# Affordable Semi-Automatic Plastic Sorting System

## I. INTRODUCTION

Being able to sort plastic quickly and efficiently is an important task in recycling facilities. While this has been refined and performed extremely well in developed countries, many developing countries still rely on human labor to perform these tasks, which is slow and prone to human error. We propose an affordable, simple, and easy-to-manufacture system that can semi-automatically sort between different types of plastic.

A sensor is used to detect the type of plastic, and the waste is then dropped on a PVC pipe mounted at an angle. The orientation of the pipe is controlled by a motor, which can lead the plastic to one of two bins, depending on the sensor data. Ideally, the sensor would be composed of either a camera or a near-infrared sensor since research has shown that computer vision and machine learning algorithms can be applied to the output of these sensors to classify plastic. However, since we did not have access to these sensors, we resorted to a single photoresistor to test for transparency, which will act as a proxy.

## II. CONCEPTUAL DESIGN PROCESS

After narrowing the scope of the design, we did some high-level brainstorming and sketching of preliminary structural layout, as seen in figure 1. This general overview allowed us to narrow to a more refined design that would allow more detailed functionality modeling. During our brainstorming process for the rotational mechanism, our team developed a motion diagram as shown in figure 2. The intention of this motion diagram was to plan out what motion is created and present in the system. By doing so, the motion diagram helps identify how components in the system interact. The basic motion identified was the rotation of a PVC half-pipe some determined angle either clockwise or counterclockwise then rotate back to the resting state.

## III. IMPLEMENTATION

### A. CAD Model

For this lab, two structural components were developed in Autodesk Fusion 360, namely the pipe bracket coupling and the motor case, as shown in figure 3. The pipe bracket propagates movement from the motor to the pipe, while the motor case provides structural protection to the motor and fixes it in its place.

The pipe bracket was developed to serve as a coupling mechanism to connect the motor couple and the pipe itself to allow the step motor to rotate the pipe. We decided that the best way for a connection to be made between both the bracket and the motor couple and pipe, given our team values simplicity, was through the use of screws. Given we also value a high degree of precision, the diameter of the pipe bracket was created with only 0.1mm of additional diameter compared to the pipe's diameter and two screw holes were implemented into the design for the connection between the pipe and the bracket. These design features would enable a tight connection with the pipe and bracket which would result in smooth, precise movements for the pipe as it rotates towards the appropriate bin. Furthermore, the height of the base of the bracket was calculated as a noticeably short base would cause the pipe to come into contact with the stand for the motor. On the other hand, taller bases would increase the torque force on the system and could result in instabilities. As such, a height in between

