Automatic Beverage bottle sorting bin

ECE 445 Final Report - Fall 2023

Project #5

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1. Introduction

1.1 Purpose

Garbage bins for bottles are typically placed near vending machines. These bins often feature separate holes: one for metal cans and one for plastic bottles. However, due to the unclear of the instructions, many individuals do not adhere to these sorting instructions, resulting in misplaced items. This results in a waste of the labor force for garbage sorting.

Figure 1: Example of a trash can with labels

To address the waste, we propose an advanced garbage bin equipped with an automatic sorting system. In general, the sorting system should be fully autonomous with no need for extra human instruction. In our design, this bin will have a singular entrance where users deposit bottles. The system will then automatically determine whether the object inserted is a bottle, and whether the bottle is made of plastic or metal by metal and optical sensor. The input object will then be classified into metal, plastic bottles, or others and sorted into three separate bins.

1.2 Functionality

In general, to achieve a tolerable scale of our high level function requirements and justification are following:

1.The system start sorting process after an object is inserted and finished analysis less than 40 seconds.

This functionality is to reduce the time for users to wait to insert a second object. This ensures its capability to function in places with a busy human traffic.

2.Our scaled down model should sort objects that are less than 1 inch in diameter and 3 inch in length into a different bin.

This functionality makes sure that our system can process the object with the correct size. We expect the same level of performance if we scale up the system.

3.It should correctly sort plastic bottles, metal cans, and others into three different bins.

This functionality requires all subsystems to work correctly in order to sort the object into the correct bin.

1.3 Subsystem Intro & inter connection

To achieve full functionality of our autonomous machine, we combine four large subsystems: power subsystem, motor subsystem, control subsystem and sensing subsystem. The specified block diagram layout that integrate all components are following:

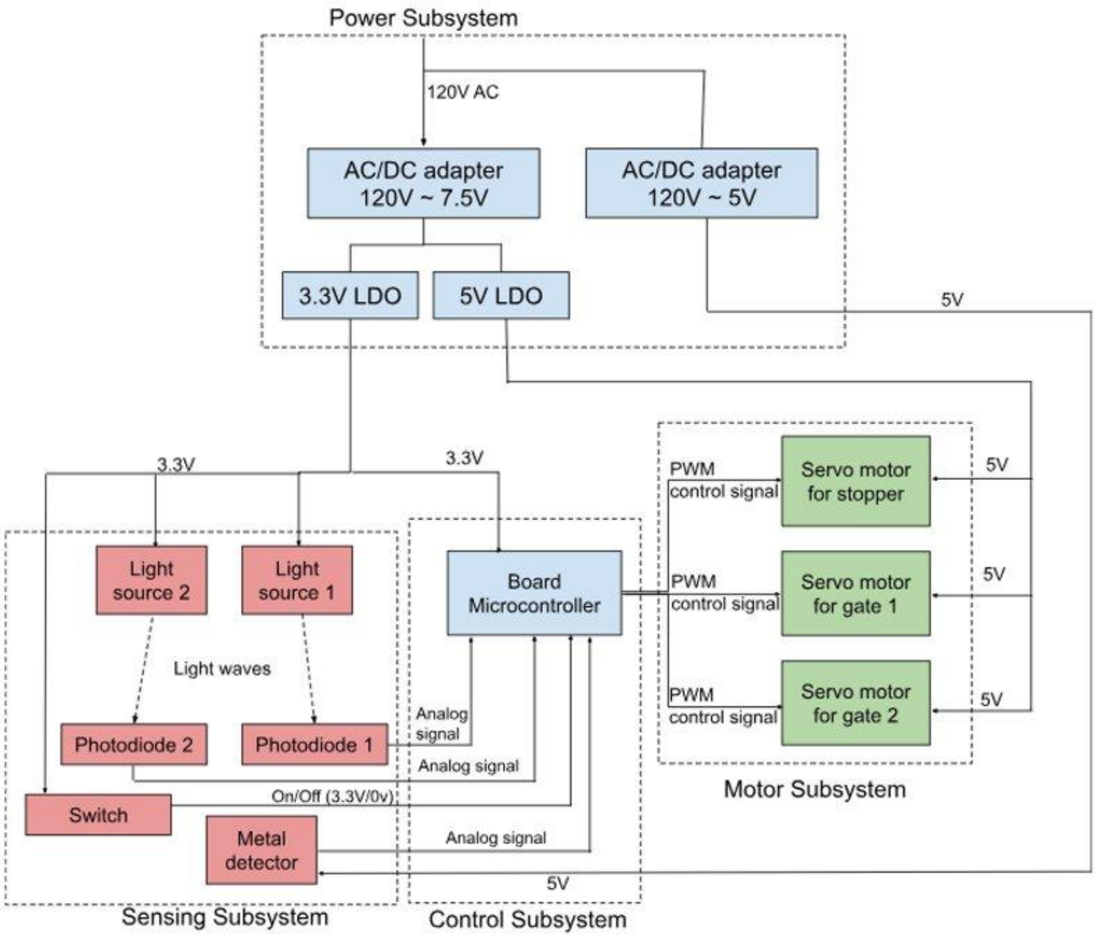


Figure 2: block diagram

The power system is purposed to support the energy requirements and connect to all other subsystems. The major power channel will drive the motor subsystem with 5V and provide power supply for sensing subsystem and control subsystem with 3.3V. The supplemental power channel provides 5V power to the metal detector to avoid signal interference.

