THE CANSORT 201

Team 83 AERO201 Project Proposal

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Executive Summary

Recycling is an environmentally geared process that allows for the reuse of materials that make up unused products. In order to be convenient for consumers, recycled products are often mixed, meaning that the recycled items being collected must be sorted into different material types. The design proposed in this document is geared towards making a proof of concept design that autonomously sorts cans for recycling. A user will load the cans, the machine will sort them into bins, allowing the user to access and transport the sorted cans. The robot will work with no need for user control and will sort cans based on the materials present. The compact design requires only a 110V AC wall outlet to power the machine and will be capable of sorting 12 cans in under 3 minutes.

The proposed cost for the design is $173.61 CAD, which is 24.5% beneath the given $230.00 budget. The proposed timeline to complete the project is 61.8 days (beginning February 1), with functional prototypes being developed in the weeks preceding the showcase date.

Andrew Bustard will act as the electromechanical lead, developing the structural components and implementing the required motors. Ben Mucsi will be the circuits and sensors lead, focussing on providing power to the microcontroller board and circuits, as well as designing the signaling pathways of the machine. Cameron Alizadeh will take the role of microcontroller lead, and is responsible for the creation of algorithms and programs required for the robot’s decision making processes.

Introduction

Recycling is a process that can economical and environmentally friendly. However, consumer participation is one large barrier to recycling gaining even more prominence than it already has. In an effort to remedy this, many municipalities have implemented single stream recycling, which means that consumers can simply put all of their recycling in one bin, negating their requirement to sort the recycling. This eases the consumers' participation, and thus increases the likelihood that they will recycle their products. However, using a single stream system has inherent difficulties: recyclable waste must be sorted, as certain materials have different recycling processes. Sorting this waste manually requires more manpower and funding, which makes this process more difficult.

In many cases, robots and automated sorting systems have been adopted to separate the individual components of this waster. One such task is the sorting of different types of cans, based on their different properties (i.e. metal type, labeling, etc.). An automated sorting machine fills this gap and eliminates human labour in sorting these cans. The task is thus to make a machine that optimizes cost, effectiveness, and efficiency. Portability, safety, and general reliability are inherent conditions that must be met as well.

Problem Formulation

The RFP supplied by the client addresses the need for a machine that sorts cans into four groups based on their physical properties. It must do this in a predetermined timeframe and with a certain accuracy in order to qualify. It also must keep track of the sorting information, and be able to present this info to the user after quick and simple navigation of the system. The cans must be loaded simultaneously, and the bins they are sorted into should be able to be removed easily by the user with no disassembly of the machine necessary. The machine must be portable, require no installations, and be able to be plugged into an AC outlet in the wall.

The four types of cans to be sorted are:

1. 222 mL aluminum beverage with pull tab
2. 222 mL aluminum beverage without pull tab
3. 284 mL tin Campbell's soup can, with label
4. 284 mL tin Campbell's soup can, without label

Goals

The robot should be able to sort the 12 cans simultaneously loaded with near perfect accuracy every time. Accuracy will need to be balanced with time and cost, both of which should be minimized. It should appear safe, and thus vibrations and noise emitted should be minimized. We want the LCD display and program to be simple to use and navigate. It should present the correct number of cans sorted, cans in each category, and the run time of the sorting process. The robot should not damage the cans in any way or hinder the recycling processes after sorting. The autonomous robot should be designed with the ability to operate with a variety of conditions in mind.

The robot should occupy no more than 0.5 m by 0.5 m by 0.5 m in volume during operation and weigh less than 5kg. The operator interface will include real time/date display, permanent logs, and PC interface features, in order to increase the robot's usability. Finally, the machine will be designed to be both reliable and easy to maintain.

Objectives

Table 1: Project Objectives. Some objectives and criteria are imposed by the RFP, while others stem from careful consideration of the problem.

Objective	Metric for Evaluation	Criteria	Constraints
Portability	Amount of space taken up by the robot during operation	Lower is better	Must not exceed 0.5 m by 0.5 m by 0.5 m
	Robot mass	Lower is better	Must not exceed 5 kg
Autonomy	Robot autonomy, with no interaction by external PC or remote control		Must be fulfilled
Safety	Presence of an emergency stop button that immediately stops all mechanical components		Must be fulfilled
	Typical damage to cans	Lower is better	
	Outward appearance	Lower levels of noise and vibration are better	
	Surface area of exposed electric and moving parts	Lower is better	
Accuracy	Number of cans sorted correctly	Higher is better	
	Displayed number of cans sorted	Closer to correct number is better	
	Displayed categories of cans sorted	Closer to correct number is better	
	Displayed operation time of the machine in seconds	Closer to correct number is better	Must be ± 1 seconds within the instructor's time
Usability	Ease of extracting data from the robot after task completion	Easier is better	
	Ease of loading the cans, measured by time in seconds	Lower is better	Loading must take less than 60 seconds
	Time required to set up before the loading process in seconds	Lower is better	Pre-loading set up must take less than 120 seconds
	Ease of can removal	Easier is better	Must be able to remove bins without any disassembly of the robot

Cost	Total cost of prototype	Lower is better	Must not exceed $230 CDN
Speed	How quickly each can is sorted	Lower is better	Total operation time of the machine must not exceed 3 minutes

Market and Literature Survey

Sorting systems have already been implemented in numerous contexts, and utilize a variety of techniques to sort objects. The eddy current system is one such technique, and is able to sort non-ferrous (and thus non-magnetic) materials. In this system, the cans travel along a conveyor. A magnetic rotor system spins at a high speed (around 3000 rpm) [1]. This induces an electrical current in the aluminium, and it travels away from the magnetic motor off the conveyor into another sorting area [2].