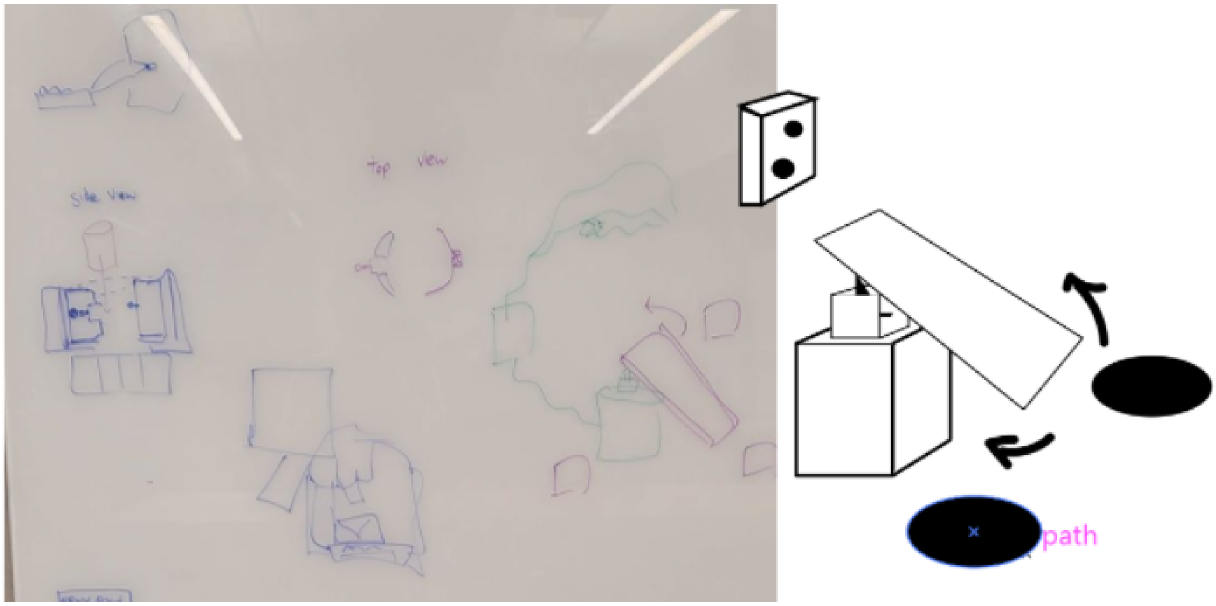


**FIG. 1:** Original whiteboard sketch of the system during the brainstorming phase.

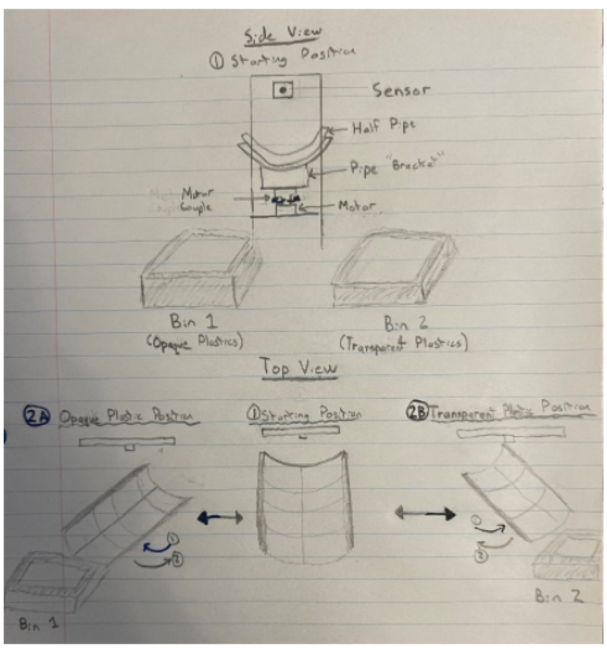


**FIG. 2:** The motion diagram of the control system, which guided our process during the manufacturing process.

these two limitations was chosen, particularly 4cm. Finally, the angle of descent for the pipe was chosen to be 35 degrees after the experimentation of sliding various plastics down the pipe at various angles. Through this experimentation, our team found that 35 degrees ensured that the plastics, regardless of size, never got stuck, while also sliding a reasonable velocity. The motor case was developed with a tight seal on the motor itself to ensure that the motor or any other components would not shift around during rotation. The four screw holes ensure a high degree of structural stability for the motor's movement while minimizing the possible use of a greater number of materials. As we intend on demonstrating greater empathy towards our stakeholders, the slide-on nature of the motor case along with the four screw hole placements allows for easy removal and reinstalment of the case during assembly.

### B. Assembly

A substantial portion of the structural components of the design is constructed using recycled wood sourced from the recycle bin at MyFab. This was a deliberate decision to address our team's value of suitability, as well as our value for accessibility by minimizing construction costs on a low budget. By using a combination of screws, nails, and wood

