June 28, 2019
Dr. Andrew H. Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

RE: ENSC 405W/440 Design Specification for **ResistWaste Resistor Sorter**

Dear Dr. Andrew H. Rawicz,

The enclosed document is the design specification of ResistWaste, the automated resistor sorter system designed by ElectroSavvs. ResistWaste is currently under active development and our ultimate goal is to make it into an accessible tool in SFU's engineering lab for students to use. Combining image processing technology with circuit and mechanical knowledge, ResistWaste will greatly reduce the resistor consumption in the labs and promote environmentally friendly behavior among future engineers.

This document will outline the design specification of ResistWaste starting from a high-level system overview of the product to design details of each major component. It will consist of design details of physical architecture, hardware specifications, and software design. Each design specification will be followed by detailed justification explaining why the approach is chosen. At the end of our document, two appendices, Test Plan and User Interface design will be attached. Due to the nature of our project, this document will mainly focus on the proof-of-concept stage as the later design will rely heavily on how well we can realize our concept. Many changes may occur but this specification will serve as the foundation and guidelines of this project.

Thank you for taking the time to review our design specification. This team consists of Lance Zhang, Tian Lu, Yuze Bian, and Weiwei Wang. We are four passionate engineering students that wish to make a change to the labs by using our product. Please do not hesitate to contact me at lancez@sfu.ca.

Sincerely,

Lance Zhang
Project Manager

Design Specification

ResistWaste

Automated Resistor Sorter System

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Submitted To: Prof. Craig Scratchley
Dr. Andrew Rawicz

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Issued on: June 28, 2019

Abstract

To prepare for the upcoming proof-of-concept demo, this document outlines the design specifications of the resistor sorter product name *ResistWaste*. At this stage, we are mainly focusing on developing the major subsystems of ResistWaste. This includes the motor controlled X-Y table system with motor driver and Arduino; the image processing system that measures the resistor value using a macro camera and OpenCV library; and a Wheatstone Bridge system that can measure resistors more accurately using circuitry. The technical specification that we got so far is all listed in the sections below.

Table of Contents

List of Figures:

List of Tables:

Glossary:

PWM	Pulse Width Modulation
Raspberry Pi	A tiny computer that runs Linux system
MCU	General Microcontroller Unit
Arduino	A type of MCU that has a processing chip of ATMEGA328P
GPIO	General-Purpose Input/Output
Numpy	A high-level mathematical Library of Python
OpenCV	Real-time computer vision library

1. Introduction

1.1 Background and Scope

In engineering labs, through-hole resistors act as a crucial role in the breadboard circuitry design for academic purposes. For each lab assignment, individuals or lab groups usually consume a variety of resistors but students tend to dump them after use. Fully functioning used-resistors pileup gradually in SFU's recycled bins every day. No one wants to search through the whole tangled pile to find the values they want. Regulation cannot stop wasteful behavior but this can be stopped. We figured that maybe students just need a little help from *ResistWaste*.

ResistWaste is designed to be an automated system that identifies and sort used through-hole resistors in the universities' labs. This document includes a detailed design specification of *ResistWaste* from a bigger picture to each subsystem. It will first start with an overview of the entire system and then narrow down to the two major systems: X-Y coordinate Table system for resistor sorting and Resistor measuring system which consists of Imaging processing and/or Wheatstone Bridge Design. For each design specification, detailed justification will be provided as we would like to share the thought process of the choices.

At the end of the document, there will be two appendices: Supporting Test Plans Appendix and User Interface and Appearance Appendix. The former will be used to address the test plan we decide to carry out for subsystems and components (proof-of-concept phase). The latter is a detailed description of how we wish the UI of *ResistWaste* will be like at a later stage.

1.2 Intended Audience

This document is intended to be used by all the project members at ElectroSavvs for the implementation and development of *ResistWaste*. Although some of the design decisions may change as the project moves forward, it will be used as our fundamental guideline for the 405W proof-of-concept demo. This document is also prepared for the instructors of ENSC 405W: Prof. Craig Scratchley, Dr. Andrew Rawicz, and TA Mohammad Akbari.

1.3 Design Specification Conventions

For clarification and reading convenience, all the design specification listed in this document will follow the following convention:

DS [Section #].[Subsection #].[Specification #]_[Development Stage]

While this project is still in the stage of developing a proof-of-concept demo, we would still like to share some insight into the future. The following Table 1 shows the abbreviated stage name of the specifications.

Abbreviation	Development Stage
PoC	Proof-of-Concept Prototype
EP	Engineering Prototype
FP	Final Product (ENSC 440)

Table 1: Development Stage Abbreviation

2. System Overview

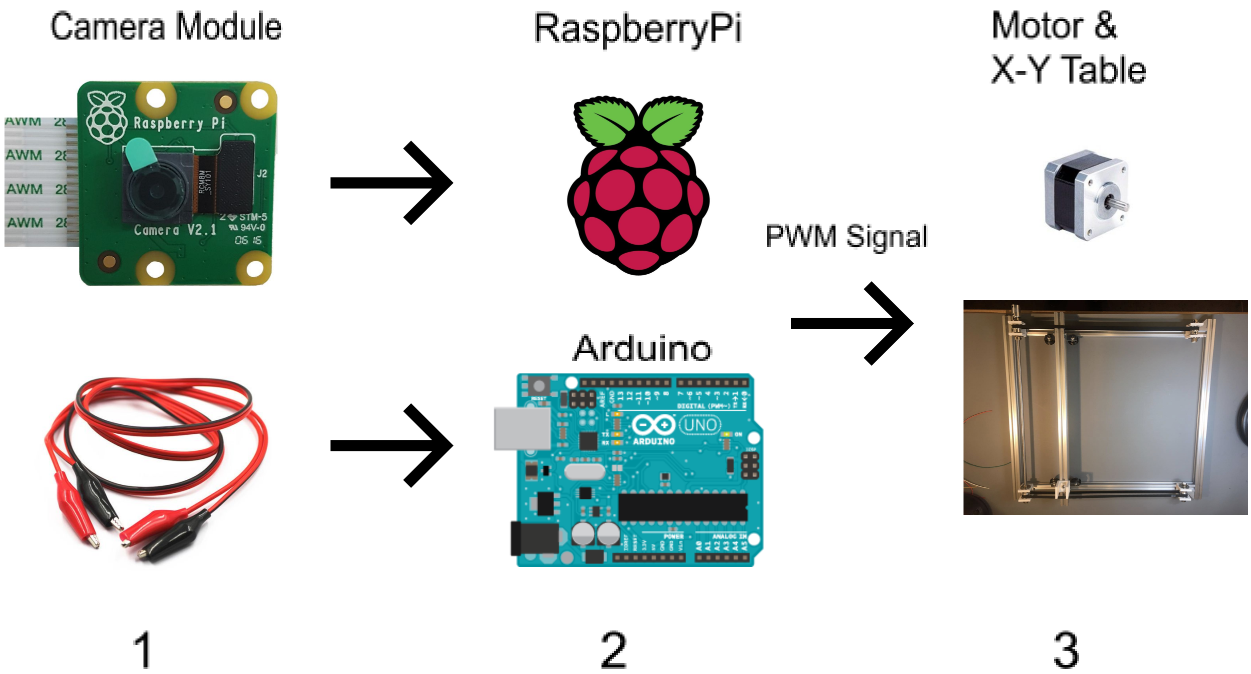


Figure 2.0 Overview of the System [1][2][3][4]

Looking at it from a higher level, *ElectroWaste* resistor sorter system can be divided into three main subsystems. The first part consists of the RaspberryPi Camera Module to collect image information from the resistors and a contacted connection to the resistor. The second part represents the brain of the system which is mainly a RaspberryPi for image processing and Arduino for Ohm measurement and motor driver control. The last part is the motor controller X-Y table that can move in a coordinate system precisely. All the details about each subsystem will be displayed in the later section.