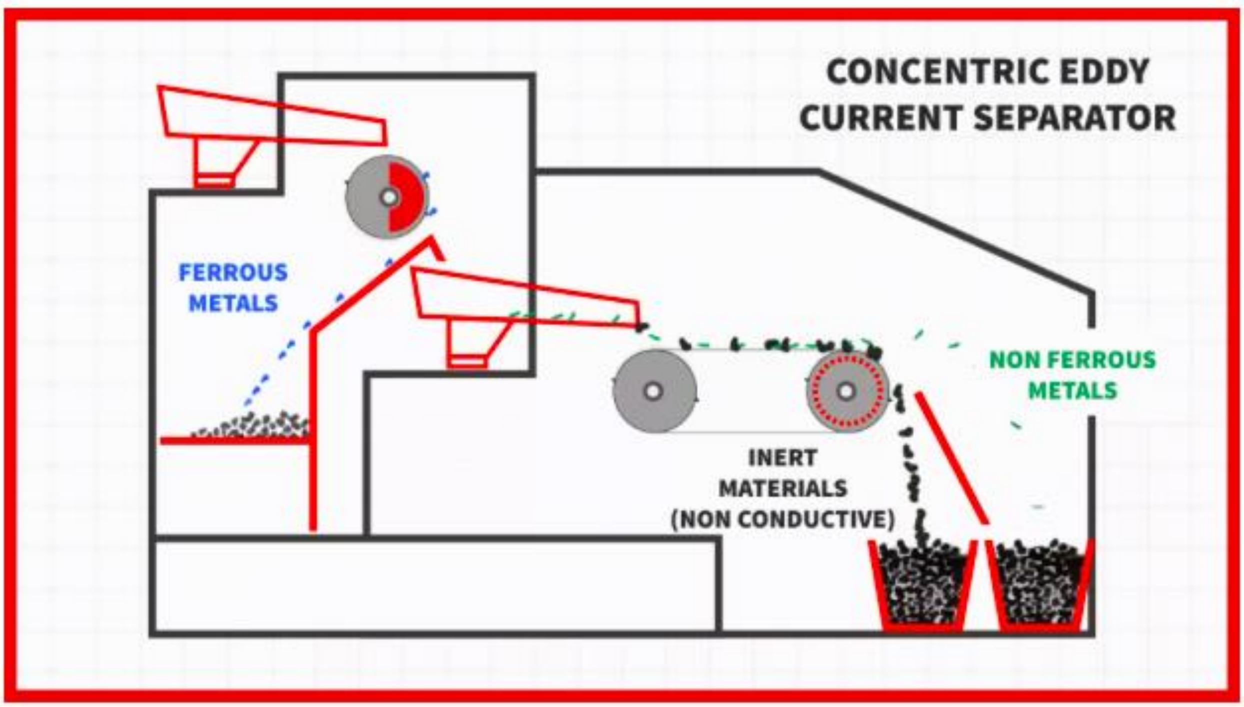

Figure 1: Operation of an Eddy Current Separator. Courtesy of Master Magnets

This design is adequate for industrial recycling processes, but given the size constraints and the low number of cans being sorted, there are simpler and more space effective ways to sort the aluminium cans.

Another reference design is the silo blower. This device works by shooting gusts of air at recycling, in order to push lighter objects (i.e. aluminium cans) off a conveyor belt into another sorting section. However, this technique is unlikely to work for the sorting needed in this project. The machine requires a large amount of power and the entire process would take up too much space for the project goals and constraints.

Figure 2: A Silo Blower, Used in a Recycling Context. Courtesy of Alibaba

The next reference reference design used magnetism, but in this case it was used to attract steel to a regular magnet that simply “grabs” the steel cans. This is an elegant means of separating cans; however, it was ultimately foregone in favour of having all cans tested in one area, in order to reduce complexity of the robot [3].

Figure 3: A Magnetic Arm Separator. Image courtesy of Magnapower

One reference design that is used for the loading can phase is a rotating drum. With stationary walls and a rotating centre, this design can be used to orient the cans and transport them into their appropriate chute [4].

Figure 4: A Rotating Drum. This reference design inspired the use of a drum-like separator mechanism in the final design. Image courtesy of Busschers

Technical Body

Conceptualization

The robots physical design is split into three unique but tightly integrated parts: loading and orientation, testing, and sorting.