The sensing subsystem analyzes the input objects. It is made by a switch, two photo sensors, and a metal detector. These sensors will provide feedback that is necessary to classify the input object, and information will be sent to the control subsystem. Specifically, the connection is one directional, it will not get feedback to the control subsystem.

The control subsystem performs the function of analysis, decision making, and control. Therefore, it takes the sensor subsystem as input, and generates pause wave signals to control the motor subsystem. It uses the switch of the door to provide notification of object input. Afterward, it uses two photo sensors to detect the scale and shape of the input object. Finally, a metal detector is applied to analyze the material of input objects. After deciding the material, it will configure the related motor configuration, and the angle information is sent to the motor subsystem.

The motor subsystem is focused to achieve the final functionality, so it takes the sequential pause wave control from the control subsystem and drives the motor using power supply from the power subsystem. Finally, each motor will rotate to the required angle and position for us to achieve the goal of garbage sorting.

2. Design & Verification

2.1 Physical design

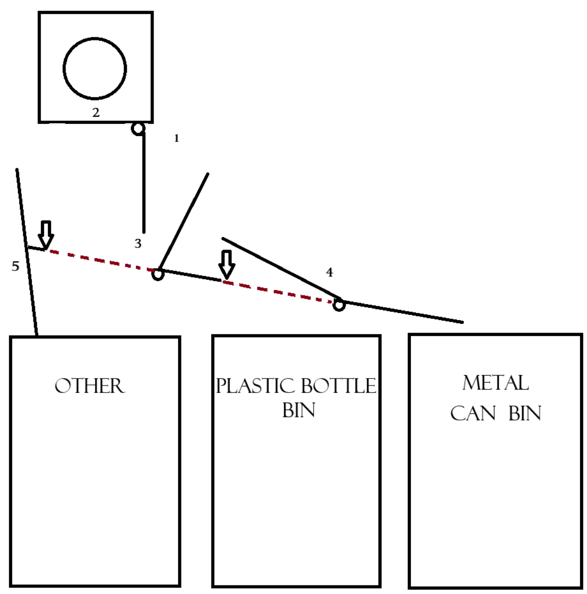


Figure 3: physical design

1. Servo motor for hold and release bottle in sorting chamber.
2. Sorting chamber with light detecting system and metal sensing system inside.
3. Servo motor which controls opening the bin when the object is others
4. Servo motor which controls opening the bin when the object is plastic.
5. Wall to make sure bottles go into the bins.

