated from the motor by a division piece.

To calculate the length R1, R2, R3 of the bars, use Torque's formula:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

$$\tau = \|\mathbf{r}\| \, \|\mathbf{F}\| \sin\theta$$

Assuming the cover is to open at a 60-degree angle, the torque required to open the wood cover which has the density of 650 kg/m^3 [11]. The volume of the cover is:

$$V = width \cdot length \cdot depth = (0.3)(0.4)(0.005) = 0.0006\ kg/m^3$$

Therefore, the mass is:

$$m = \rho \cdot V = (650)(0.0006) = 0.39\ kg$$

The force required to push open the cover is:

$$F = Mg = (0.39)(9.98) = 3.822\ N$$

The position of the support point that is connected R1 and the cover is 0.1 m (R1 = 0.1m), so the torque required for the motor is:

$$\tau = (0.1)(3.822)\sin(60) = 0.3310\ kg \cdot m^2 \cdot s^{-2}$$

To calculate that the length of the pillar (R2) which is connected to cover support joint and bar R3, which will have a 90 degrees angle between R2 and R3 (fully opened and closed state):

The length of the Pillar (R2) that connects the motor and the cover, is calculated as:

$$R2 = \frac{\tau}{3.822 \cdot \sin(90)} = 0.0889\ m$$

The length of R3 will be half of the height from support joint to the top of the box:

$$R3 = \frac{h}{2} = \frac{R1 \cdot sin\,(60)}{2} = 0.0433\text{ m}$$

From Figure 5.2.4 and Figure 5.2.5, a gate under the scanning area will be controlled by a stepper motor which allows waste to descend. To use the step motor to control opening and closing of the gate, the edge of the scanning cuboid will have a gear track installed which will allow the gate to slide open or close. A series of gears will be attached to the stepper motor to control the opening and closing speed. When the step motor rotates with the specified number of rounds, the gate will be opened. If it rotates counterclockwise with the same number of turns, the gate will close.

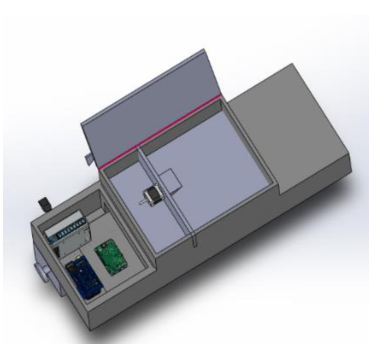


Figure 5.2.4 - Waste Falling Mechanism (Gate open)

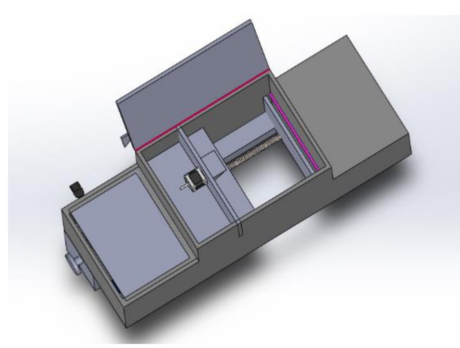


Figure 5.2.5 - Waste Falling Mechanism (Gate close)

Table 5.2 - Scanning Unit Structure Design Specification

Design ID	Design Specification Description	Corresponding Requirements
Des 5.2.1 C	The length of the scanning cuboid has a length of 40cm, width of 30cm, height of 15cm. The division piece will be placed small cuboid, 10cm from left.	Req 3.1.1 C
Des 5.2.2 C	The camera will be placed in the middle of the left edge, within the scanning cuboid. The camera will be tilted down at 45 degrees. To facilitate better shooting, the camera module contains its own flashlight for low light intensity.	Req 3.1.2 C Req 5.3.3 P Req 7.1.6 F
Des 5.2.3 P	The bottom gate has a length of 38cm, a width of 27cm, and a thickness of 1cm; allowing the gear track to move freely.	Req 5.3.1 C Req 5.3.4 P
Des 5.2.4 P	The motor will be attached to the bottom gate. The bottom gate will slide 22.5cm to open when the motor rotates.	Req 5.2.7 P Req 7.1.7 F Req 7.2.1 C
Des 5.2.5 F	The scanning cuboid will be made of LDPE material that is easy to clean [12].	Req 7.1.1 P

5.3 Lower cuboid Internal body Structure

5.3.1 Control Unit

The control unit area of Sort-e is located on the left side of the bottom cuboid. Within the control unit area, Raspberry Pi, motor driver, breadboard and power supply will be placed. Allocation of the components are as shown in Figure 5.3.3. To facilitate wire connections of the camera, Raspberry Pi will be placed beside the scanning area.