Loading and Orientation

As per the RFP, the cans must all be loaded simultaneously into one container on the machine. In order to effectively test and sort them, the movement of the cans must be 'controlled' in some way. Both are cylindrically shaped, which immediately offers the options of both sliding and rolling. When rolled down a ramp, the cans would rarely maintain their direction without a guide wall. When they slide lengthwise, the aluminum cans have a chance of sliding into the open end of the tin cans, which would make testing almost impossible. These issues needed to be tackled with the first step of the robot function.

Dual Ramp

By pouring the cans into a ramp with inclined walls, they will orient themselves head to tail due to the shape of the ramp. This requires no force other than gravity, which makes it a very simple mechanism to orient the cans. The top ramp has a disconnected lower half, which is wide enough to allow the smaller aluminum cans to fall through while keeping the tin cans on the upper level. It also takes advantage of the size difference between the cans to pre-sort them and to potentially make testing a lot faster by running two simultaneous testing sites. However this is very complex, and would require a very high level of programming to make such a design functional. Furthermore it takes a lot of space to allow the ramps to be long enough for the cans to sort and align themselves, which would greatly decrease the portability of the design.

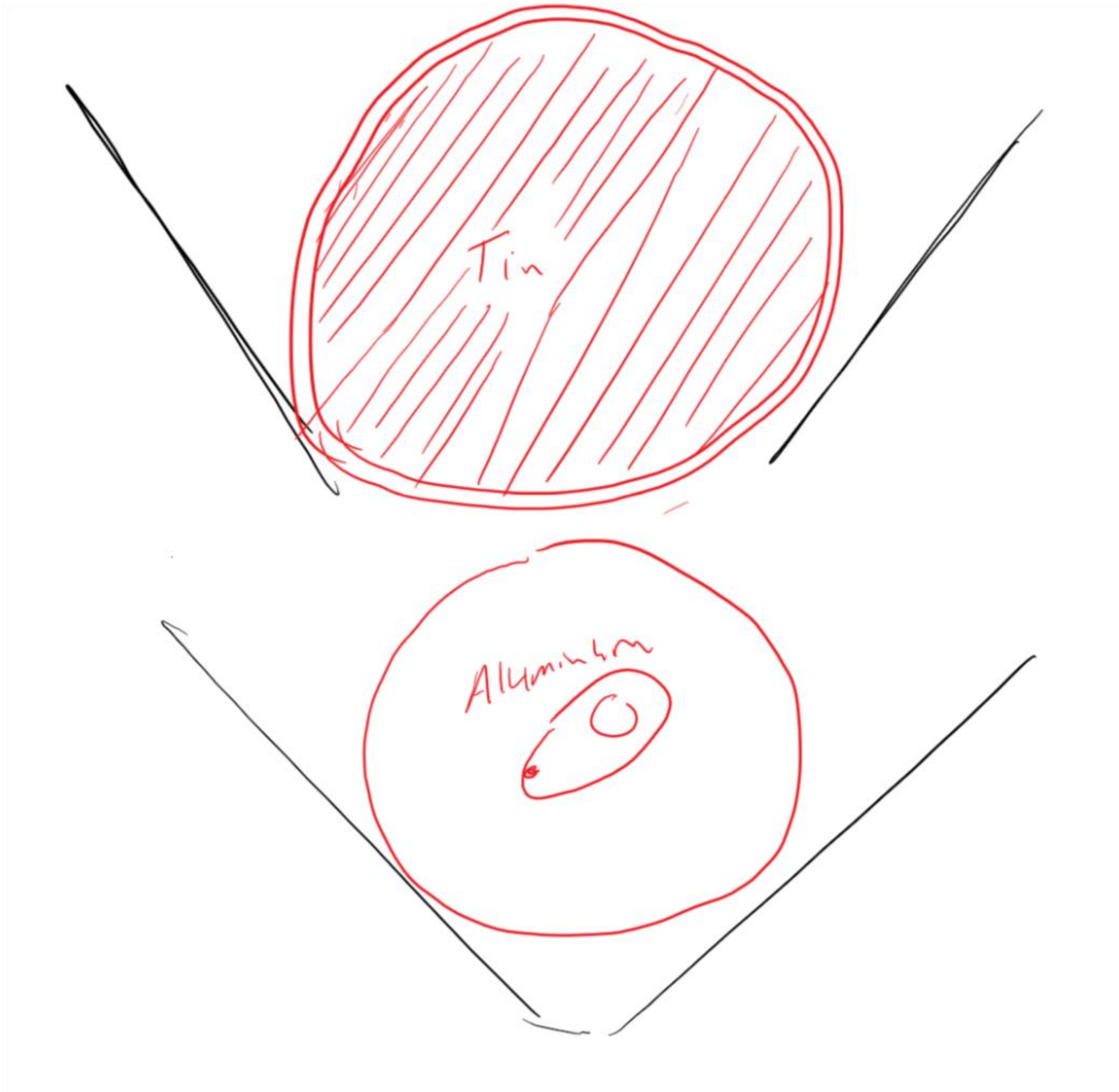

Figure 5: Cross-Section of a Dual Ramp Loading Mechanism

Funnel

One of the most intuitive ways of orienting the cans after loading is using a funnel, with a specially designed shape that will help guide the cans into the desired orientation. After some low fidelity testing, it was decided that the uncertainty of this method was too great, and that it would run the high risk of jamming. It could also potentially require lots of vertical space within the confines of the machine, as the cans need to travel enough due to gravity to allow the shape of the funnel to orient them.