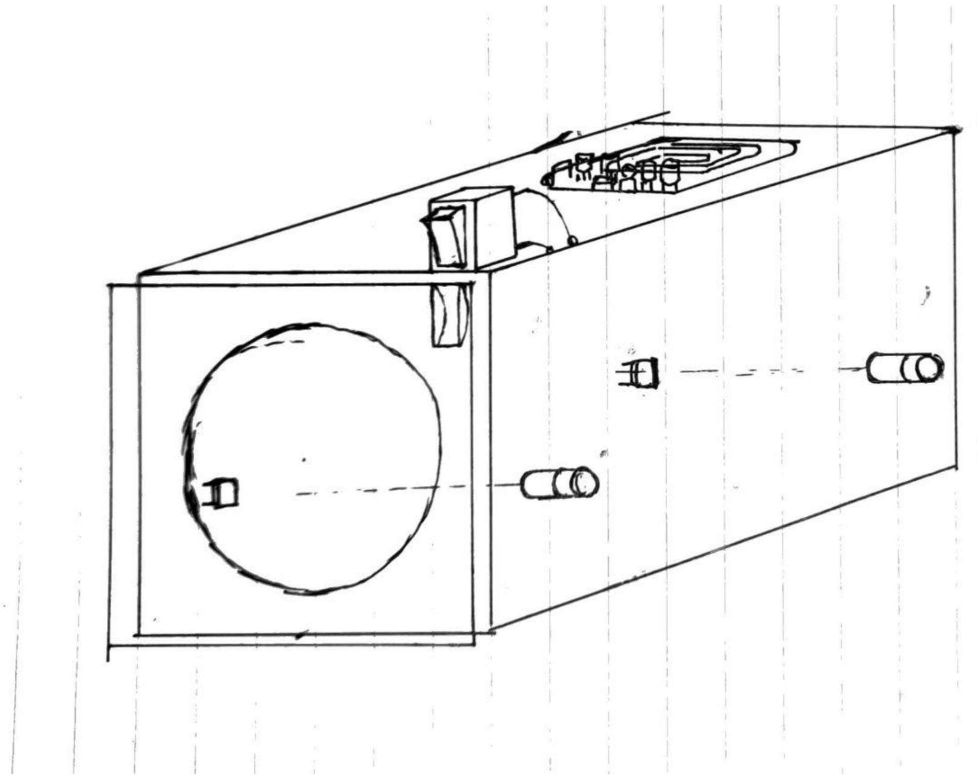


Figure 4: Chamber design

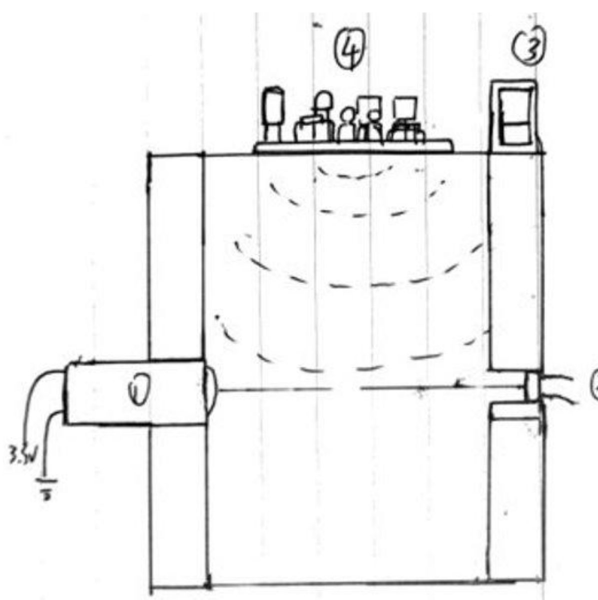


Figure 5: Front view

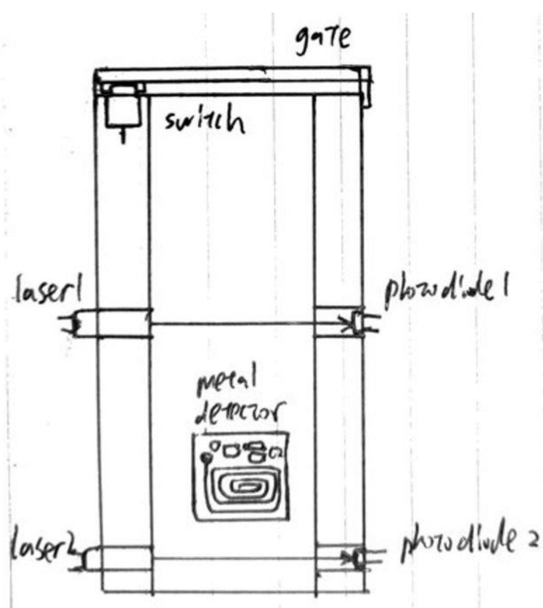


Figure 6: Top view

1 : laser diode   2 : photodiode 3 : switch 4 : metal detector

2.2 Power Subsystem

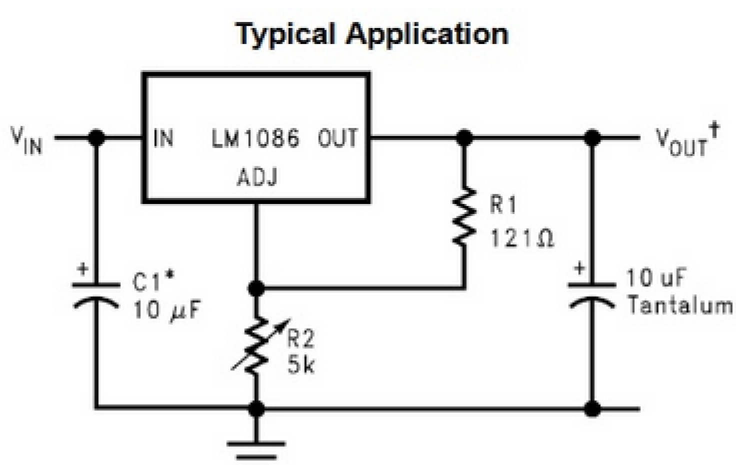
2.2.1 Description

Power subsystem includes two AC DC converters and two LDO. AC DC converter converts 120V AC from the wall plug to 5V and 7.5V DC voltage in order to power the regulator. The regulator then provides 3.3 VDC to control the system and sensing system. The 5 VDC LDO powers the three servo motors. The 5V AC to DC converter provides power to the metal detector.

2.2.2 Design procedure

The design originally planned to use only one AC to DC converter. The metal detector and the servo motor use the same 5V LDO as power supply. However, after we built the whole circuit proto type on the breadboard and tested the circuit functionality, we observed the voltage output of the metal detector would increase when the servo motor was operating. We measured the 5V output of the LDO and found it will have small oscillation when motors operate. We realized that the oscillation of 5V VDD output of LDO will cause oscillation for our metal detector. So we decided to separate the power supply of the metal detector and motor and use a 5V AC-DC to directly power the metal detector.