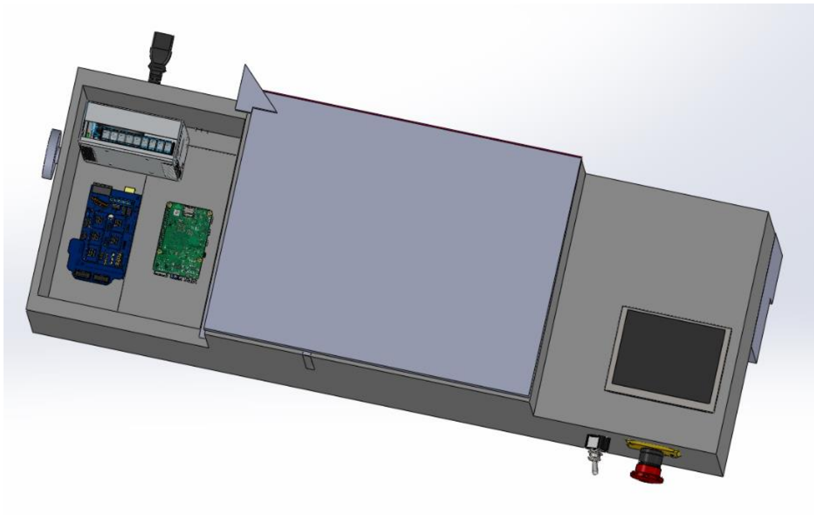


Figure 5.3.1 - Internal Components Distribution

5.3.2 Waste sorter Mechanism

To be able to direct the waste to the corresponding bin, two flaps will be installed under the scanning area. The two flaps will be controlled by the stepper motors (Figure 5.3.4). Each flap will be attached to its own motor which will then also rotate with their designated motor (Figure 5.3.5). The angle of rotation of flaps will be according to the size of the waste bins.

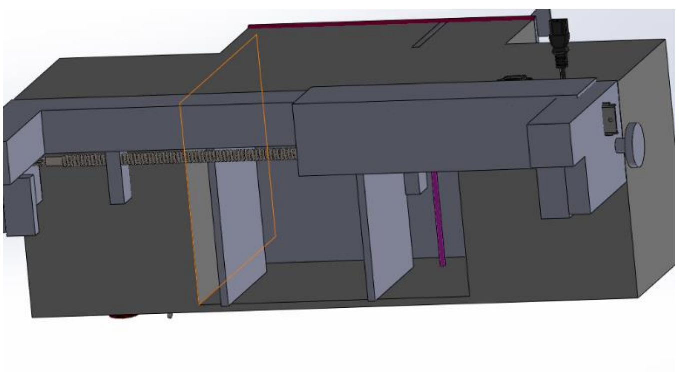


Figure 5.3.4 - Schematic Diagram of the Waste Sorter Mechanism

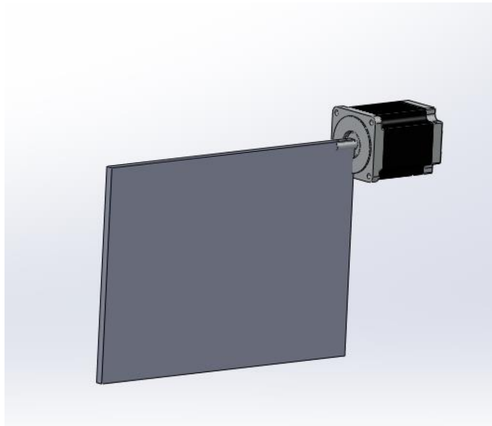


Figure 5.3.5 - Schematic Diagram of the Flap Attached to the Motor

Table 5.3 - Lower Body Internal Structure Design Specification

Design ID	Design Specification Description	Corresponding Requirement
Des 5.3.1 P	The power supply will occupy 10cm(L)*5cm(W) of the area; The Raspberry Pi will occupy 8cm(L)*6cm(W) of the area; The motor drive will occupy 10cm(L)*7cm(W) of the area.	Req 3.1.5 P Req 5.2.2 C Req 7.1.9 P
Des 5.3.2 P	The length of the flap will be 40cm, and the maximum rotatable angle will be 50 degrees. To ensure the waste will be dropped into the desired bin, the maximum length allow for the bin will be 0.306 m.	Req 3.1.6 P Req 5.3.1 C
Des 5.3.3 P	The control unit area will be the circuit protection for all hardware components. In order to fit all of the required components, the control unit has a size of 10cm(L)*5cm(W)*20cm(H).	Req 5.1.4 P

6 Conclusion

Document provides an explanation of design specifications for Sort-e and will be referred to as a reference for BGreen's team. The design specifications document outlines each design component which includes Software design, Electrical design, and Mechanical design. The summary of each design component as mentioned in the document are as listed below:

1. Software Design
    a. Image Classification: classify the category of the waste based on the captured image.
    b. AI Training: Program learning from input dataset to generate a AI model.
    c. Accuracy: Increases the model's accuracy using data augmentation with small dataset.
    d. Processing Speed Optimizer: Decreases the latency by reducing the size of the model.
    e. Device Interface: controls and responds to different the system's status which will depend on the user's input.
2. Electrical Design
    a. System Controller: controls the system's components to perform image processing using an AI model.
    b. Camera module: captures images of the waste placed within the scanning area.
    c. Motor Driver: distribute and manage power for all motors.
    d. Stepper Motor: used to move mechanical parts to achieve the goal.
    e. Ultrasonic Sensors: Uses to determine for different scenarios.
    f. LCD Monitor: provides graphic user interface (GUI) for users.
    g. Power Supply: provides sufficient power to each component of the device.
3. Mechanical Design
    a. External Structure: a protection shell that will protect all internal components. This also includes the attachment piece which allow the device attach onto the waste bins.
    b. Scanning Unit Structure: the area which allows the user to place the waste for image capturing prior to waste disposal.
    c. Lower Cuboid Internal Structure: The shell that will protect the control unit. This also will contain the mechanical part to perform waste sorting.

For future developmental purposes, BGreen will refer to this document regarding the design specifications. This document will provide guidance in seeking solutions during the prototyping phase. During the development of the device, design components will be subject to change.

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Appendix A: Supporting Test Plans

The purpose of the corresponding test plan is to guarantee that every component can function together and individually. The goal for the hardware system is to ensure the major mechanical part(s) and electronic components can work properly. The goal of the software system is to ensure that the trained model can process and classify the image with accuracy.

A.1 Hardware Testing

Test #1: Power on the system	Date:	Tester:
Test Procedure: The motor driver and the Raspberry Pi will be powered by a power supply, and the LCD display shall be on.		
Expected Outcome: Once the system is powered on the LCD will display the main menu and the LED light (indicating power on) will turn on.		
Observed Outcome: Pass / Fail		

Test #1: Ultrasonic sensors	Date:	Tester:
Test Procedure: The motor driver and the Raspberry Pi will be powered by a power supply, and the LCD display shall be on.		
Expected Outcome: The ultrasonic senor outside of the device will detect the user approaching the device, and the stepper motor will open the cover. The ultrasonic sensor inside of the scanning box will begin to scan if waste is present in the scanning area after the cover is closed.		
Observed Outcome: Pass / Fail		

Test #1: Release waste	Date:	Tester:
Test Procedure: Once the system has completed image processing, the waste will be released from the scanning area.		
Expected Outcome: Once the system has identified the category of the waste, the gate under the scanning area will open (driven by the stepper motor) which releases the waste material.		
Observed Outcome: Pass / Fail		

A.2 Software Testing

Test #1: image classification result accuracy test	Date:	Tester:
Test Procedure: Twenty pre-labelled test images (not used for AI training) will be used to test the model's accuracy.		
Expected Outcome: To meet the requirement of an 80% accuracy, at least 16 correct predictions are required.		
Observed Outcome: Pass / Fail		

Test #2: image classification processing speed test	Date:	Tester:
Test Procedure: Input 5 random waste images for image classification. Start timer when the program starts to run. Stop timer when all predictions are complete. Record the processing time.		
Expected Outcome: To meet the requirement, the average process time for each input image must be less than 1 second; a total time of 5 seconds.		
Observed Outcome: Pass / Fail		

Appendix B: User Interface and Appearance Design

1.1 Introduction

The Sort-e is designed to be a smart sorting system to sort waste automatically with its unique mechanical component. The majority of interactions between the user and Sort-e will be through an LCD touchscreen and LED lights. The goal of Sort-e's user interface (UI) is to achieve a user-friendly device.

Referred to Don Norman’s book, The Design of Everyday Things, where the focus will be placed on the seven main parts of UI design: discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints, to construct a better experience for users.

1.2 Purpose

The following appendix will illustrate both the hardware and the software components of the device. The document will also provide reasonings for implementing our specific designs.

1.3 Scope

This document will focus on the following terms: user analysis, technical analysis, graphical presentation, engineering standards, analytical usability testing, empirical usability testing.

1.4 User Analysis

The target users of the Sort-e device are for those who require assistance in categorizing different waste materials. In Canada, there are garbage and waste bin systems implemented to encourage recycling waste materials; however, only 9% of recycling materials are actually recycled [23]. BGreen aims to minimize contamination of recycling materials while promoting waste literacy, promoting a greener future.

To increase accessibility, we have minimized the buttons and switches in the device, so that the process is intuitive. The user will place the waste material into the scanning area according to the instructions displayed on the LCD screen. The entire process will be touch free to create a hygienic and clean experience.

1.5 Technical Analysis

1.5.1 Discoverability

In order to enhance the discoverability of our product, an LCD monitor and LED lights will be used to communicate with the user. This will provide a touch free experience for the user. The LCD will display the instructions regarding when to dispose the waste material.

Main actions:

1. The device must be easy to turn on and off.

2. The device should be easily attached or detached from the waste bins.

To achieve these actions:

1. An LED light will be installed to indicate the device's power status (on/off).

2. Waste bins will be separated with each other to ensure that each bin can be removed separately.

1.5.2 Feedback

Feedback refers to responses generated based on the user's input. This ensures that the system has received the input. In addition, the system will generate outputs associated with the input. The ultrasonic sensor will act as the input system, it will receive action signals, then the board will transfer the signals to output signals to the other components of the system.