Table 2.0: High-Level Design Specification	
Des 2.0.1-EP	*ResistWaste* shall be able to measure the **value** of a through-hole resistor using image processing and/or Wheatstone Bridge.
Des 2.0.2-EP	*ResistWaste* system shall be able to compute the measured value and utilize the motor for X-Y movement.
Des 2.0.3-EP	*ResistWaste* system should be easy to assemble and components shall be easy to replace.
Des 2.0.4-EP	The X-Y Table should move to the top of the desired grid where it corresponds to the value of the resistor.
Des 2.0.5-EP	All the components and the entire system should be tested based on the test plans in the requirement specification [5] and the supporting test plan in Appendix B of this document.

3. Physical Architecture

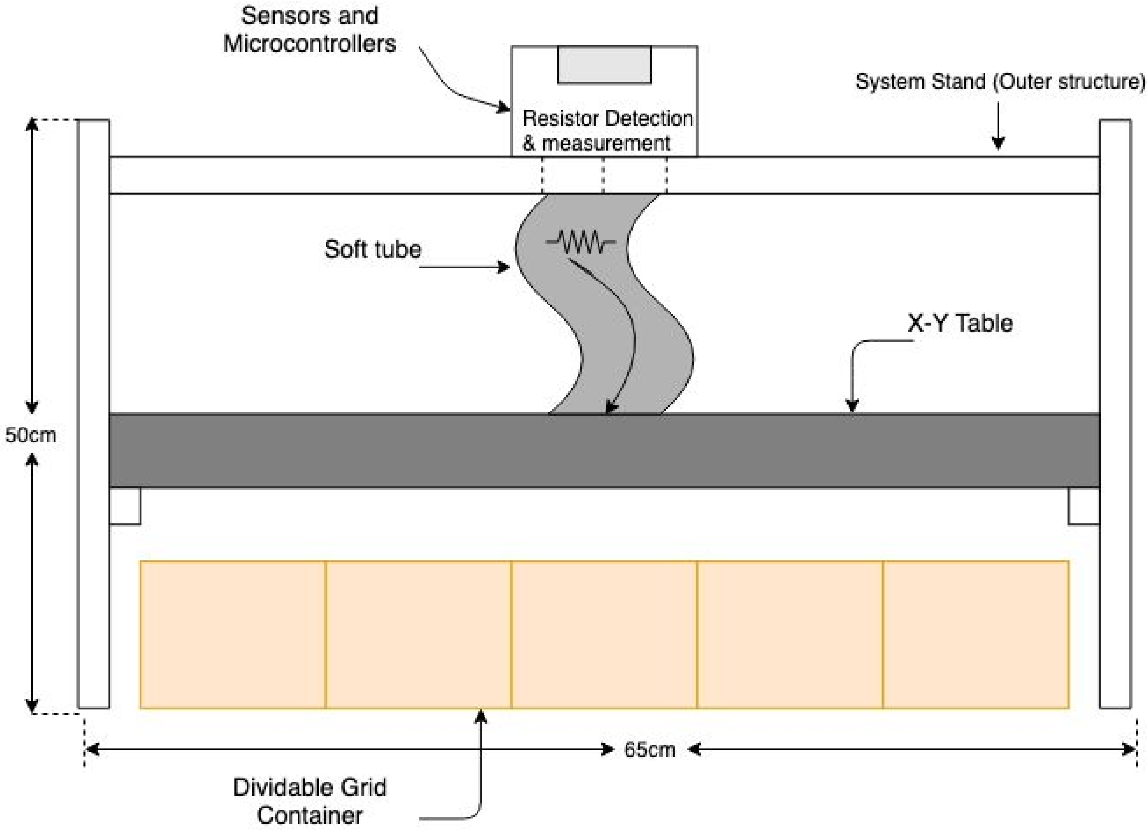


Figure 3.0 Physical Architecture

The image above is the conceptual model of a cross-section overall look of *ResistWaste* system. Although for the proof-of-concept stage our main focus is to build the resistor detection component and having the X-Y table controllable with motor drivers, we found that it is crucial to have a clear picture of what the entire system should look like.

Starting from the engineering prototype, we should be able to achieve a model that connect all the subsystems together like the image above: both the X-Y table and resistor Detection component should be mounted on top of a supporting stand. Below the sorting system, there should be a 5x5 dividable Grid Container. The top end of the "soft tube" is connected to the Resistor Measuring component and the bottom exit of the "soft tube" should be above the grid container. When the value of the resistor is measured, the X-Y table should move the exit end of the soft tube to the desired coordinate, right above the corresponding grid of the container. And then the resistor will be dispensed down the soft tube, finally landing into the correct grid location. Table 3.0 below shows the physical architecture design, note that the material of the soft tube, system stand, and grid container has not been finalized yet.

Table 3.0: Physical Architecture Design Specification	
Des 3.0.1-EP	The outer structure (shown above) shall be able to hold still under 6 kg weight on top.

Des 3.0.2-EP	The dimension of the outer structure should be 50cmx65cmx50cm.
Des 3.0.3-EP	The soft tube should be flexible enough and allow a single through-hole resistor to pass through freely. The diameter should be at least 5 cm.
Des 3.0.4-EP	On the top end of the soft tube, a clamp-release or pushing mechanism shall be built in order to dispense the measured resistor into the top opening of the soft tube.
Des 3.0.5-EP	The dividable grid container should have a 5x5 grid evenly divided corresponding to the coordinate that is programmed in the X-Y table.