LDO circuit and calculation



[2]Figure 7 : LDO Circuit

$Vout = 1.25\times(1 + (R1\div R2)$

For 5 V LDO, R1 = 121Ω, R2 =360Ω

For 3 V LDO, R1 = 121Ω, R2 = 200Ω

2.2.3 Requirement & Verification

Requirements
A 3.3/5 V DC regulator should provide 3.3/5 VDC +/- 0.1 V with at most 0.5A of current.

We connected the LDO circuit's VDD to the AC-DC converter LDO outputs connect test load resistors. We use the load resistor to adjust the load current to 0.5A for both LDO and measure the output voltage using voltmeter.

Table 1: LDO testing results

LDO type	Load Current	Output voltage
5V	0.5A	4.901
3.3V	0.5A	3.323

2.3PhotoDiode

2.3.1 Description

A Photo diode is composed of a reversed biased photodiode circuit and a laser. The beam of the laser is aligned with the photodiode. The voltage output decreases when the laser is blocked by an inserted object.

2.3.2 Design procedure

Our first design uses VIP1188SH photodiodes and LM 358 op amp. VIP1188SH photo diodes have a voltage output range from 0.2 to 0.15 when the laser beam is on and off. We decided to buffer and amplify the signal to make the sensor more sensitive. We decided to use LM 358 since it has a very low Vcc requirement at 3V. We provided 5V Vcc and a feedback loop consisted of three 330 ohms. The feedback loop has a feedback factor of 1/3 so the output is approximately 2 times the input.

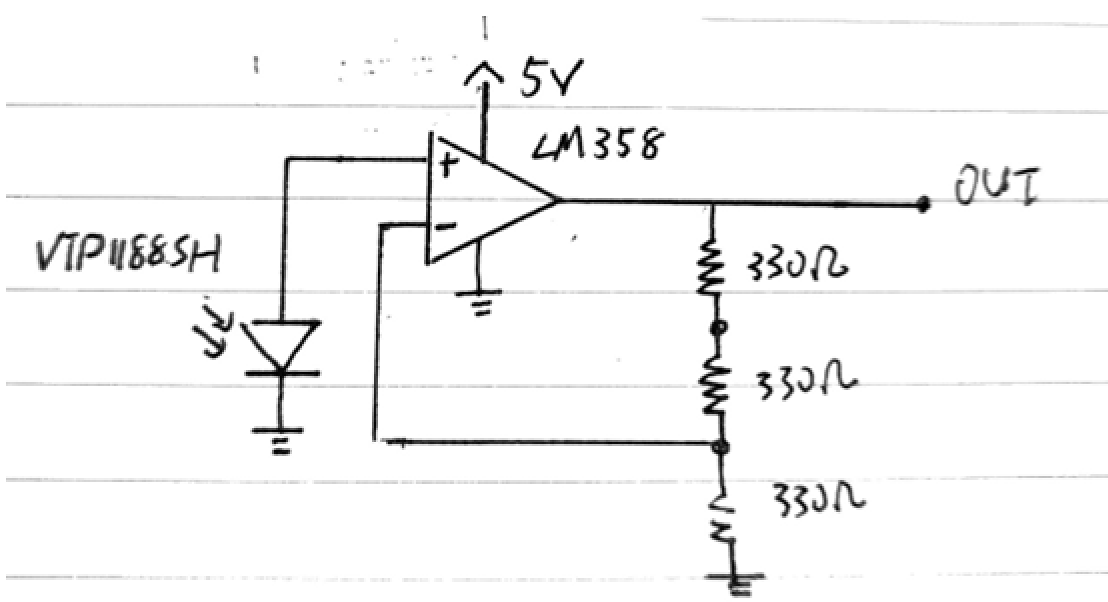


Figure 8: Photodiode amp circuit

In order to determine the maximum feedback factor, we used four 330-ohm resistors and put a sign wave with 0.4 V peak to peak from the signal generator into the op amp V+ port. We tried feedback factors from 1/4 to 1/2. With a smaller feedback factor, the transistor in the op amp will be out of saturation thus the output will simply equals to Vcc. As a result, the peak of the output sine wave is cut off. We found the smallest feedback factor which the output can give a complete sine wave is 1/3. So we choose this feedback factor for our circuit.

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$$feedback\ factor\ \beta = \frac{v^-}{vout}$$

$$vout = \frac{A}{1+\beta A}$$

$$vout \sim \frac{1}{\beta}$$

V- is the v- input to the opamp and A is the open loop gain of the opamp which should be a huge number