User inputs such as approaching the scanning area are to be acknowledged with visual feedback. The LCD monitor will guide users throughout the waste sorting process. Notification on the LCD monitor will be treated as feedback. The LCD monitor will also indicate the feedback of the loading status of each garbage bin.

The LCD monitor will represent feedback messages:

1. Out of order: The system is out of order because one or more waste bins are full.

2. Scanning: The gate is open, and the scanning area is ready to receive the waste material.

1.5.3 Conceptual Models

The conceptual model explains the functionality of the model and explains how the model operates. For our device, the UI will satisfy the requirement of the conceptual model to ensure that functions of the device are able to operate. Each button and instructions displayed will be intuitive for the users to ensure an effortless experience.

1.5.4 Affordance

Affordance provides hints for the user for controlling the system. Our UI design will be inspired by existing designs to provide familiarity and create a better understanding as to how to operate the device. Signifiers and mapping considerations will also improve the affordance of the UI.

1.5.5 Signifiers

A signifier is anything used to indicate affordances. In our system, an LED light will be used to indicate the power status. When the device powers on, the LED lights up. When the device powers off, the LED turns off. Text is displayed on top of the LCD screen will be used to indicate the system's current status. For each status, the text is displayed on the screen will correspond to the status of the device. For instance, when the system is in the ready state, there will be a text 'ready' on top of the screen. The color of the garbage bin icon will be used as a fullness indicator. There are 3 colors for indicators including green, brown, and red. When the fullness is from 0% to 60%, 60% to 90%, and 90% to 100%, the color will be green, brown, and red correspond.

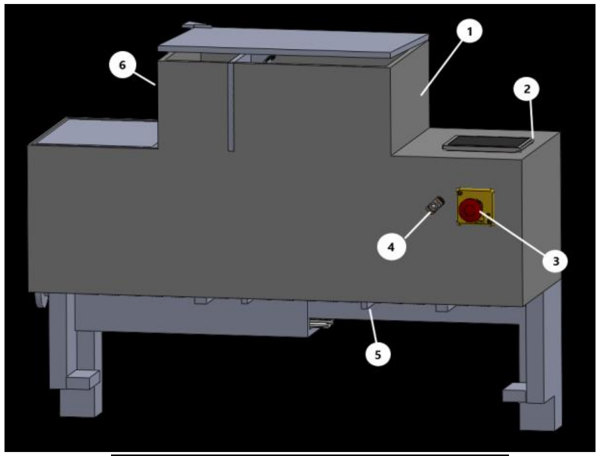
1.5.6 Mapping

Mapping refers to the relationship between control and action. In our system, the power button will be near the power supply cable to inform the user it is a power button.

1.5.7 Constraints

Constraints refer to the things that guild user action and interpretation. In our system, the screen only shows the current system state and fullness of the garbage bin to reduce the information density in one screen. Less density of information will increase the user experience. A plastic box will cover the emergency button so that the user will not press it by mistake.