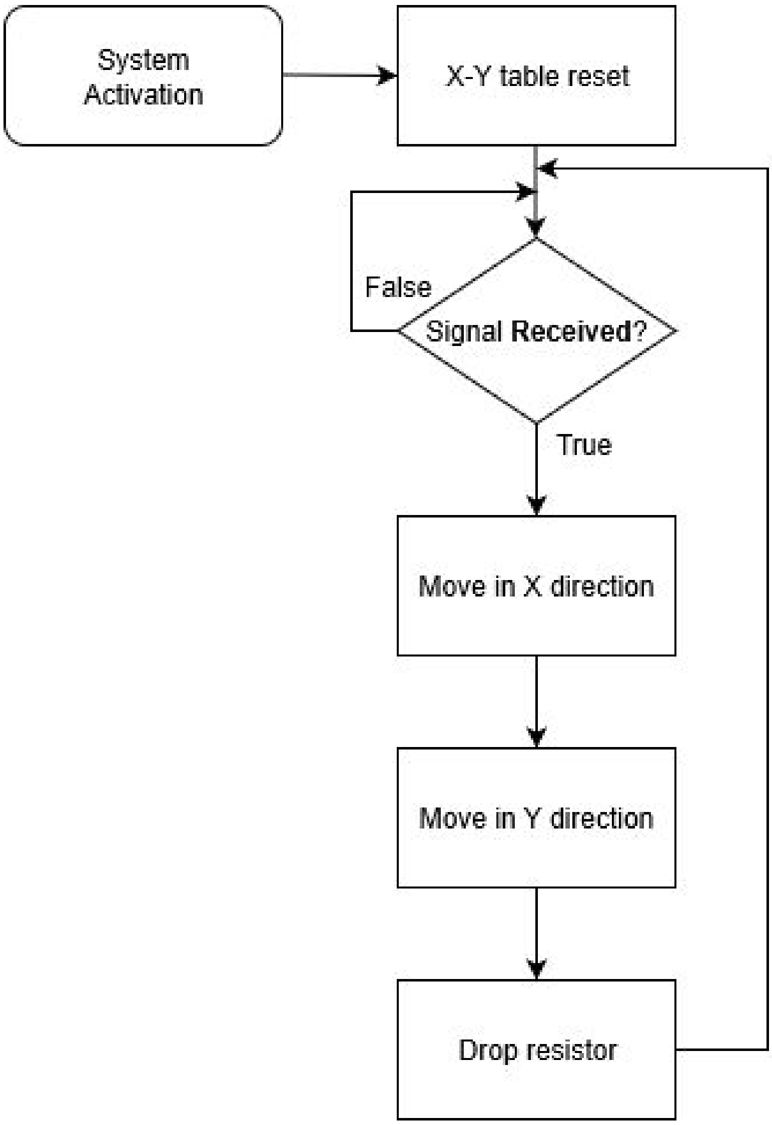


Figure 3.1 Flowchart of the System

Justification

1. Why is there a soft tube in the design?
   This may surprise you that the design of *ResistWaste*'s X-Y table sorting system is quite different from a typical doll catching arcade machine. After researching, we found that building a "catch and release" robotic arm is too hard for tiny objects like resistors. Additionally, our team has only four students that do not have any mechatronics background. So we would like to keep our design simple and easy to maintain for the consumers. The soft tube will act as a slide for the resistors and guide them toward the desired location on the X-Y coordinate.
2. All the parts and materials we got so far are easy to find and purchase locally, therefore, replacement and maintenance will be relatively easy for lab managers.

4. X-Y Table Design Specification

The X-Y table essentially consists of aluminum extrusions, bearings, pulleys, axial rods, timing belt, motors, and motor drivers. The aluminum extrusions form a stage frame and have a mounted rail with wheels that allow movement in X and Y direction. The motors and motor drivers work together to control the timing belt that can pull the rail in both directions. The picture below shows the X-Y table work in progress as only the movement in X-direction has been implemented.

Figure 4.0 X-Y table Design

One major goal by the end of 405W for us is to prove that we can build a working X-Y stage coordinate table with motors and motor drivers. As the image shown above, we will connect a stepper motor to a coupler shaft, which is supported by ball bearings and a steel rod as an axial. On the steel axial, there will be pulleys which will rotate the timing belts and move the mounted extrusion along the side rails. The detailed specification for each part shown in the picture will be listed out in the next section. The table below shows the design specification for the entire X-Y table at the proof-of-concept stage.

Table 4.0: X-Y Table with Motion Control Design Specification	
Des 4.0.1-PoC	In the X-direction, movement of the mounted extrusion shall be smooth and free, within a range of 40 centimeters.
Des 4.0.2-PoC	In the Y-direction, movement should be allowed with a range of 30 centimeters.
Des 4.0.3-PoC	The ball bearings, pulley, axial rod, and the timing belt should cooperate as a whole system.
Des 4.0.4-PoC	Turning the coupler shaft should move the mounted extrusion simultaneously. The resistance force should be even regardless of the location of the moving parts.
Des 4.0.5-PoC	Stepper Motors shall be in a fixed position and directly connected to the coupler shafts. Turning in both directions shall be allowed.
Des 4.0.6-PoC	The speed of movement caused by the stepper motor shall be faster than 3 cm/s and less than 10 cm/s in a linear direction.
Des 4.0.7-PoC	By controlling the PWM signal, the turning degree of the motors should be controlled with acceptable accuracy.

Since *ResistWaste* only handles one resistor one at a time and each time it requires the user to place an untangled resistor properly at the designated area, the sorting speed directly affects the user experience. This is why we are very careful with the movement speed of the motor and the X-Y table. However, the movement speed can also not be too fast due to the limitation of materials and the stepper motors, crazy speed will make the system more unstable.

The remainder of section 4 will have the detailed technical specifications of the parts we used to assemble the X-Y table. The circuit of how the motor is controlled by motor drivers and Arduino is shown in the 4.2 section.

4.1 X-Y Table Frame and Rail Component

4.1.1 Aluminum Extrusion

The Aluminum Extrusions act as the bone and spine of *ResistWaste*. We ElectroSavvs designed and build the X-Y table completely by ourselves. They function not only as of the frame of the X-Y table but also as the rails. The Aluminum material also ensures the sturdiness and light weight of the system.

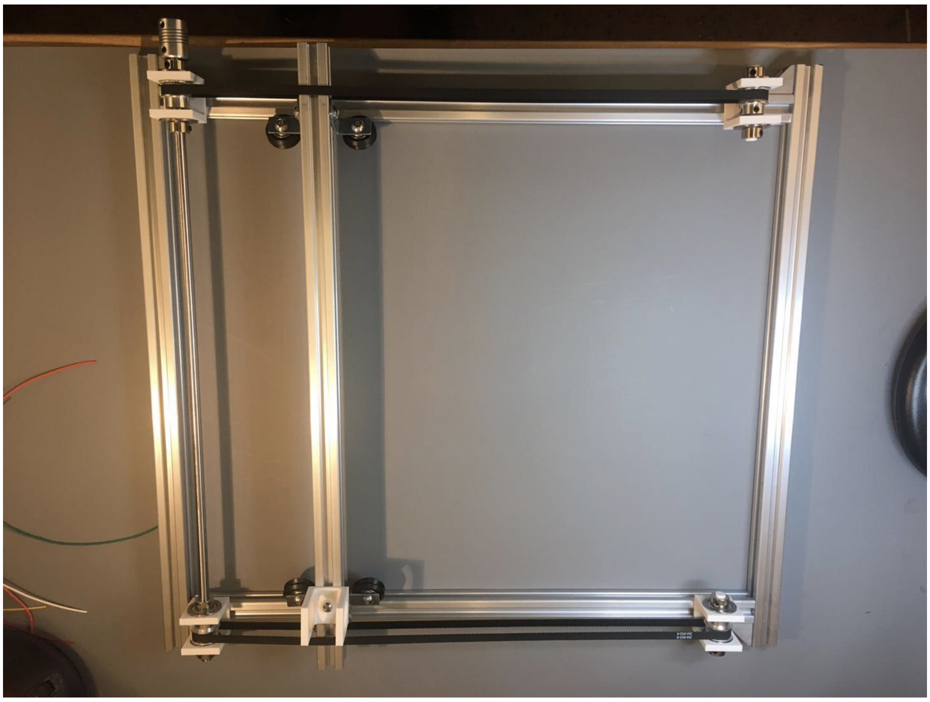


Figure 4.1a Top view of the X-Y Table

Figure 4.1b Aluminum Extrusion Specification [5]

4.1.2 Flange Ball Bearing

The ball bearings are used to hold the axials in place, therefore, they have to be consistently smooth and sturdy.

Figure 4.1.2 Ball Bearing Specification [6]

4.1.3 Pulley and Timing Belt

The stepper motors will induce the rotate of the pulleys and the pulleys will further cause the timing belt to move forward and backward.