2.3.3 Requirement & verification

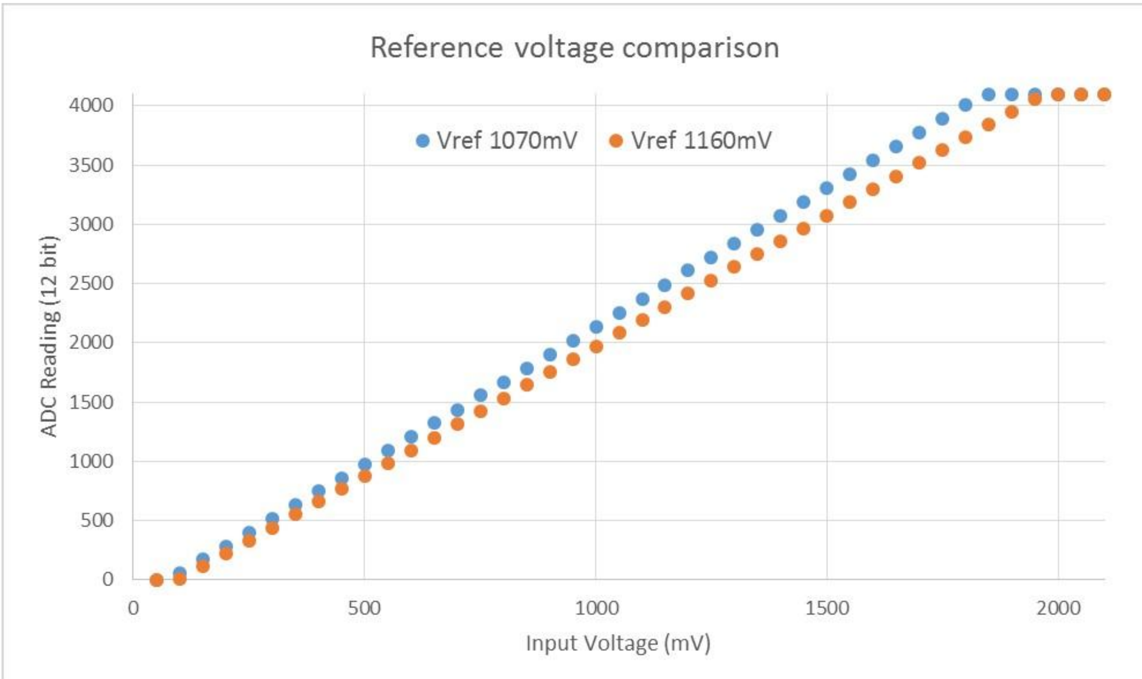
Requirements
The lowest resolution for the ADC of our microcontroller is 0.56mV. Light sensing system should have a change in its DC output voltage much bigger than 0.56mV when laser beam is blocked by transparent plastic bottles.

Table 2: photodiode testing results

Laser is on	Output voltage
YES	0.381V
NO	0.319V

Since this design is not sensitive enough, I decided to operate the photodiode in the reverse bias region and use a large resistor to measure the increase in reverse current.

Our new design is the actual design implemented in the system. The idea is to use a reversed biased photodiode in series with a 5000k ohm resistor. The leakage current will change based on incident light intensity. The output voltage will be the voltage drop across the 5000k ohm resistor. We parallel the resistor with two diodes and a resistor and take the voltage output across the second resistor as our voltage output. Since the esp32 analog to digital converter can not differentiate voltages beyond 2V, we add two diodes to add a negative DC offset to the output.



[1] Figure 9: reference voltage comparison

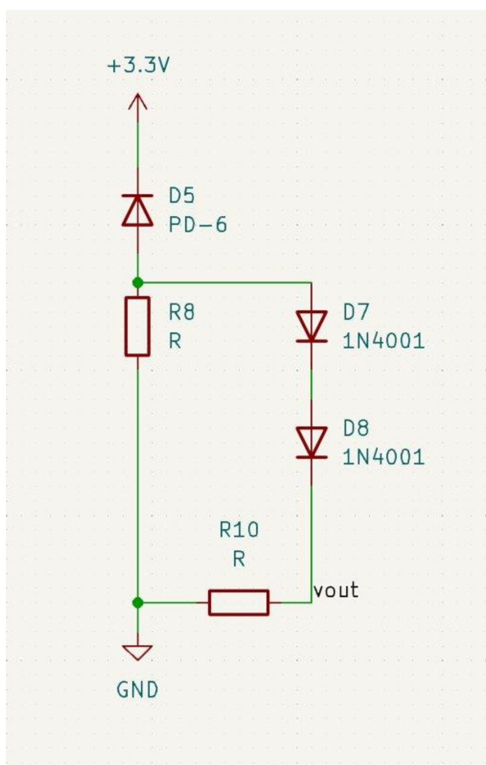


Figure 10: Photodiode biasing circuit

We built this circuit on the breadboard together with a laser diode. The photodiode and laser diode was installed in the courting chamber. The power is provided by an adjustable voltage supply. We test the voltage output under several conditions, including no blocking, metal bottle model, transparent plastic bag. It is proved the sensor is very sensitive which produces a 0.6V voltage drop when the laser is blocked by a transparent plastic bag. Notice that the output for two circuits is different. This error is caused by alignment issue errors of photodiodes.

Table 3: Photodiode testing results

Test condition	**Vout1**	**Vout2**
Directly hit by laser	1.4V	1.9V
Block by single layer of transparent plastic	0.8V	1.1V
Laser off	47mV	205mV

2.4 Metal detector

2.4.1 Description

The metal detector is on an individual PCB with all the circuit and two printed coils. The output of the detector is a DC value. When metal is inserted in, the output voltage will increase.