Ramp with Rollers

This concept is based off the idea that using additional, controlled forces to move the cans could help decrease the chance for jamming. As the cans must be loaded simultaneously, the randomness of their distributions and orientations poses quite a challenge for any system relying solely on gravity. This design consists of a ramp that moves the cans to the site of two spinning motorized wheels, which then push the cans through a slot one by one to queue up. The top of the mouth tips over any standing cans so that they are all in one plane, and the peg in the centre helps prevent jams. The challenge with this concept comes from the material properties of the can, as its coefficient of friction is quite small with a lot of common materials. Although this is a useful property for sliding the cans to transport them through the machine, in this case it becomes a hindrance as they can obstruct the mouth if the wheels can't get a solid grip to guide them through. Higher fidelity prototyping would need to be conducted to adequately assess the functionality of this design.

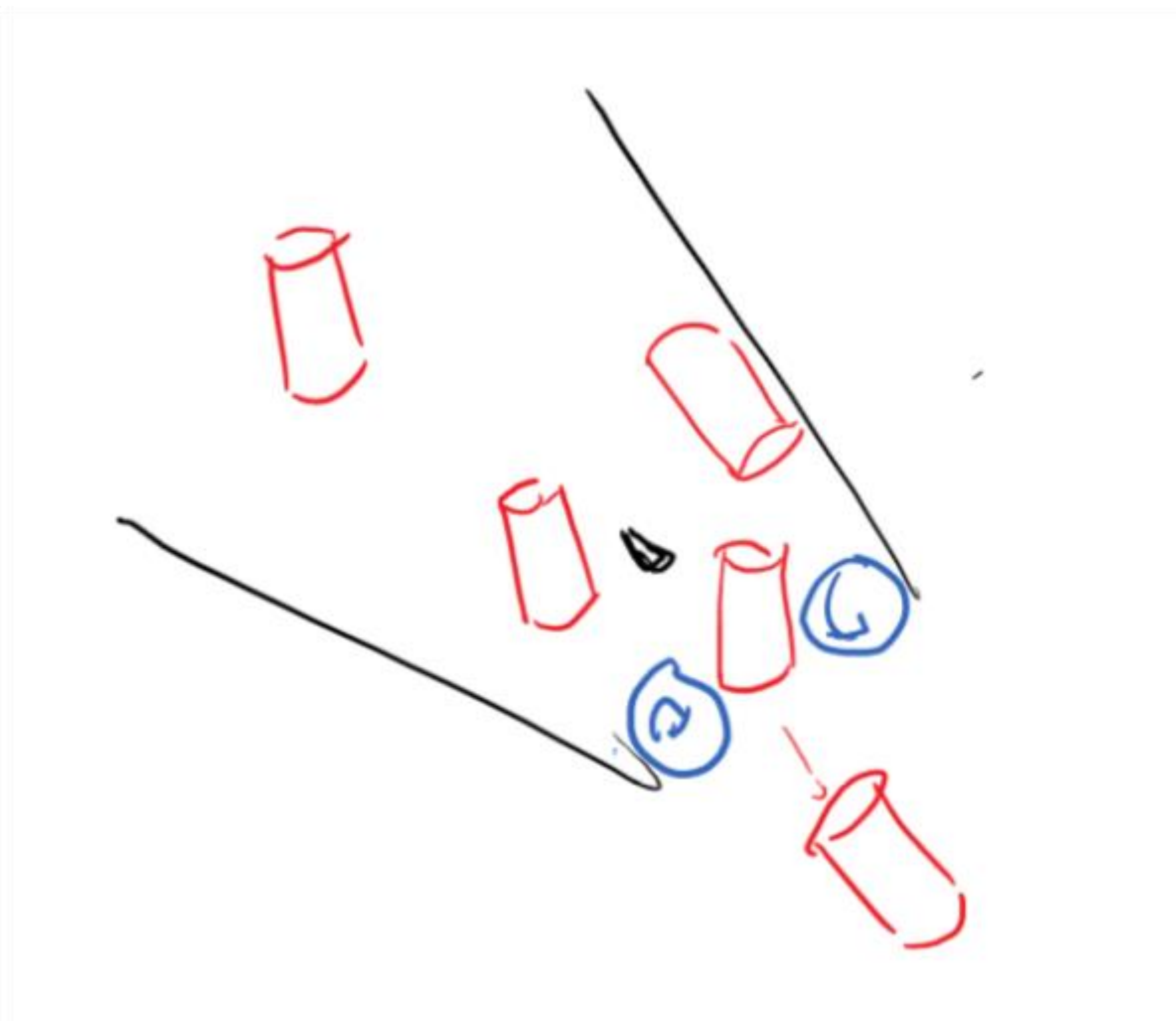

Figure 6: Rollers Agitate the Cans and Move them Down the Ramp

Drum

This design features a large spinning drum that utilized the centrifugal force "generated" by the spinning motion to align the cans. While it is not entirely space efficient, as the large drum is useless for the rest of the machine and blocks off a large chunk of space, this design does not take up a lot of vertical space. Powering the motor could be done with a simple DC motor circuit for continuous rotational motion. Low fidelity prototyping was used to confirm the functionality, although some potential problems were encountered. The cans leaving the drum need to be efficiently moved away from the drum to prevent backlog, and the drum mechanism needs to be well supported mechanically to avoid damages or breakdowns.