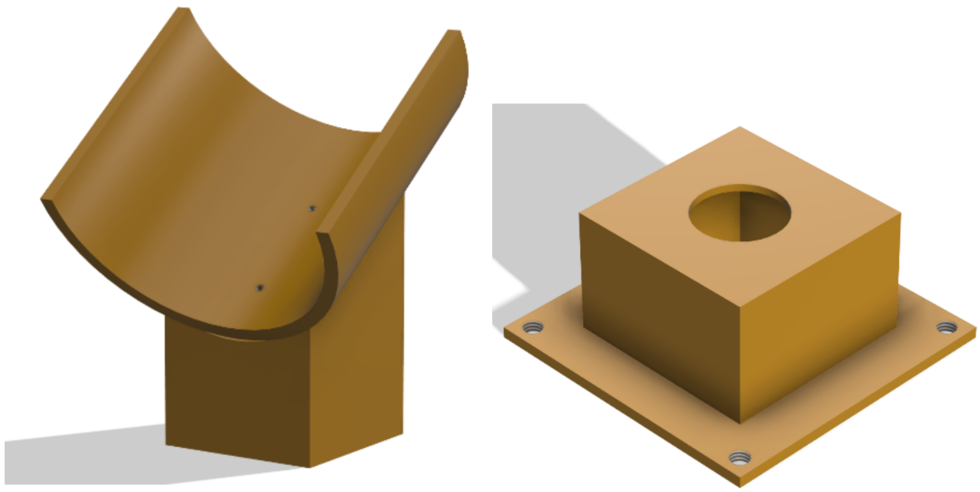

**FIG. 3:** 3D Renderings of the CAD model for our pipe bracket (left) and motor case (right).

glue, we constructed an elevated platform to mount the motor to an ideal height and act as a protective casing for the circuitry that controls the step motor. A sliding door was implemented to close off the circuitry casing as well as ensure the system is easy to access and maintain, as shown in figure 4. The sensor circuitry housed in a 3d printed case is mounted at the top of a tall backboard. The case is held in place via a fitted shelving ledge, with a front hinge mechanism. A lot of focus was put toward clean wire management to ensure user safety, ease of maintenance and protection of system components. This was done by routing the wires behind the backboard and cutting out fitted holes in the sliding door. This ensured all wires were tucked away to not impede the motor rotation, and not act as a potential safety hazard for the user. All structural components are easy to deconstruct and reconstruct for ease of transportation and storage.

### C. Code

The behavior of the system is straightforward, as described by the behavior table in table I. During the moving state, the system performs a series of sequential steps that cannot be interrupted:

1. Rotate clockwise (if transparent), or counterclockwise (if opaque) by 40 degrees

2. Play a notification tone on the speaker

3. Wait 2 seconds for the plastic to be dropped, and into the appropriate bin.

4. Rotate counterclockwise (if transparent), or counterclockwise (if opaque) by 40 degrees, returning to the idle state.

To get accurate readings on whether a material is transparent or opaque, we created a threshold value that needs to be fine-tuned depending on how bright the environment is. This value can be found in the given environment by verification testing of materials manually sorted. The general functionality checks for light values higher than the threshold, indicating light can pass through the material and is therefore transparent.

### D. Circuit

To accomplish the task of having a button and buzzer to initiate the classification of the plastic using photoresistor and transferring them to different bins, we modified our circuit from lab 2 and connected it with the cir-