1.6 Graphical Representation



1	Scanning Area
2	LCD Monitor
3	Emergency Button
4	On/Off button
5	Flaps
6	Control Unit Cover

Figure - B.6.1 Overview of Sort-e

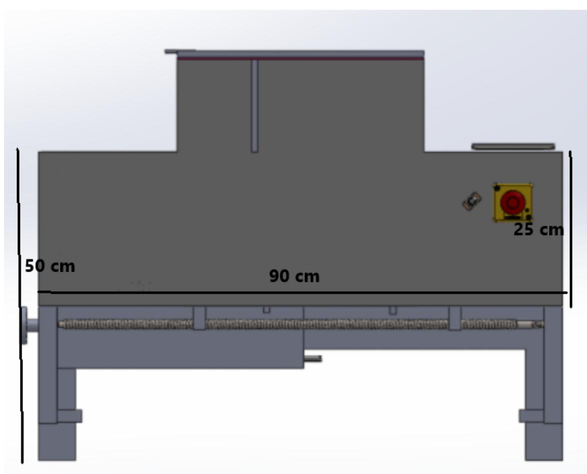


Figure B.6.2 - Front View of Sort-e

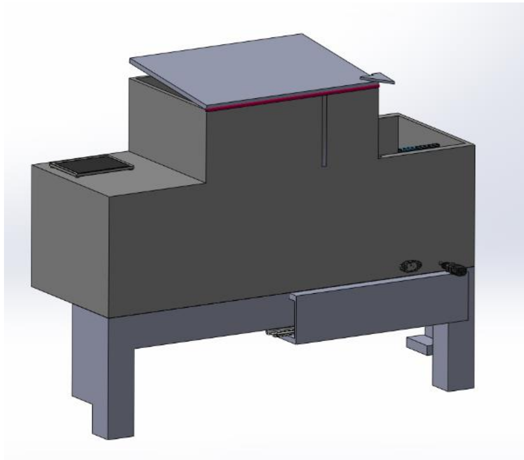


Figure B.6.3 - Rear View of Sort-e

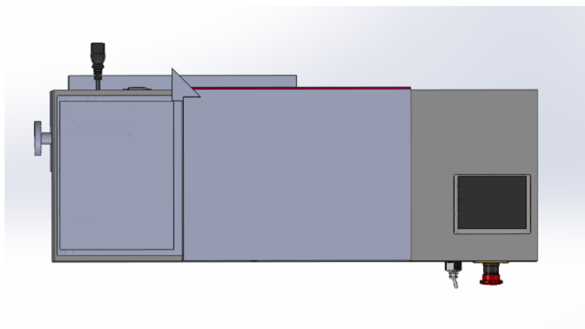


Figure B.6.4 -Top View of Sort-e

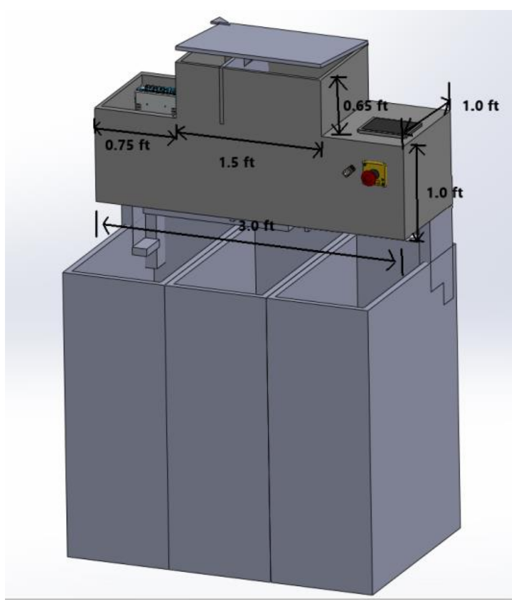


Figure B.6.5 - Physical Dimensions of Sort-e

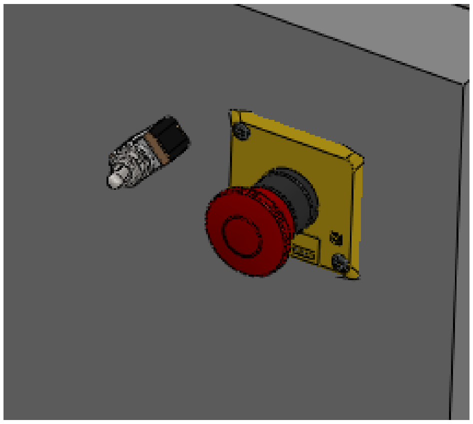


Figure B.6.6 - Power Switch and Emergency Button

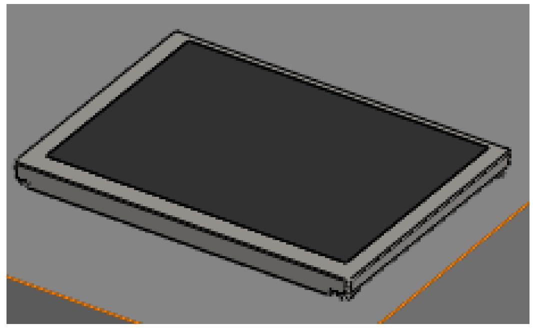


Figure B.6.7 - LCD Screen for UI Display

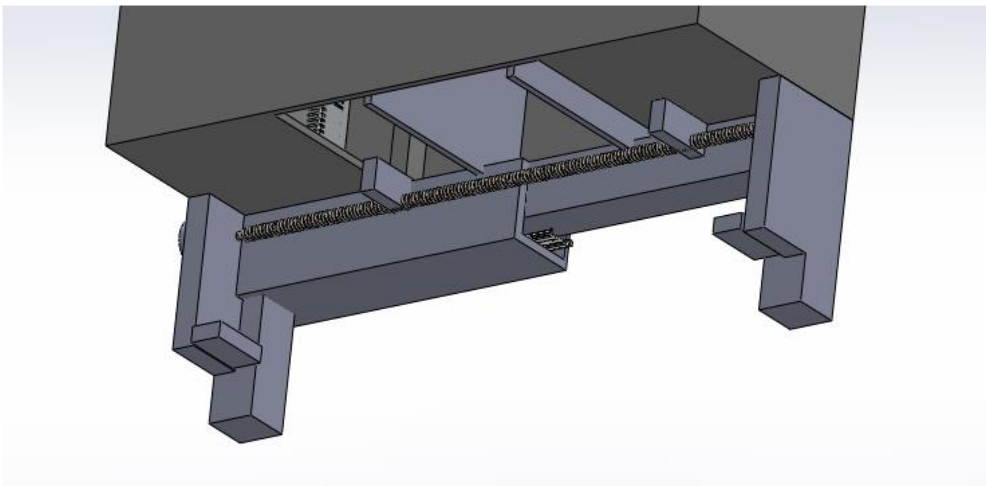


Figure B.6.8 - Bottom View and Attachment Piece of Sort-e

Figure B.6.9 - UI Display (Out of Order)