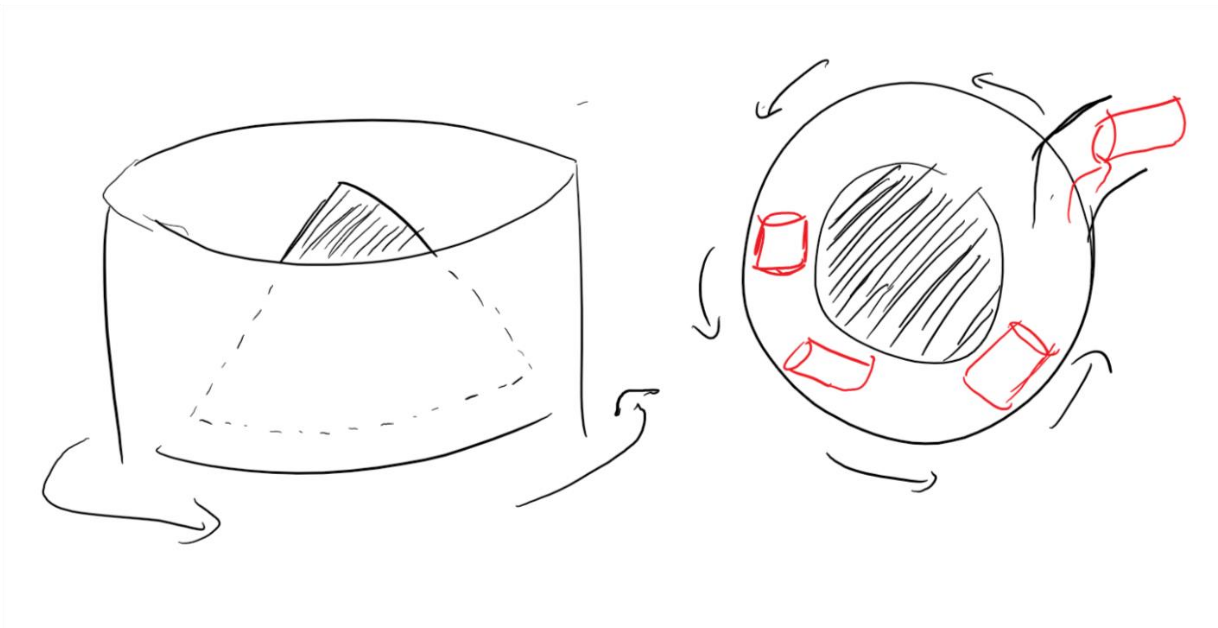

Figure 7: High-Level Sketch of the Rotating Drum. Side and birds-eye views provided

Testing

The RFP outlines for separate categories of cans that need to be separated:

- Aluminum can with tab
- Aluminum can without tab
- Tin can with label
- Tin can without label

The first design decision that was made was regarding the testing sites. For simplicity of design of both electrical and mechanical components, it was decided that all the tests for distinguishing cans would be performed at one location. This reduces the number of moving parts required, and is also very efficient with space use. However the largest drawback of this type of design is that cans can only be tested one at a time, which therefore could make the device somewhat slow. Considering the limited timeframe, as well as the team's level of expertise, the decision was made to limit the robot to a single testing location.

Aluminum vs Tin

The first test to be run is that which distinguishes the aluminum cans from the tin cans. Several techniques were proposed to accomplish this:

Magnet

A key difference in the material properties between aluminum and tin is their ability to be magnetized. Magnets have no observable effect on the pop cans, however the tin cans are ferromagnetic. As a result, utilizing magnets to separate or identify tin cans is a very simple option. Magnetic fields could be used during the transport of the cans to send them on a different path, however the option that was explored more extensively was using a magnet as a switch for a stationary test. The most effective option, based on conceptual drawings and low-fidelity testing was a magnet attached to the end of a microswitch lever.

Figure 8: Operation of a Basic Magnetic Switch

Size

As the two different material cans are completely different products, their dimensions are distinguishable. Although the heights are similar, the can diameters are quite different, with the tin can measuring 7.62 cm in diameter and the aluminum can measuring 5.8 cm in diameter. A few different options were explored to sort based on size, including the dual ramp mentioned above, and break beams positioned wider than the aluminum can that would still catch the tin cans. These sensors would have to be positioned almost perfectly, as the difference is somewhat significant but it is not possible to perfectly control the movement of the cans throughout the machine.