2.4.2 Design procedure

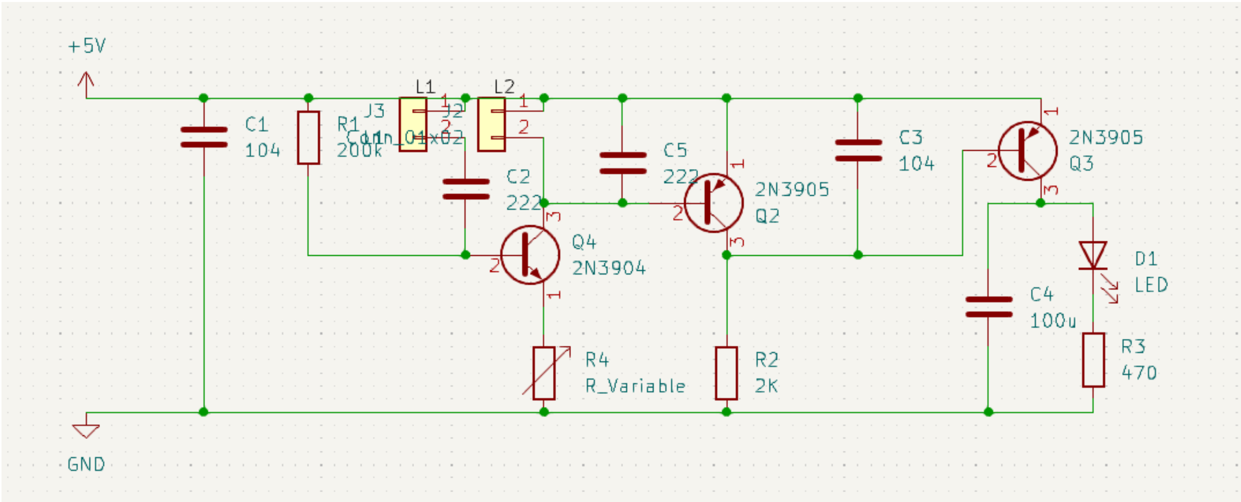


Figure 11: Metal detector circuit

We purchased the model online but made some modifications. The original output is a buzzer which produces different sounds when it detects a metal. We remove the buzzer. The circuit outputs an AC signal at the base of Q3 BJT which has an increase in both frequency and DC offset. Since the DC offset changed from 2V to 4V, we decided to ignore the change in frequency and measure the change in DC offset. We added a 300uF capacitor in order to filter the AC signal and got a very clean dc value. In addition, the voltage changes from 2V to 4V while the biggest voltage range ESP32's ADC can measure is 0V to 2V. It cannot tell the difference between 2V and 4V. We need to eliminate the 2V dc offset in order to enable ESP32 to read the output. So, we add a red LED which has a turn on voltage above 2V in series with a resistor. The LED can consume 2V, thus subtract the 2V offset. We measure the voltage across R3, which changes from 0.2V to 2V when a metal is nearby.

2.4.3 Requirement & verification

Requirements
The lowest resolution for the ADC of our microcontroller is 0.56mV. Metal detector should have a change in its output voltage much bigger than 0.56mV when metal is inside the chamber.

We install the metal detector and use the 5V AC to DC to provide power to the detector. We use an oscillation scope to detect the output voltage. We measure output under conditions when the metal bottle is inside the chamber and empty chamber.

Table 4: Metal detector testing results

Metal is nearby	Output voltage
YES	2.145V
NO	0.23V

2.5 Switch

2.5.1 Description

The switch connected 3.3 V to a 4700 ohm resistor. The voltage is high when the gate is open.

2.5.2 Design process

A way to know if something is inserted in is needed to start the sorting process. We designed a door in front of the chamber. The circuit should let the microcontroller know when the door is closed and open. The following graph is our circuit for the switch.