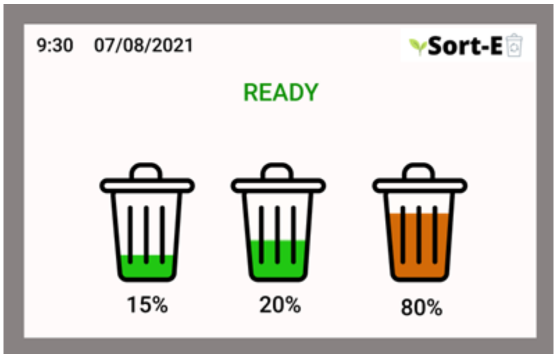


Figure B.6.10 - UI display (Ready)

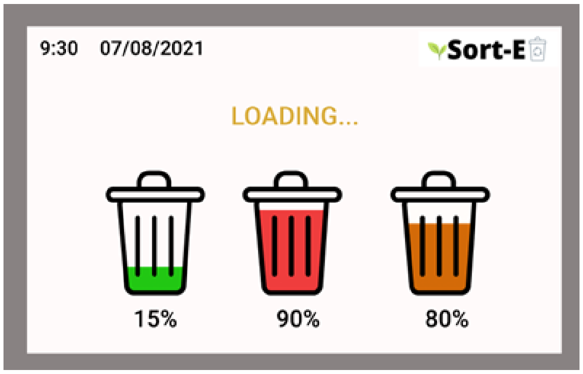


Figure B.6.11 - UI Display (Loading)

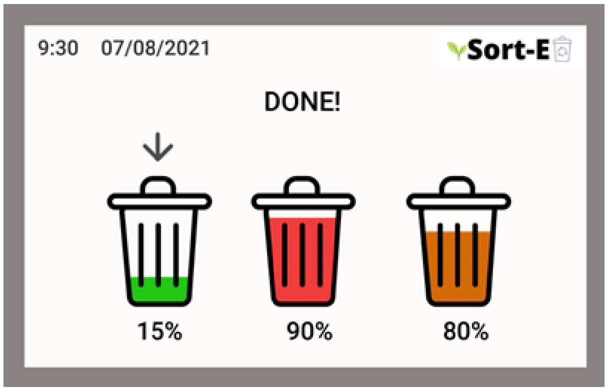


Figure B.6.12 - UI Display (Done)

Figure 1.6.1 shows the top view of the Sort-e. The LCD monitor will be placed at the top of the Sort-e. The Sort-e provides a simple and intuitive user-feedback system located on LCD touchscreen, by viewing the touchscreen, a user can interpret the status of the collection system, Bluetooth connectivity, and power as shown in figure 1.6.2. There will be a power button which can control the power system of the Sort-e as shown in figure 1.6.2 and 1.6.3. There will be three garbage bins attached to the Sort-e as shown in figure 1.6.4. Figure 1.6.3, figure 1.6.6, figure 1.6.1 and figure 1.6.8 represent the front, back, top, and bottom view of the Sort-e. Figures from 1.6.9 to 1.6.12 show the different stages of the LCD monitor.

1.7 Engineering Standards

To meet the safety, quality, and comfort for the user interface of Sort-e, Sort-e must comply with the engineering safety standards, such as ASTM, CSA, ISO, IEC, IEEE. Users will interact with Sort-e though both software and hardware systems. To ensure that the user's personal safety and health are guaranteed during the use of Sort-e's software and hardware systems. Sort-e will comply with the following standards during the process of prevent bodily harm and maintain the user’s privacy.

Table B.7.1 Engineering Standards for User Interface

Standard	Description
CSA ISO/IEC 29138-1	Information technology — User interface accessibility — Part 1: User accessibility needs [24]
ISO 9241-161:2016	Ergonomics of human-system interaction -- Part 161: Guidance on visual user-interface elements [25]
ISO/IEC TR 11580:2007	Information technology -- Framework for describing user interface objects, actions, and attributes [26]
IEEE 1686-2013	Intelligent Electronic Devices Cyber Security Capabilities [27]

PiTFT touch screen will construct the user interface of the Sort-e. The PiTFT touch screen is based on the CSA ISO/IEC 29138-1 which provides guidance for developers and user interface designers to create user interface as well to improve the user interface accessibility. This standard will improve the user experience. ISO 9241-161:2016 describes the visual user interface elements presented by the software and provides requirements and recommendations on when and how to use them. ISO/IEC TR 11580:2007 defines a format for describing user interface objects, operations, and attributes. It provides a basis for standardizing the names and attributes of user interface objects, operations, and attributes across multiple applications and platforms.