Tab vs No Tab

As the smallest observable difference between two categories of cans, detecting the presence of pull-tabs requires high precision regardless of the specific test being used. Like the can itself, the pull tab is made of aluminum, however it was determined through testing that it is conductive. This allows for conductivity testing to determine whether the tab is attached to the can. The top of the can was not conductive, and therefore the contact distance does not have to be aimed in the range between the tab height and the top of the can.

Force Sensor

In almost all cases, the tab sticks out from the regular profile of the can. This means that in order to flatten it, additional force is required. This force could be measured by moving in a force sensor to a predetermined distance and recording the reading. Value ranges can be programmed in the microcontroller to determine whether there is a tab based on the magnitude of the exerted force.

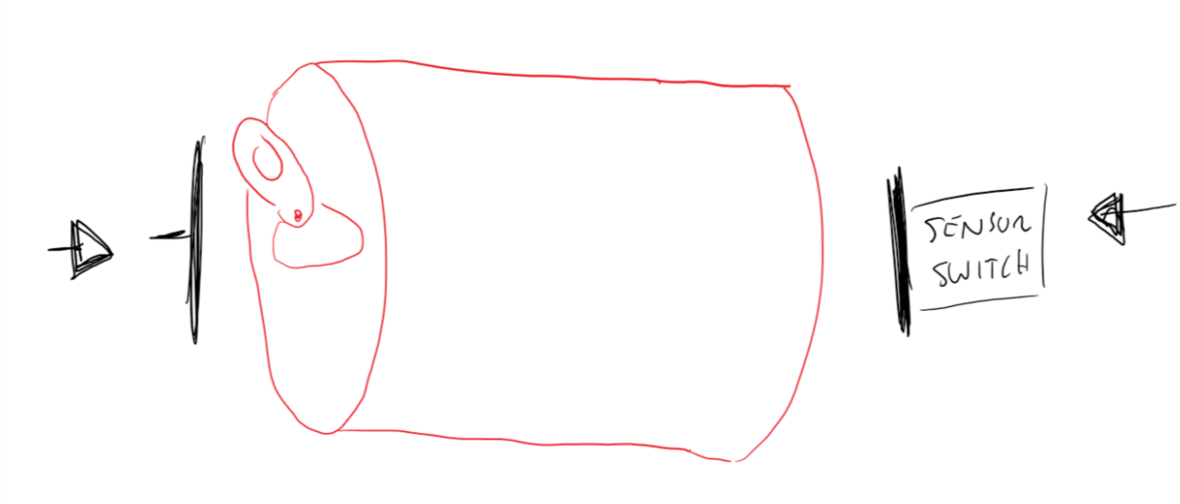

Figure 9: A Force Sensor Applied End-to-End to Determine the Presence of a Tab

Break Beam Sensor

Since the pull tab extends beyond the length of the can, a break beam sensor could be used at the end to detect the presence of the tab. Consisting of a laser and a phototransistor, this circuit is not particularly complicated nor difficult to assemble from the various components. However, orienting the can correctly for this to work may become very difficult.

Distance Sensor

Using a distance sensor aimed at the face of the can, the smaller distance value resulting from the presence of the tab could be detected. To ensure that the sensor does not miss the can, it would need to be mounted on a rotating motor and scan a circle on the face of the can. This creates difficulties with mounting, and increases the complexity of the test with more sophisticated moving mechanisms compared to some of the other options.

Conductivity

As the tab sticks out, a precisely aimed solenoid could push an electrode into contact with the tab, and if the can doesn't have one then it would make no contact. Assuming expected conductivity with aluminum, this test would consistently work if the distance could be calibrated within the margin of error of the solenoid range. During experimentation, it was discovered that the top face of the can is non-conductive due to a chemical coating. This allowed for more freedom in contact design, and ensures that if the solenoid can reach the face of the can, the test will be accurate.