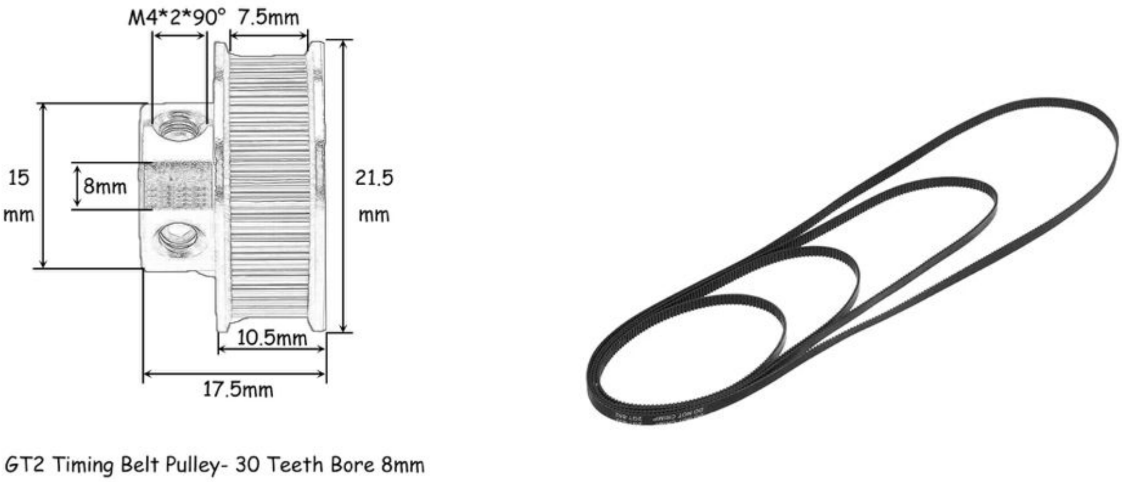


Figure 4.1.3 Pulley and Timing Belt [7]

4.2 X-Y Table Motion Control Part

4.2.1 Stepper Motor

The reason why we chose stepper motor over servo motors was because of the accuracy that stepper motors provide. Although *ResistWaste* does not require the accuracy level of a 3-D printer, we still need it to be accurate enough to move in a 5x5 coordinate. The downside of using stepper motors will be the speed and torque limit, but these factors do little impact to our project.

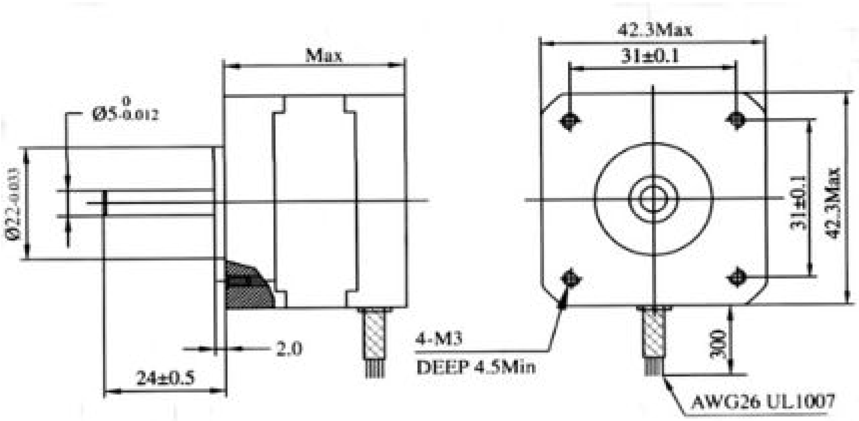


Figure 4.2 Stepper Motor Specification [8]

Item	Specifications
Step Angle	1.8°
Temperature Rise	80℃ max
Ambient Temperature	-20℃~+50℃
Insulation Resistance	100 MΩ Min. ,500VDC
Dielectric Strength	500VAC for 1minute
Shaft Radial Play	0.02Max. (450g-load)
Shaft Axial Play	0.08Max. (450g-load)
Max. radial force	28N (20mm from the flange)
Max. axial force	10N

Table 4.2.1a Technical Specification of Stepper Motor

Electrical Specification:

Model No.	Step Angle	Motor Length	Rate Voltage	Current /Phase	Resistance /Phase	Inductance /Phase	Holding Torque	# of Leads	Detent Torque	Rotor Inertia	Mass
	(°)	(L)mm	V	A	Ω	mH	g.cm	No.	g.cm	g.cm	Kg
JK42HS34-0404	1.8	34	12	0.4	30	37	2600	4	200	34	0.22

Table 4.2.1b Electrical Specification of Stepper Motor

4.2.2 Motor Driver

The image below shows the design of the motor controlling circuit using Arduino.

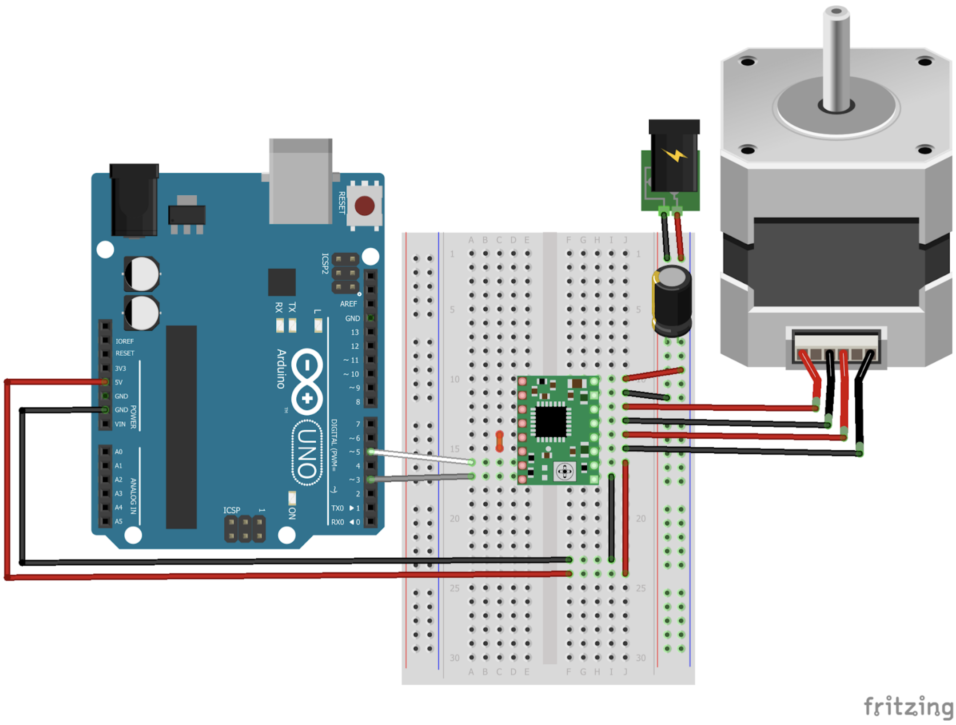


Figure 4.2.2a Breadboard View of Motor Control System

The specification of Arduino will not be given here as it is a very standard requirement and you can easily find information on their website. The stepper motors require a 12V input to operate and we use motor driver Allegro's A4988 breakout board to control the motors. The image below shows the schematics of the motor controller. Its technical specifications are also given in the table below.

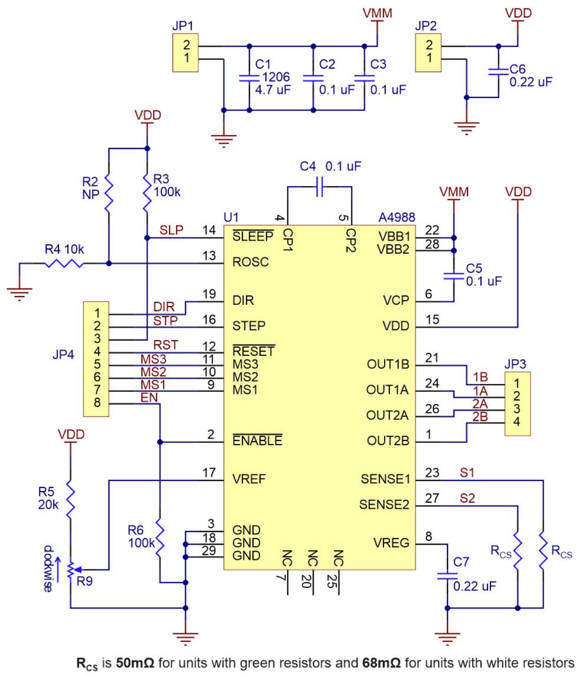


Figure 4.2.2b Schematic View of Motor Driver [9]

General specifications

Minimum operating voltage:	8 V
Maximum operating voltage:	35 V
Continuous current per phase:	1 A[2]
Maximum current per phase:	2 A[3]
Minimum logic voltage:	3 V
Maximum logic voltage:	5.5 V
Microstep resolutions:	full, 1/2, 1/4, 1/8, and 1/16

Table 4.2.2 Technical Specification of Motor Driver

5. Image Processing Design

Image processing design is one of the core steps in resistor recycle system. The expected functionalities of image processing design are detecting the recycle resistor, determining the value of the recycle resistor, and giving feedback to the system. It will be implemented by python and work on the raspberry pi with the raspberry pi camera module. The image processing is supposed to be the initial procedure of the system. When the User put the resistor in the detection zone, the system will take a picture of the resistor and analyze the image of the resistor. In the end, it will provide feedback which is the value of the recycle resistor for the further procedure.