Table B.7.2 Engineering Standards for Safety

Standard	Description
CAN/CSA-C22.2 No. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems — Part 1: General requirements [28].
CAN/CSA E60335-2-14-05	Household and Similar Electrical Appliances - Safety - Part 2.14: Particular Requirements for Kitchen Machines [29].
IEEE 1789-2015	IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers [30]

Since sort-e interacts most with users in its mechanical part, sort-e must ensure the safety of users when interacting with the scanning area. CAN/CSA-C22.2 No. 61508-1:17 National International Standard covers those aspects to be considered when using electrical/electronic/programmable electronic (E/E/PE) systems to perform safety functions. CAN/CSA E60335-2-14-05 The national international standard relates to the safety of electric kitchen machines for household and similar purposes. IEEE 1789-2015 includes the definition of the concept of light-emitting diode (LED) modulation frequency.

1.8 Analytical Usability Testing

Analytical testing will be performed by the BGreen's team without users participating. The main purpose of the analytical testing is to ensure that the LCD monitor and LED lights can operate based on the inputs.

1.8.1 Designer Testing

The following steps are to be conducted by members of the team:

1. Connect camera, LCD monitor, motor driver and power supply to the Raspberry Pi corresponding pins.
2. Connect stepper motors to the motor drive.
3. Turn on the power supply and verify the yellow LED light and the LCD monitor turns on.
4. The LCD will display the instructions of the system.
5. Using the Raspberry Pi to control the motor driver which can control the stepper motors.
6. Approach the device.
7. Place waste into the scanning area.
8. Replace waste bins that are full.

1.9 Empirical Usability Testing

Heuristic evaluation will be done through the user testing and the internal testing. The testing result will be used as an implementation tool to improve the quality of the product. The BGreen team will focus on the user feedback form to make sure the product is easy to be used. Requirements can be categorized in the two following stages:

1.9.1 Proof of Concept

- The cover of scanning area works as intended.
- The stepper motor can drive the scanning area to right location.
- Switch turns on power to the system.
- LCD can display the correct instruction.

1.9.2 Prototype

- User is able to drop the garbage into the scanning area
- LCD will display each step the system is working on
- Garbage bin can be set up and taken off
- LED lights will clearly indicate the status.
- User documentation will be concise and clear

1.9.3 Internal Testing

In order to make sure the system can work for social use, the BGreen team will do the internal test before the user test. The main purpose is to test whether each component can do its job and troubleshoot some unexpected errors.

1.9.4 End User Testing

In order to give users a better experience, we are going to invite some friends or strangers from different ages to test the product. After the testing, users will be asked to complete a User Feedback Form. The purpose of the end user testing is to give the BGreen team information about the user experience or suggestions.

Additionally, one of our members from BGreen will be accompanied with the user who is going to test the product for technical and safety reasons. The member will not interrupt the process of testing except for some safety reasons.

User Feedback Form

Test Environment:	
Rating Scale: 1-10 (from poor to good)	
Question	
First Impression of Sort-e	
Ease of use	
Helpfulness of the LCD monitor	
The speed waste disposal?	
How likely are you to recommend this product to your friends?	
Please rate your Sort-e using experience	
Additional comments:	

1.10 Conclusion

Friendly user interface is part of our product goal. Our team will follow the 7 design parts that mentioned above to achieve our goal. As our system does not need too much user control, we are aiming to provide easy to use garbage classification system. For more details, the user interface of LCD and body struct of the system will not provide extra user control except power button and emergency button. Currently, we have the initial user interface design for the whole system, we are going to work on internal testing and end user testing so that we can get some feedback to improve the user interface. For prototype, we expect to provide the product that is effective and intuitive to use.

Appendix C: Supporting Design Options

C.1 Device Body

Table C.1.1 - Requirements for the Device Body

Requirement ID	Requirement Description
Req 5.1.6 F	The product must be suitable for both outdoor and indoor environments
Req 5.1.4 P	The product must have circuit protection for all hardware components, which includes camera, Raspberry Pi, and power supply.
Req 5.1.5 P	The bottom attachment piece must be able to support the weight of the remaining components.

Table C.1.2 - Design Options for the Device Body

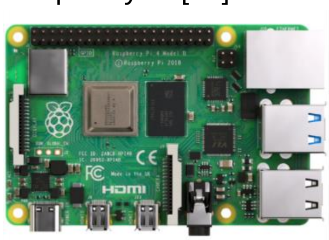
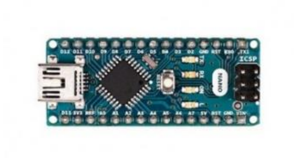
Design Options	Specification
Wood and metal material	This design is light and affordable but is not waterproof for outdoor environments. The cover of the scanning area will be constructed with wood, as it is more affordable and allows the cover to be moved by the stepper motor.
Wood and stainless steel	This design may be more expensive, but it is outdoor friendly as this will be water resistant, ensuring it can satisfy the requirement for both the indoor and the outdoor use.

The wood and stainless steel will be chosen for our device, which can satisfy the requirement of indoor and outdoor use.