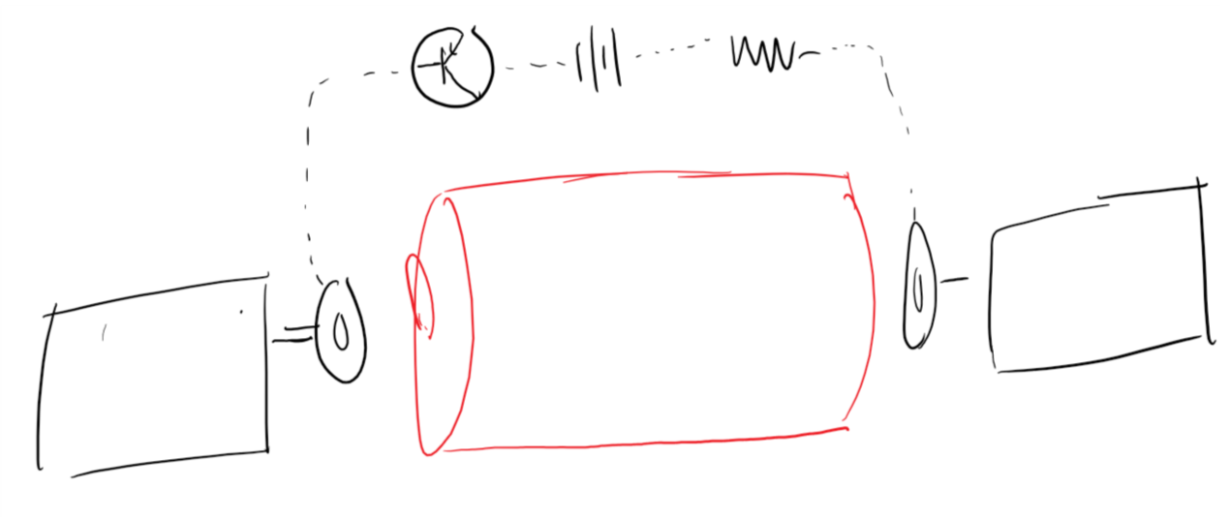

Figure 10: Conductivity Test Applied to Determine the Presence of Tabs

Label vs No Label

IR Sensor

The tin cans without the label expose bare metal, whereas the paper label envelops the majority of the side surface of the can on those that have it. The difference between their surfaces can be identified by a reflexivity sensor, as the paper label was discovered to be significantly less reflective than the tin. The IR sensor, consisting of an LED and phototransistor, can be quite small, thus providing a viable option for the final design. The most significant challenges brought on by this testing method are the close spacing between the cans and the sensor, as well as the potential interference of other sources of light and heat.

Conductivity

Tin, like most metals, conducts electricity quite well, and could therefore be used as a wire in a circuit. The label, made of paper, is an insulator, therefore a continuity test could be used to determine whether or not a label is present. By running a current through the object with a transistor attached to the circuit, it is fairly simple to send a signal if the object in question is conductive.

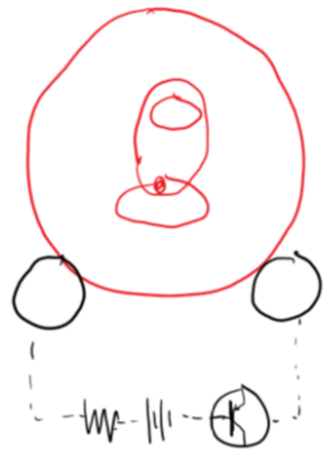

Figure 11: Conductivity Test Applied to Determine the Presence of a Label

Sorting

As per the RFP requirements, the cans will be sorted into 4 bins. The cans need to be moved from the testing site to the bins, which provided lots of open design space as the location for the bins is not specified within the machine. A few possible ideas were explored, all under following through with the same design decision of having one testing region for all cans.

Ramp with Trapdoors

This design features a long ramp, with multiple trap doors that can open or close to control which bin the tested can would fall into. It can effectively sort the cans with simple signals from the PIC board, but requires lots of space and multiple separate localized movements.

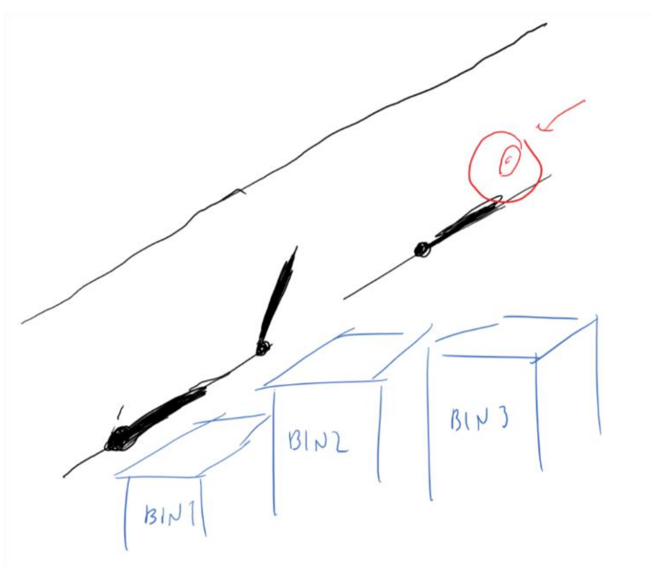

Figure 12: Trapdoor Sorting Mechanism

Top Ramp with Pivot

This design aims to shorten the vertical distance travelled by the tested cans to conserve space and time. A short, shallow angled platform would be mounted on a rotating mechanism directly below the testing site, which would in turn need to be moved to the centre of the robot. Once the necessary tests are completed, the platform rotates to set the ramp to aim at the corresponding bin before the can is released from the testing hold. This design would require a slightly more complex mounting mechanism than the other prospects, and could potentially require additional vertical space to leave room for attachment and clearance space to rotate the ramp.

Rotating Base

This concept removes the need for additional ramps beyond the testing site, thus conserving space. The four bins are seated on top of a rotating platform being moved by a stepper motor. When the correct bin has been determined, neither the can nor the testing area have to be moved to the bin, as instead the bin is moved to them. Although this design is quite simple and elegant, it requires a relatively high powered stepper at the base, and a staple rotating platform to hold the bins.