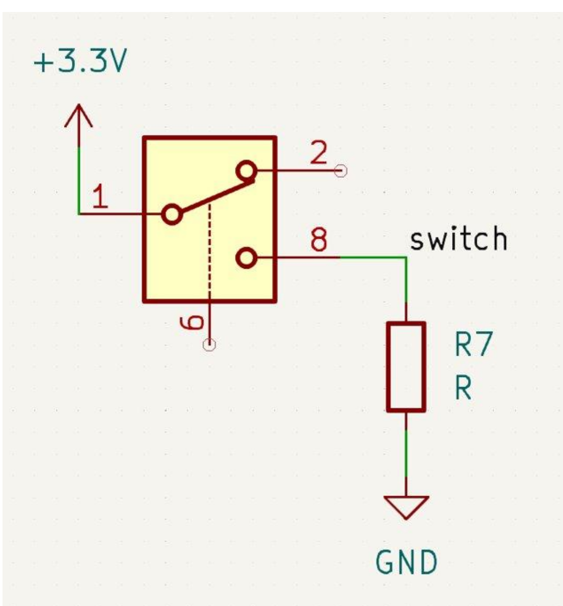


Figure 12: Switch circuit

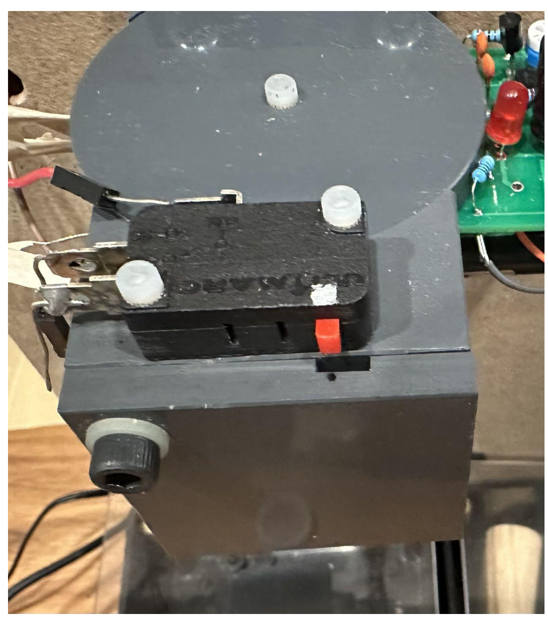


Figure 13: physical switch

2.5.3 Requirement & Verification

Requirements
The lowest resolution for the ADC of our microcontroller is 0.56mV. Switch should have a change in its output voltage when the gate opens much bigger than 0.56mV.

We use a voltmeter to monitor the circuit output and see output changes when opening and closing the door.

2.6 Motor Subsystem

2.6.1 Description

The motor subsystem consists of three motors: Insertion gate motor and two ramp motors. The gate motor controls the opening and closing of the chamber gates. The ramp motors direct the object into different bins by changing the angle of the ramp. The servo motors are driven by a pause wave with a frequency of 50 Hz, and the angle has linear dependency on pulse width. We use the <Deneyap_Servo.h> library to send various degree signals to achieve sequential control.

2.6.2 Design Process

Initially, we drive the motor with default library frequency. However, we find out that the incorrect frequency would cause the servo motor to keep rotating. We find out that , for stable performance, we need to drive the servo motor with 50 Hz pause wave frequency.

2.6.3 Requirement & verification

To fine tune the motor system to satisfy the specified angle requirement, we have adjusted each gate angle as shown below.

Table 5: Motor angles

Motor series	**Open angle**	**Close angle**
Insertion gate motor	**40 degree**	**123 degree**
Ramp 1 motor	**120 degree**	**27 degree**
Ramp 2 motor	**120 degree**	**52 degree**

The angle shown here is not the angle of the ramp, but rather, it is an angle measurement inside the motor. We install the ramps with certain angles with the shaft of the motor. The motor can change from 0 to 165 degrees. We try to only use angles from 30 to 130 degrees so that we can leave some buffer zone if we need to fine tune the angle of the motor in our program. For tolerance, any error within ± 1 degree is acceptable.

Verification

We hard code the angle signal to esp32 ADC output and connect it to the motor to check if the angle is correct.

2.7 Control Subsystem

2.7.1 Description:

The control subsystem is made of ESP32-S3 chips and mini-usb to UART protocol for program loading. It mainly integrates all the sensors for input object analysis and controls the servo motor with a pause wave. In general, our system can perform the correct instruction based on various input objects, and control the motor system to sort input objects into the correct garbage kinds.

2.7.2 Design Process

For the control system, we use photo detectors first to determine the material of input objects. The input object will then be classified to bottle and none bottle type. We further use the metal detector on all the bottle type objects, then we can classify it to plastic bottles and metal bottles. The following is the analysis tree to handle various of input objects:

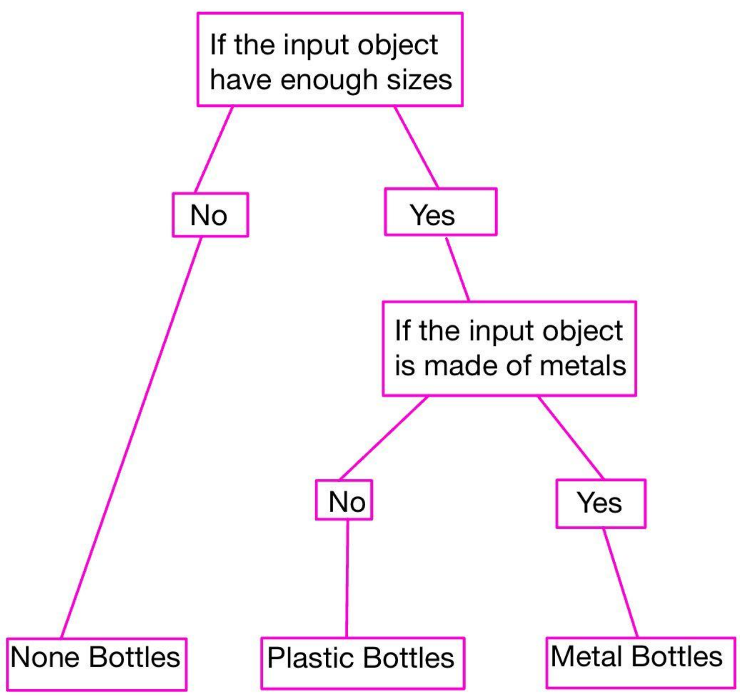


Figure 14: control logic tree

Finally, based on the variety of classification, we design the specified sequential control logic for motors to sort the input objects into different categories. This whole process configures our general control logic.