C.2 Microcontroller

Table C.2 outlines the different options for microcontrollers considered: Arduino Nano and Raspberry Pi. Both Arduino and Raspberry Pi boards have the similar functionalities; however, our device focuses more on image processing, the speed of analyzing images will be the main priority. Table C.2.1 lists the design options for the microcontroller.

Table C.2.1 - Design Options for Microcontroller

Design Option	**Technical Specification**	
Raspberry Pi [31] 	Operation Voltage	5V
	Clock Speed	1.5GHz
	DC Current per I/O Pins	40mA
	Input Voltage	5.1V
	Power Consumption	100mA
	Weight	9g
Arduino Nano [32] 	Operation Voltage	5V
	Clock Speed	16Mhz
	DC Current per I/O Pins	40mA
	Input Voltage	7-12V
	Power Consumption	19mA
	Weight	7g

Multiple experiments were conducted for both boards and found that the Arduino is not suitable for processing large dataset comparisons, which result in a long processing time. On the other hand, Raspberry Pi has its own component set which includes the camera. Therefore, the system may be easily set up by connecting the components together.

C.3 Motors

Table C.3.1 - Requirements for the Motor System

Requirement ID	Requirement Description
Req 5.2.7 P	The motor must be able to rotate with the weight of the waste.

Table C.3.2 - Design Options for the Motor System

Design Options	Specification
Stepper motor Nema17	The Nema17 has less power consumption, but it has smaller torque to drive the gate or the cover of the scanning area. It does not have the ability to drive heavy parts. A 46N*cm torque will be enough to drive the cover of the scanning area.
Stepper motor Nema23	The Nema23 has more power consumption with larger torque, which means that it can drive open the cover of scanning area. However, if the part is too light for the motor, the stepper motor will be more difficult to control as the rotation of the stepper motor will be too fast.

As shown in table C.3.2, both stepper motors will be used. The Nema 17 will be used for opening and closing the cover of the scanning area. And the Nema 23 will be used for driving the gate and the flaps, allowing waste to be released into their corresponding waste bin.

C.4 Cover Opening System

Table C.4.1 - Requirements for the Cover Opening System

Requirement ID	Requirement Description
Req 5.3.4 P	All gates must automatically reset after disposing the waste.
Req 5.3.3 P	The cover of the scanning area must be able to open.

Table C.4.2 - Design Options for the Cover Opening System

Design Options	Specification
1. Ultrasonic sensor	The ultrasonic sensor can detect if waste is approaching by determining the distance between sensor and the object. It can sense distance increasing or decreasing to ensure that the cover will open.
2. Motion sensor	The motion sensor will detect the speed of the object by calculating the time to point A to point B. To ensure that the waste is approaching with the user, defining the range of speed which indicate this scenario must be completed.

The motion sensor can identify the speed of waste approaching by calculating the distance between the object (waste) and the sensor. That being said, it cannot determine whether waste is approaching or leaving. The ultrasonic senor will be the best option as it detects when the user is approaching the system.

C.5 Waste Detection System

Table C.5.1 - Requirements for the Waste Detection System

Requirement ID	Requirement Description
Req 3.2.1 C	The system must be able to capture image of the waste and determine its category.
Req 3.1.1 C	The system must have a designated scanning area for holding waste

Table C.5.2 - Design Options for the Waste Detection System

Design Options	Specification
Gravity sensor	The gravity sensor will measure the force of the object which also means that it can measure if waste is placed in the scanning area, allowing the camera to function.
Ultrasonic sensor	The ultrasonic sensor will detect the distance of the waste material. If there is waste inside of the scanning area, then it can determine that the distance between the object and sensor has changed, then it signals the camera to work.

Both sensors have similar functionalities in detecting waste material in the scanning area. However, there is an exception where if the waste material is too light, the gravity sensor can not pick up any values regarding the waste material. The ultrasonic sensor has an exception where if the waste material is too small, the ultrasonic sensor will possibility ignore the waste material and will not detect change in distance. A potential solution will be to install two ultrasonic sensors in different directions for the sensor to detect smaller waste material.

C.6 Bin detecting System

Table C.6.1 - Requirements for the Bin Monitoring System

Requirement ID	Requirement Description
Req 3.1.8 P	The system must detect whether the bin is full or not.
Req 5.1.3 P	The sensor must send signals when waste bin is full.

Table C.6.2 - Design Options for the Bin Monitoring System

Design Options	Specification
Gravity sensor	The gravity sensor will be place at the bottom of the bin. The output value of the sensor will show how much waste is inside the waste bin.
Ultrasonic sensor	The ultrasonic sensor will be place at the top of the waste bin. Then detect the distance between the top of the waste bin and the waste level.

Both the gravity sensor and the ultrasonic sensor functions to check the loading status of the waste bins; however, it is difficult to indicate the fullness of the bins by calculating the weight. This is due to the fact that waste differ in density (ie. Large waste materials may be light in weight). The best option for monitoring the bin will be implementing ultrasonic sensors to determine fullness of each bin.