5.1 Image Processing Equipment

The Specifications of the equipment of image processing are as follows

Device	Raspberry Pi 3 B+
Camera	Raspberry Pi Pinoir Camera Module
Additional device	Magnifying Lens

Table 5.1a Image processing equipment specification

Image processing is using the following programing language and library to complete the image analyzation.

Programming language	Python 3.7
library	OpenCV-python 4.1.0.25
library	Numpy 1.16.4

Table 5.1b Programming Environment Specification

The figure below is the block diagram of engineering prototype version of the system.

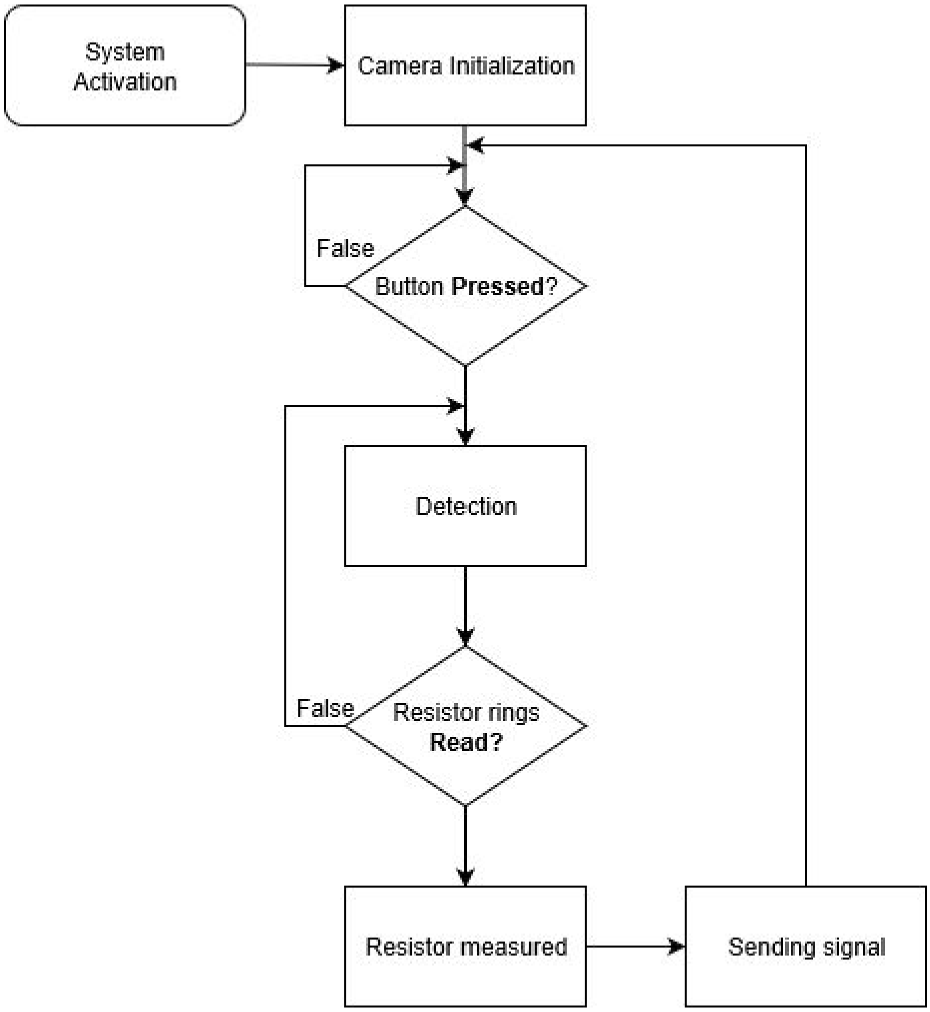


Figure 5.1 Overview of the Decision Making System

5.2 Image processing procedures

In the first procedure, the system will use the OpenCV library to capture an image of the resistor and resize the image to the apparated size. We set up the image size to 300 * 300 unit. And then the system will use bitwise operation which is highly useful while extracting any part of the image to analyze the color of the image. We will extract a circle which has a 1-unit radius from the image and starting position of the circle will be the Leftmost center. When the analysis is going, the position of the circle will move horizontally to left until reaching the rightmost center. We set up once movement will be 5-unit which should be less than the circle diameter. The following figure shows the movement of the circle.

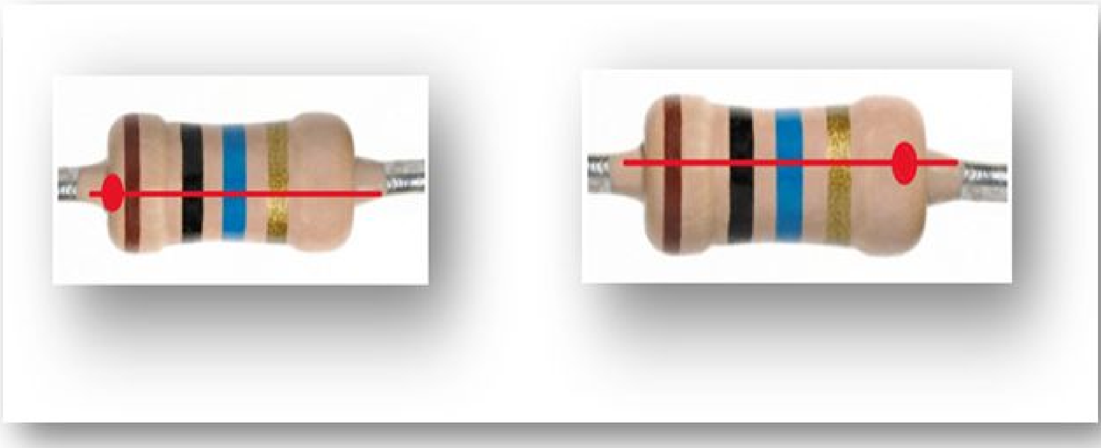


Figure 5.2a Movement of circle

The system will read the color of the circle in the first position. RGB color value is referred to in our system since RGB color values are supported in all browsers. For RGB color value is specified with RGB (red, green, blue), each parameter (0-255) means the intensity of the color in the image.[12] After we access the color of the circle, it returns 8 array of RGB values which means [11] In order to determine the color accurately, the system will calculate the average of 8 arrays. In the end, the system will analyze the data and determine which color range the output belongs to. The figure below is an example that when the position of the circle is on the blue band.