2.7.3 Requirement & Verification:

According to our design, We expect the motors can rotate in sequential order. To test the functionality, users can insert different classes of objects into the system. In response to different bottles, the gate should open and close in following fashion:

Table 6: State of control

Classification	Insertion Gate Motor	Ramp1 Motor	Ramp 2 Motor
None Bottles	Open	Open	Close
Plastic Bottles	Open	Close	Open
Metal Bottles	Open	Close	Close
Default/None-trigger	Close	Close	Close

From default state to different classification state, the ramp motor has higher priority to move so that the bottle will fall into correlated bins before the gate is open. From different bottle sorting state back to default state, the insertion gate motor has higher priority to move to avoid collision between gate and ramps. The whole process should end in 7.1 seconds, and the tolerance is in 10 seconds.

verfrication

We put different objects into the chamber and check whether the bottle is dropped to the right bin.

3. Cost & Schedule

Table 7: Cost

Component name	Manufacturer	Quantity	Price ($/each)
LDO, Lm1085it-3.3	texas instrument	1	$1.80

LDO, LM1085IT-5.0	texas instrument	1	$2.74
metal detector	unknown	1	$7.99
Photo diode, PD-6	unknown	2	$0.43
Servo motor, HS-318	Hi-Tec	3	$13.54
laser diode	Quarton Inc.	2	$13.37
AC to DC converter	Belker	2	$14.90
esp32-s3-wroom-1-n16r2		1	$3.62
			Total: $114.17

Table 8: Schedule

Week	Team goals	Jingjie	Jiajun	Tianyu
9/25	Design Document	Design Document/ Start PCB layout	Design Document/ Finalize sensors	Design Document/ Finalize motors and power hardwares
10/2	Design Review/ PCB Review	PCB Layout	Build & test sensors	PCB layout/ Build & test sensors
10/9	1st PCB Orders/ Teamwork Evaluation 1/ Machine shop	Teamwork Evaluation/ PCB Layout/ Microcontroller Code	Teamwork Evaluation/ Finalize with machine shop	Teamwork Evaluation/ Finalize with machine shop
10/16	2nd PCB Orders	Assemble & edit PCB/ Microcontroller Code	Assemble & edit PCB/ Microcontroller Code	Assemble & edit PCB/ Microcontroller Code
10/23	3rd PCB Orders/ Individual progress reports	Individual progress reports	Individual progress reports	Individual progress reports
10/30	Software & hardware debug	Software debug	Hardware debug	Hardware debug
11/6	Wrap up	Demo Preparation	Demo Preparation	Demo Preparation
11/13	Mock demo	Test all functionalities	Test all functionalities	Test all functionalities
11/20	Fall Break			
11/27	Final Demo	Prepare for Final presentation	Prepare for Final presentation	Prepare for Final presentation
12/4	Final Presentation/ Final Papers	Final Paper	Final Paper	Final Paper

4. Conclusion

4.1 Accomplishment, uncertainty, and further improvement

In conclusion, our sorting chamber can correctly differentiate between transparent plastic bottles, metal cans, and garbage that is smaller in size than the minimum size we determined. It can also drop the objects into three bins according to the type of object within 40 seconds. However, our design cannot differentiate big waste from bottles because they will block both photo sensors. To solve this problem, we can monitor the power consumption of the motor that controls the sorting chamber gate to determine the weight of the inserted object. This can help us identify the type of object by its weight. Another approach is to add an AI system to determine the shape of the inserted object.

4.2 Ethical Consideration

In terms of ethics, our project aims to improve the environment by facilitating garbage recycling. The system's shape and the machine's decoration did not contain any malicious intent, including, but not limited to, discrimination and harmful content.[5] We did not engage in any unlawful conduct during our design process, including sexual harassment or causing harm to others. In conclusion, our project meets all the high-level requirements and has a positive impact on the environment and society.

References

[2]LM1086 1.5-a low dropout positive voltage regulators datasheet (rev. J). (n.d.-b). https://www.ti.com/lit/ds/symlink/lm1086.pdf?HQS=dis-mous-null-mousermode-dsf-pf-null-wwe&ts=1694226213634&ref_url=https%253A%252F%252Fwww.mouser.cn%252F

[3]Graph illustrating effect of differing reference voltages on the ADC voltage curve. (n.d.). https://docs.espressif.com/projects/esp-idf/en/v4.4/esp32/api-reference/peripherals/adc.html#id1

[5]*IEEE code of Ethics*. IEEE. (n.d.). https://www.ieee.org/about/corporate/governance/p7-8.html