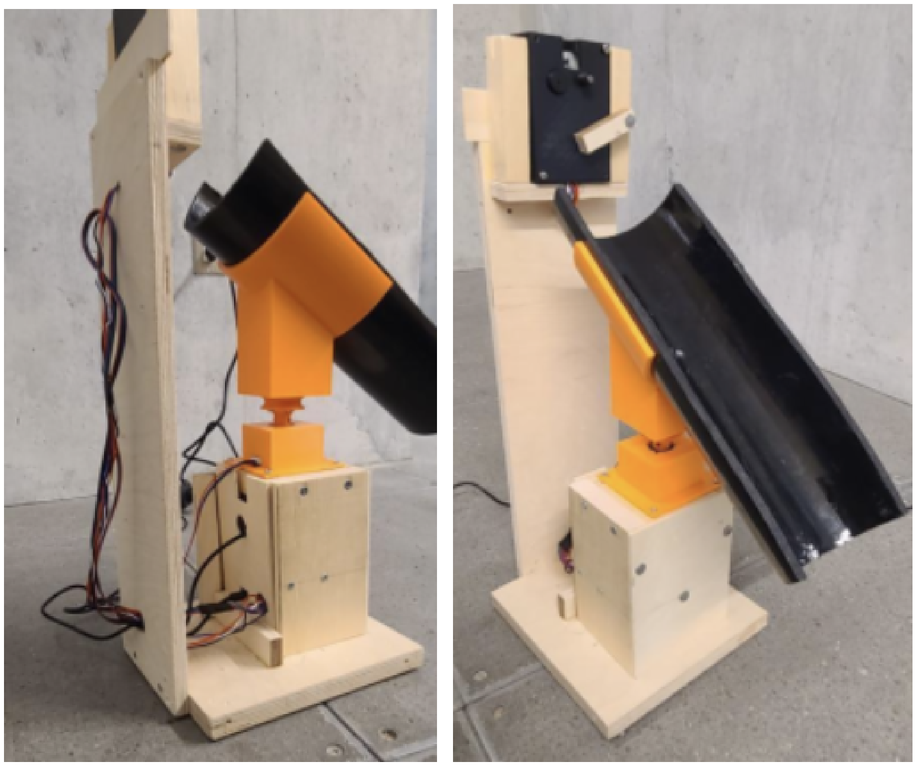

**FIG. 4:** Pictures of the final prototype. The back view (left) shows the wire management through the various holes, while the front view (right) shows how the pipe is connected to the pipe bracket. Most of the wires are hidden from view for aesthetic purposes.

| State | Button State | Sensor Input | Action |
|---|---|---|---|
| Idle | Not Pressed | Any | Nothing |
| | Pressed | Transparent | Changes state to Moving and performs action to put plastic into the transparent box |
| | | Opaque | Changes state to Moving and performs action to put plastic into the opaque box |
| Moving | Any | Any | Cannot be interrupted until action is completed and returns to idle state |

**TABLE I:** Table showcasing the behavior of the control system.

cuit that incorporated the motor, using the A4988 motor driver. The circuit diagram is shown in figure 5. The final implemented prototype used three separate breadboards connected to achieve the desired functionality. The breadboard mounted at the top of backboard implements the circuitry for the button, photoresistor sensor, and buzzer, which is connected to the two breadboard houses in wooden casing. The functionality was implemented using circuit python uploaded to the Arduino circuit board.

## IV. EVALUATION

### A. Verification

One concern we had was that the mass and length of the PVC pipe used to have a mo-

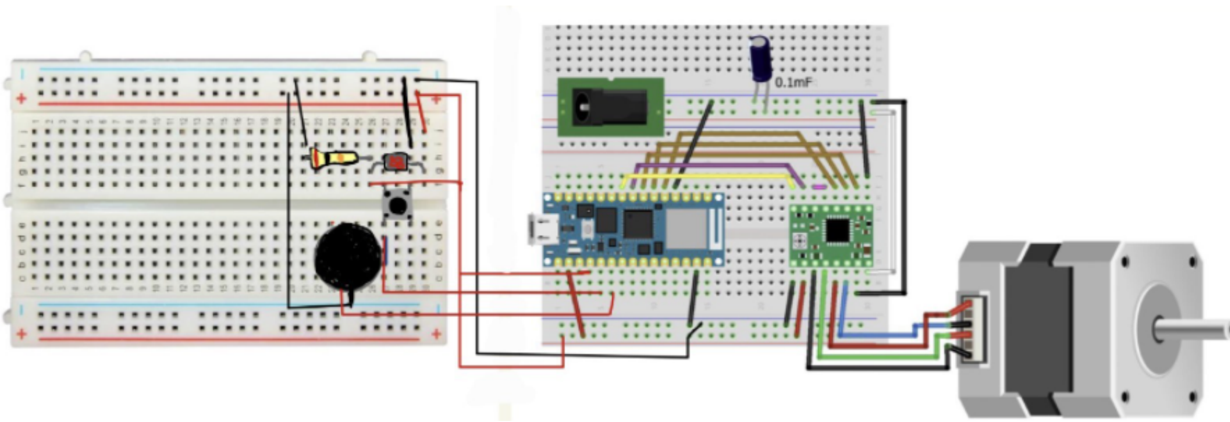


**FIG. 5:** Circuit diagram showcasing how the breadboard which consists of our sensors (left breadboard) is connected to the breadboards that run the motor (right breadboard). Note that the wires that connect the two are much longer than shown here.

ment of inertia too high for the motor to turn. While the motor was able to turn it, we observed that sometimes steps were skipped, meaning rotation may over or undershoot. To test the severity, we marked the starting position of the motor and had it turn a full rotation (rotate to transparent bin, rotate to opaque bin, then rotate back to neutral position) 100 times, which took around 10 minutes. After reviewing the footage of the rotations, we observed that there was no noticeable shift in the position of the motor when allowing the motor a brief pause between rotations. The lack of final displacement implies that if there are skipped motor steps, they are just as likely to occur when the motor is spinning clockwise as when it is spinning counterclockwise. The additional break time between rotations minimizes the propagated rotational error. To further address the issue, a small rotational tolerance is left on either end of the rotation allowing a range of final positions to still reach the desired recycling bin.