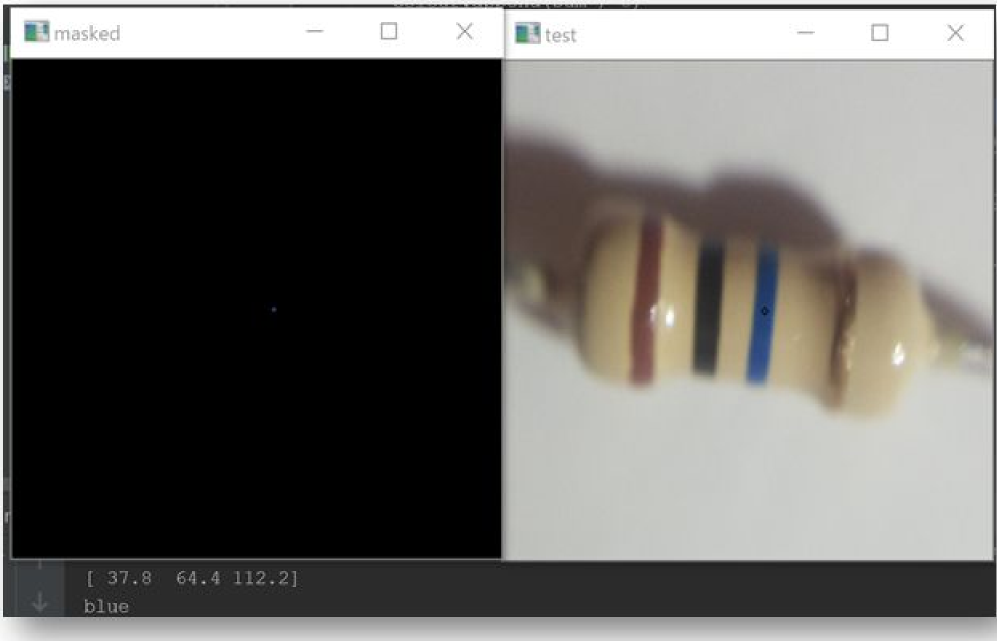
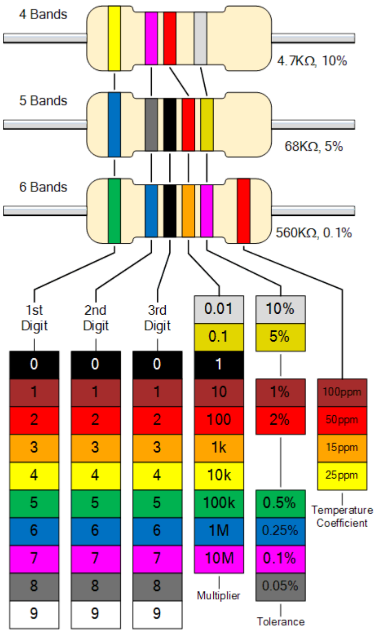


Figure 5.2b Example of blue color output

After data are collected from leftmost to rightmost. The system will successfully distinguish the color band of the resistor and calculate the value of the resistor based on the resistor value chart [3]. The progress of the output data is showing below. As it showed in the figure, the final analysis is giving us good feedback and recognized the right color of the resistor. At the end of ENSC 405, we are expecting that we can successfully and accurately execute the image processing on our target resistor and send the feedback to the X-Y table system.



First Analysis	Second Analysis	Third Analysis	Final Analysis
[141.4 141.4 133.4]	[141.4 141.4 133.4]	[141.4 141.4 133.4]	[141.4 141.4 133.4]
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[171.6 153.6 115.6]	[171.6 153.6 115.6]	[171.6 153.6 115.6]	[171.6 153.6 115.6]

Figure 5.2c Resistor Colorband Encoding [10]

5.3 Lighting

During the whole image processing, we find out the lighting is playing a vital role in the system. It will affect the quality of the image and hinder color recognition. In order to avoid the error that brings from lighting, the camera will be implemented in the airtight area and we will install the light to provide constant and natural lighting.

Table 5.0: Image Processing Design Specification	
Des 5.0.1-PoC	The Raspberry Pi Pinoir Camera Module should be able to capture clear resistor image with Magnifying Lens
Des 5.0.2- PoC	The system should be able to resize the image to 300 *300 pixels and resistor are in the middle of the image.
Des 5.0.3-PoC	The recycle resistor should be recognized by the system and system is able to output the corresponding value of the resistor.
Des 5.0.4-PoC	X-Y table is able to receive the execution signal from the image processing system
Des 5.0.5-PoC	The total image processing should be able to complete the whole process in less than 2 second

6. Wheatstone Bridge Design

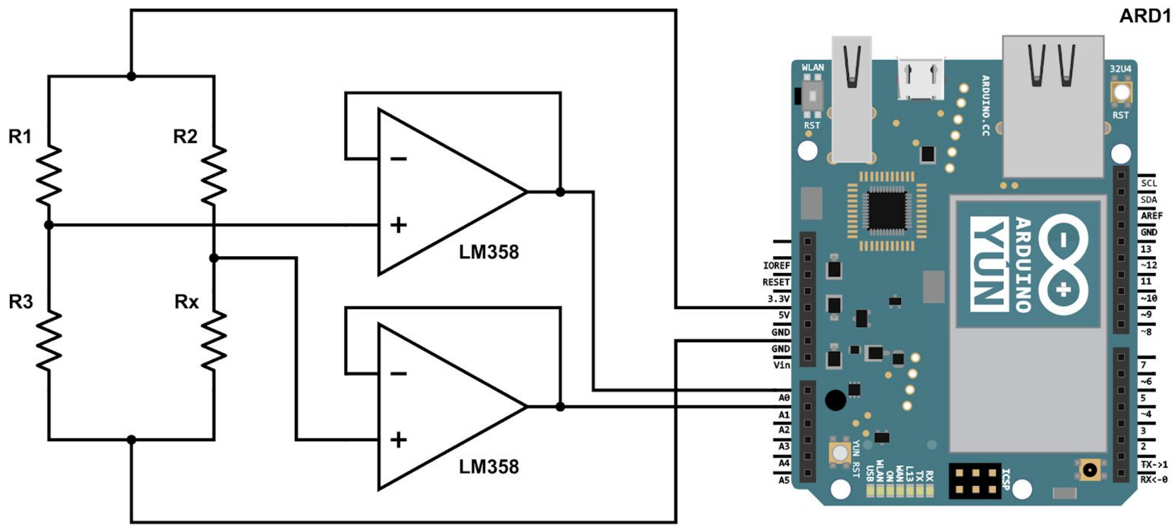

Figure 6 Wheatstone Bridge Circuit

The circuitry above shows the Wheatstone Bridge Design for the resistor measuring system of *ResistWaste*. This is a more accurate way than the standard voltage divider method to measure a resistor value. Depending on how far the image processing feature goes, we are also considering implementing this resistor measurement method. But this is all the information we can give for this design at this moment.

7. Conclusion

This design specification document will serve as a guideline for the development of proof-of-concept and engineering prototype. Due to the limitation of space, we did not list out all the details and our thought process during development. However, the most essential designs like the physical structure of the X-Y table, the implementation of the motor system, the approach to the image processing, and the Wheatstone Bridge design are clearly specified in this document. These are the crucial subsystems that will eventually be combined together and become the final product of *ResisteWaste.*

The following list sums up all the design specifications in this document:

Physical Architecture Design Specification: (Mostly for Engineering Prototype Stage)

- ➔ The outer structure should be able to support the weight of the X-Y table system + resistor measuring system.
- ➔ A soft tube should connect the Resistor Measure System and the X-Y Table and act as a slide of resistors.
- ➔ *ResistWaste* will be designed to sort resistors into a 5x5 different piles. A special divider grid container will be made for the system.

X-Y Table Design Specification:

- ➔ Smooth movement in both X and Y direction should be enabled
- ➔ The movement caused by the motor system should be in between 3 cm/s and 10 cm/s.
- ➔ Each movement of the X-Y table after the resistor value has been measured should be no longer than 4 seconds to get into the desired coordinate.

Image Processing Design Specification:

- ➔ The system should be able to take a clear image of the resistor and resize it into a 300x300 pixels image.
- ➔ Using the OpenCV library should be able to recognize the color band and divide the value of the resistor in 2 seconds.
- ➔ After the decision is made, a signal should be sent to the X-Y table system to start the movement.

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Appendix A: Supporting Test Plans

A.1. X-Y Table Test Plans

Test Case 01: Assembly and structure of X-Y Table			
Steps	Expected Output	Actual Output	Pass/Fail
Move and Shake the whole X-Y table	● The X-Y table should be moved as one item ● No part falls down during the shaking and moving.		☐Pass ☐Fail
Manually move the bar on X direction from the front to the end	● The bar can be moved smoothly through the whole distance ● The bar does not interrupt the other bar on Y direction ● The belt is always held tightly during the movement		☐Pass ☐Fail
Manually move the bar on Y direction from the front to the end	● The bar can be moved smoothly through the whole distance ● The bar does not interrupt the other bar on X direction ● The belt is always held tightly during the movement		☐Pass ☐Fail

Test Case 02: Movement of X-direction driven by a microcontroller			
Steps	Expected Output	Actual Output	Pass/Fail
1. Connect Arduino with Raspberry Pi and power on Raspberry Pi	● Raspberry Pi is successfully turned on ● Arduino is successfully turned on		☐Pass ☐Fail

2. Send a signal with a time period from Arduino to the motor controller	● Print a line saying 'Signal sent successfully'. ● The motor starts to operate		☐Pass ☐Fail
3. Wait until the motor stops and record the operation time	● The bar moving smoothly during the whole operation time ● The Y-Direction bar does not move ● The time recorded matches the time period sent with the signal		☐Pass ☐Fail
4. Repeat step 2-3 with 5 different time period	● Each recorded time should match their assigned time period		☐Pass ☐Fail

Test Case 03: Movement of Y-direction driven by a microcontroller			
Steps	Expected Output	Actual Output	Pass/Fail
Connect Arduino with Raspberry Pi and power on Raspberry Pi	● Raspberry Pi is successfully turned on ● Arduino is successfully turned on		☐Pass ☐Fail
Send a signal with a time period from Arduino to a motor controller	● Print a line saying 'Signal sent successfully'. ● The motor starts to operate		☐Pass ☐Fail
Wait until the motor stops and record the operation time	● The bar moving smoothly during the whole operation time ● The X-Direction bar does not move ● The time recorded matches the time period sent with the signal		☐Pass ☐Fail
4. Repeat step 2-3 with 5 different time period	● Each recorded time should match their assigned time period		☐Pass ☐Fail

A.2. Wheatstone Bridge Test Plans

Test Case 04: Voltage Measurement and Resistor Calculation			
Steps	Expected OutputVol	Actual Output	Pass/Fail
1. Connect Arduino with Raspberry Pi and turn on the power	● Raspberry Pi successfully turned on ● Arduino successfully turned on		☐Pass ☐Fail
2. Connect the required pins of Arduino to a breadboard and send the supply voltage (5V) to the circuit	● The connection is stable ● Print a line saying ‘Signal sent successfully’.		☐Pass ☐Fail
3. Measure the voltage of the required point (B and D in fig xx) and calculate the resistor value	● Print lines with measured voltage and calculated resistor value. ● Compared the calculated value with actual value. The error should be in ± 10%		☐Pass ☐Fail

A.3. Image Processing Test Plans

Test Case 05: Picture Taking			
Steps	Expected Output	Actual Output	Pass/Fail
1. Connect the camera with Raspberry Pi and mount the microlens to the camera	● Camera connected and lens mounted stably		☐Pass ☐Fail
2. Run the script to activate the camera through Raspberry Pi	● A smooth live video can be shown on the monitor ● The environment light has enough brightness to see the background		☐Pass ☐Fail
3. Put one resistor under the camera and run the script to take a picture of the resistor	● A highly focused picture is taken and stored at the assigned directory ● The picture has no vibration		☐Pass ☐Fail

Test Case 06: Resistor Color Detection and Value Calculation			
Steps	Expected Output	Actual Output	Pass/Fail
1. Import a clear picture of the real resistor and reshape the picture	● The original and reshaped image can be shown onto the monitor ● The reshaped image should be as clear as the original one		☐Pass ☐Fail
2. Run the color detection script on a reshaped image	● The program should print out what color is found and the position of each color		☐Pass ☐Fail
3. Calculate the value of the resistor based on the color detected	● The calculated value should match its actual value		☐Pass ☐Fail
3. Repeat 1-3 step with 10 pictures having a different resistor	● Each calculated value should match their actual value		☐Pass ☐Fail

Appendix B: User Interface Design

B.1 Introduction

The ResistWaste is a visually pleasing and easy-to-use resistor sorting system that replaces tedious measuring with automated experience. This appendix provides an in-depth analysis of how we would like ResistWaste to interact with its uses. It will first start with introducing the characteristics of the targeting users. Secondly, a detailed UI design of the proof-of-concept model and engineering prototype will also be provided. By strictly following the engineering standards that were discussed in the requirement document, how the analytical and empirical usability tests will be designed will also be discussed.

B.1.1 Purpose and Scope

The purpose of this appendix is to explain the needs of the users that ResistWaste wants to address and how the system's user interface is designed. For the proof-of-concept phase, since it is more focused on having the major "resistor measuring" and "X-Y coordinate positioning" feature working so UI will tend to be the bare minimum and just for developers. However, for the later engineering prototype in ENSC 440, the developers will shift the main focus to enhance the user experience. The seven elements of UI such as discoverability, feedback, conceptual models, affordance, signifiers, mappings and constraints [] will be discussed.

B.2 User Analysis

The targeting use of ResistWaste is narrowed down to academic usage in universities' electronics labs. To use Simon Fraser University as an example, engineering students who are enrolled in ENSC 220/225/325/425 will have mandatory lab assignments which involve using around 5~10 resistors per person/group. This section will analyze the characteristics of this type of users and explain how ResistWaste is designed to be accessible to lab students.

B.2.1 Who is going to use ResistWaste?

Starting from the introduction of Ohm's law, engineering students are exposed to basic circuit knowledge and start to build circuits using breadboards and through-hole packaged resistors/capacitors/inductors. This group of people are highly educated and are usually aware of the safety rules in the lab. Although occasional mistake could be made such as shorting a circuit or plugging into a wrong pin, we ElectroSavvs may assume that the users are technical enough to use ResistWaste properly.

For this specific group of people, research shows that they tend to show up in the lab a few times per two weeks (usually a lab assignment cycle), grab resistors from the tray (values are based on the lab requirements) and use them. After finishing with the lab, they either keep a dozen of the tangled resistors in their lab kits or dump all the resistors to the recycled bin/garbage bin. From personal experience, even for those who keep their resistors, chances are they have no idea what values they have got the next time they show up for the next lab assignment.

B2.2 What differences are ResistWaste going to make to the experience of lab students?

Currently, there are only two ways for a lab student to tell the value of a used resistor: First is to have the resistor color band encoding system memorized and to have the color paint distinguishable under proper lighting; Second is clamping the resistor to a DMM and write down the value before forgetting.

However, although both measuring processes will be quick, going through resistors one by one just to find the resistors you need for the new lab is frustrating and inefficient. This is especially difficult for impatient students at the lab prepping phase. So most students rather directly "shop" from the resistor tray which has resistors clearly labeled for them. With ResistWaste, as long as students are willing to sacrifice a few minutes to put their used resistors into our sorting machine, the used resistors will be sorted into labeled grids and ready to go the next time they come.

B2.3 Is there any existing similar product?

The answer is surprisingly no. The closest thing we found was some self-made open source project that utilizes phone cameras to read resistor values in real time. However, as we tested and their documentation stated, the application is incomplete and extremely reliant on lighting and camera focus conditions. Also, it still requires the users to test resistors one by one instead of just grabbing the value they want from a labeled bin.