To verify the functionality of the sensor, a wide range of plastic and materials of different transparency levels were held to the sensor and the system response was recorded. This data was compared to expected outcomes to validate the accuracy of the plastic sorting. This method yielded a final prototype with a high success rate of accurate sorting. Errors were noted for a few edge-case scenarios that will require further work in later prototypes. Sorting errors occurred in materials that could not fully cover the sensor area or during shifts in environmental lighting.

### B. Technical Issues

One of the technical issues we encountered was the motor not spinning after the circuit was assembled. This was solved by using voltmeter to measure the voltage between the in and out ports of each component and found which pin failed to have the expected voltage. Eventually, we found that it was the connection between the pins of the stepper motor and the driver. The connection of a1 and b1 pins on the driver was messed up with the pins of the motor which resulted in the motor not having any current passing through it.

We also experienced the issue of the power regulator and wires being loose on the circuit during our process of placing it into the wooden box we created for the breadboard. To solve this issue, we utilized electrical tapes for the wires and an elastic band with a zipp-tie for the regulator to mount them steadily on the breadboard.

## V. INDIVIDUAL CONTRIBUTIONS

This project was primarily done by everyone working together. I, alongside my other teammates spent a lot of time together brainstorming, and working on building the actual system through several hours at MyFab, often staying for several hours at a time, for multiple days. One particular aspect I spent a lot of time working on was getting the circuit into the enclosure without wires breaking off. There were several loose wires and there would always be one that loses the connection. Since we weren't able to solder, we had to find alternative solutions to secure them better, which mainly revolved around electrical tape. Besides the manufacturing process, I gave input and helped with the CAD models as well as writing the code for the widget.

## VI. REFLECTION

Something I learned and that was very new to me was a lot of the manufacturing techniques we used to construct the physical prototype. This was the first large scale project I helped out on that consisted of 3D printed parts, electronics, and other components. I learned how to make various cuts in wood, such as cutting them into specific shapes, making indentations, as well as cutting specific-sized holes. I also learned different techniques to piece together different types of wood, ranging from using wood glue to using nails and screws.

One thing that really helped my learning was my teammates who had more experience than me, and the advice of the MyFab staff, who gave us great advice on how to accomplish certain tasks and showed us machines that we didn't even know existed! They were also very patient when helping us debug problems with our circuit, which includes pointing out problems with our Arduino and driver and showing us how to fix it.

Prior to this lab, the only type of motors I worked with before were very simple. They consisted of a positive and ground pin and when a voltage is supplied across it, the motor turns. Thus, being able to work with a much more powerful motor, and under the fact that the motor is a different type (stepper motor), it was very interesting to play around with it, as well as write code that can interact with it. It also improved my intuition of how powerful stepper motors can actually be. When I first saw the motor, I was very skeptical of whether it was powerful enough to turn an object with such a large moment of inertia, but I was pleasantly surprised when I got proven wrong!

While we had an overall idea of what we want to achieve at the very start, we did not carefully plan out some of the more specific details. Some of these details were minor, which resulted in some slightly misaligned components, while others were major. One of the major details we didn't carefully work out was how we were going to fit the breadboards inside the enclosure. Originally, we were going to place it on its side, but the positioning was very awkward and put unnecessary strain on the wires. We later changed it into the design we have now, with a two-story layer. Despite this, we struggled a lot with trying to fit the breadboard in with all the wiring. If we had planned better, we could have made an enclosure that was more open, i.e. by having two removable walls instead of only one. By being lazy and trying to save time, we actually wasted more time trying to fix the problems that arose from our laziness.