In conclusion, ResistWaste will only simplify the experience that the students have and there is no special extra knowledge or physical restraints to it.

B.3 Technical Analysis

B3.1 Discoverability

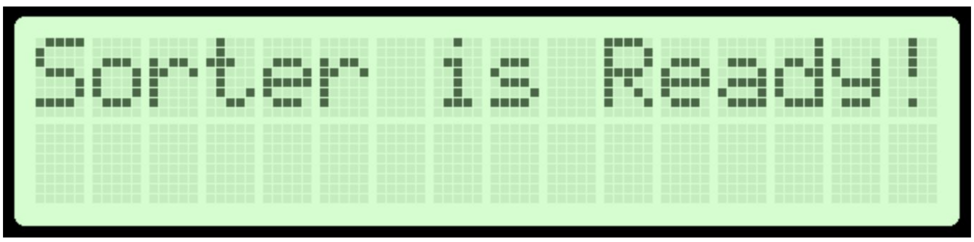
Discoverability or some call it learnability[1] is a measurement of how easy it is for users to find the functionalities and use them. In other words, users should be able to discover the main feature of ResistWaste without needing too much guidance or training. Since the nature of ResistWaste is an automated device, having a UI that allows the user to quickly understand the automating process is crucial for discoverability.

The table below shows the major feature of ResistWaste and our strategy of UI design to make it easy to learn for students:

Feature	UI Design Strategy
User needs to single out the resistor and make it ready for detection.	Requires training or instruction sign beside the ResistWaste "Please place untangled resistor onto the detection area".
Valid scan area for placement	Distinguishable Colored area on the platform telling the user to place a resistor inside the area
The nature of the system is a detection system + X-Y coordinate table	The user can see the whole structure clearly as it is not fully enclosed, it will be relatively easy to figure out what it does

B3.2 Feedback

Although ResistWaste is an almost fully automated system, having an intuitive feedback system is still not only good for users but also for testing and debugging purposes.
In the early stages of development (which we are currently still in), developers are going to use Microcontrollers and RaspberryPi's own "print" function to report back the state of the system and test the functionality.
For the prototype stage, we will be installing Green colored LED light to indicate the system is turned on and ready to operate. And we will use Yellow color to tell the user that the device is processing a resistor to prevent users refrain from feeding more resistor.
Depending on the progress, for further optimization, we are going to use an LCD screen to display a more detailed status. An example is listed below.



B3.3 Conceptual models

The process of using ResistWaste is actually very similar to using a printer. The UI design tries to mimic the same feeling when a user uses a printer to photocopy stuff: The person first need to place the object on a designated area with proper position; Knowing that the device is ready, the user will press a button for the system to start working. Once the job is done, the indicator light will light up or there will be information display screen instructing the user to go to the next step.

B3.4 Affordances

The appearance of ResistWaste will look like a 3D printer. We believe that the user will understand that it is a delicate device just like those expensive printers and avoid practicing harmful behavior to the machine such as resisting the movement of motors/belts, place the system upside down when running, etc.

B3.5 Signifiers and Mappings

For the proof of concept stage we do not plan to enclose the RaspberryPi, Arduino and other motor components, therefore, the UI will be mostly done in 440. The image below is the conceptual button and signifier layout.

B3.6 Constraints

Constraints may sound like a downside of a system, however, it is actually beneficial to restrict the possible choice action that the users can do when using ResistWaste. The control panel for users will have only one pressable button and they are only asked to place resistors properly onto the detection platform.

Having this kind of simple design simplifies the whole process, reduce the chance of having first-time users confused or perform misuse of the device.

B.4 Engineering Standards

UI design directly involves the interaction between the system and the users, therefore engineering standards including accessibility, safety standards for installation and symbol information.

Requirement Code	**Requirement Description**
ISO/IEC 24786:2009	Information technology -- User interfaces -- Accessible user interface for accessibility settings. [2]
CAN/CSA-ISO/IEC 11581-3:02 (R2011)	Information Technology - User System Interfaces and Symbols - Icon Symbols and Functions - Part 3: Pointer Icons [5]
CAN/CSA-C22.1-18	Canadian Electrical Code, Part I (24th edition), Safety Standard for Electrical Installations [3]
IEC TS 60034-20-1:2002	Rotating electrical machines - Part 20-1: Control motors - Stepping motors [4]

B.5 Analytical Usability Testing

Analytical Testing is a type of test that does not involve target users. The benefit of it is being easier and faster. However, since analytical testings are usually performed by the developers themselves, it is very likely that they are biassed. To reduce this effect, all team members are going to perform the evaluation of the system usability separately and without sharing opinions.

Note that the development of our automated resistor sorter "ResistWaste" will be heavily focused on the core technical development in the early stage, therefore most of the optimized UI testings will not likely to be applied until mid 440 stage. But we will reserve enough time for UI testings before the final product for room of adjustment and improvement.

We will mainly use qualitative testing to evaluate the usability of ResistWaste. On a scale of 1 to 5, from unusable to effectively functioning. The list below is a tentative checklist of the analytical usability tests, this could change over time as we are getting closer and closer to the final product.

Index	Description
1.	How comfortable the station height, button texture, and the entire system feels in use.
2.	Debounce of the buttons (how consistent the system is no matter how the buttons are pressed)
3.	The brightness of indicator light (how visible it is under lighting condition in the lab)
4.	Mapping (how intuitive and convenient the UI layout is)
5.	Device status and instruction displayed correctly on the LCD screen
6.	Is the control panel clearly labeled?

B.6 Empirical Usability Testing

The ultimate purpose of ResistWaste project is to keep our users happy, therefore user feedback and testing will be crucial for us to know what the users really like and not like. Upon finishing the prototype and the final product we will find engineering students to test it out. We will also reach out to Fred, the lab manager of SFU ENSC lab to provide feedback.

For proof of concept stage, by the end of 405W, we intend to finish the two core function of the system: resistor measuring and X-Y table motor controlled movement. Although we might not have time to put all the functions together and form a complete system, you can still have the users to test on the core function of ResistWaste and ask for feedback.

For the prototype stage and the final product, the device will be operating as a whole and the user control panel consists of the "Start" button and the status LCD screen will be implemented. Starting from here we can invite people to user meetings. The table below shows the testing sequence that we would like to perform with user testers.

Empirical Index	Testing Session Step by step
1.	Provide an info sheet to the users, introducing the basic idea of the project and provide necessary basic instruction.
2.	Without exactly telling them how to operate the system, observe if they can figure out how ResistWaste. (discoverability test)
3.	On the survey after user using the system, asking their opinion and suggestions on the feedback of ResisWaste.
4.	Observed during the testing, how comfortable are the users with ResistWaste. Does any physical property of the device confuse the user? (Affordance test)
5.	On the survey, ask the user to rate the experience on the signifiers, button mappings.
6.	Allow the user to explore and play with the device as they like. The purpose of this is to see if we have enough constraints on the device to prevent the user from using the device incorrectly.
7.	If any error occurs during the usage, we need to test how easy it is for users to recover the error. (Error recovery implementation, for example, resetting the device.)

B.7 Conclusion

This concludes the Appendix B which introduces the user interface design of *ResistWaste*. To provide the best user experience to the consumer, we know that the user interface will be the most important thing. For the proof-of-concept stage, we do not plan to implement the control panel which includes the indicator LED lights, LCD status screen and any buttons mentioned above since our focus right now is on developing the functional subsystems. But for the engineering prototype phase, we will use this appendix as our foundation and guideline to implement the UI. Further details and improvement on the UI design will be updated in later documents in ENSC 440.

Reference of Appendix B

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