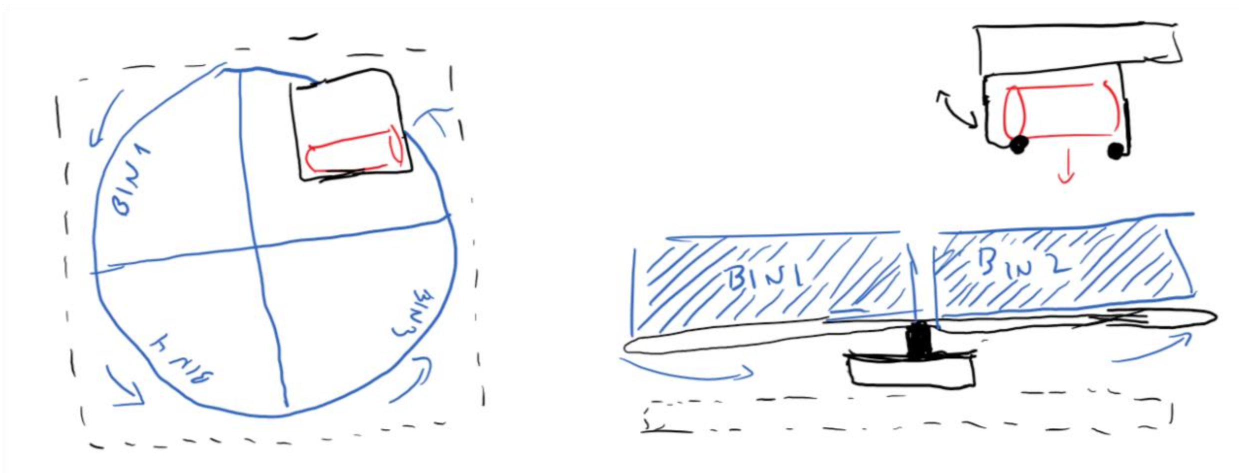

Figure 13: The Rotating Bin Mechanism. Side and birds-eye views provided.

Statement of Work

General Functional Description

The initial loading will be into a drum. Cans will simply be poured simultaneously into this drum. Once the start process begins, the drum will begin to spin. The cans will move to the edge adjacent to the walls as they move around the drum due to the effects of the imaginary “centrifugal” force. The cans will be knocked down lengthwise by a small ledge at the height of the can. They will then exit the drum by travelling through a slot in the drum wall into a transfer chute.

The transfer chute will act to maintain the orientation of the cans, transport them to the testing area, and limit the flow of the cans into the testing area. The geometry of the chute will serve to limit the flow of the cans in one direction and keep their lengthwise orientation the same. It will be slanted downwards in order to use gravity for downwards transportation. Finally an actuation device will limit the can flow in order to ensure that only one can is in the testing area at once.

One can will be allowed into the testing area at a time. It will enter lengthwise, and will be supported by two rails from the underside. A magnet switch will be used to determine if the can is made out of tin or aluminium, as only the former is magnetic. A circuit will then be attempted from one rail through the can to the other if the can is tin, in order to determine if there is a label on the can. If the can is found to be aluminium, another conductivity test will be used. The flat surface of the end of the aluminium can doesn't conduct electricity, but the tab does; thus, a voltage will be applied through the tab to the end of the can. If electron flow is detected, the can is known to have a tab.

After testing is conducted on the cans, they need to be sorted in their respective bins. This will be achieved by storing the bins underneath the testing area, and having them rotate when needed. The microcontroller will keep track of which bin is in the drop zone, and once a new bin corresponding to the identified can is required the turntable will simply rotate to accommodate the right bin. Once the bin is in the right location, one rail will be moved out allowing the can to drop. The rail then will return to its previous position, and the machine will continue testing.

Once the robot is done working, it will enter standby mode once again. All electromechanical components will cease to move. A termination message will be displayed on the LCD, and a sorting log will be available in order to retrieve information such as the total number of cans sorted, the number of each type of can, and the runtime of the process.

Electromechanical Components

Drum and Supporting Components

The rotating section of the drum will be made of polypropylene, an inexpensive and light material with a density of 905 kg/m^3 [5].A moulding that fits the design will be used to construct it. Tests will be conducted to determine the optimum coefficient of friction for the drum surface, and to condition it accordingly via lubricating or roughening the surface. The walls of the drum will simply be made out of smooth polypropylene as well. There will be a small protrusion from the drum wall that is just below the standing height of the drum, in order to knock the cans down into a lengthwise orientation.

A 12V Brushed DC Motor will be used due to the simplicity of DC motors. Additionally, its small size of just over 2 cm is useful due to the height restriction, and its high torque (0.88 N*m) will be enough to drive the drum during its operation. Despite its weight (210 g) and price, this motor has the high torque needed to drive the drum, and thus will be used in the design. The drum may need to be placed on a slight incline, in order to reduce the chance that an aluminum can enters a soup can, inhibiting the sorting system.

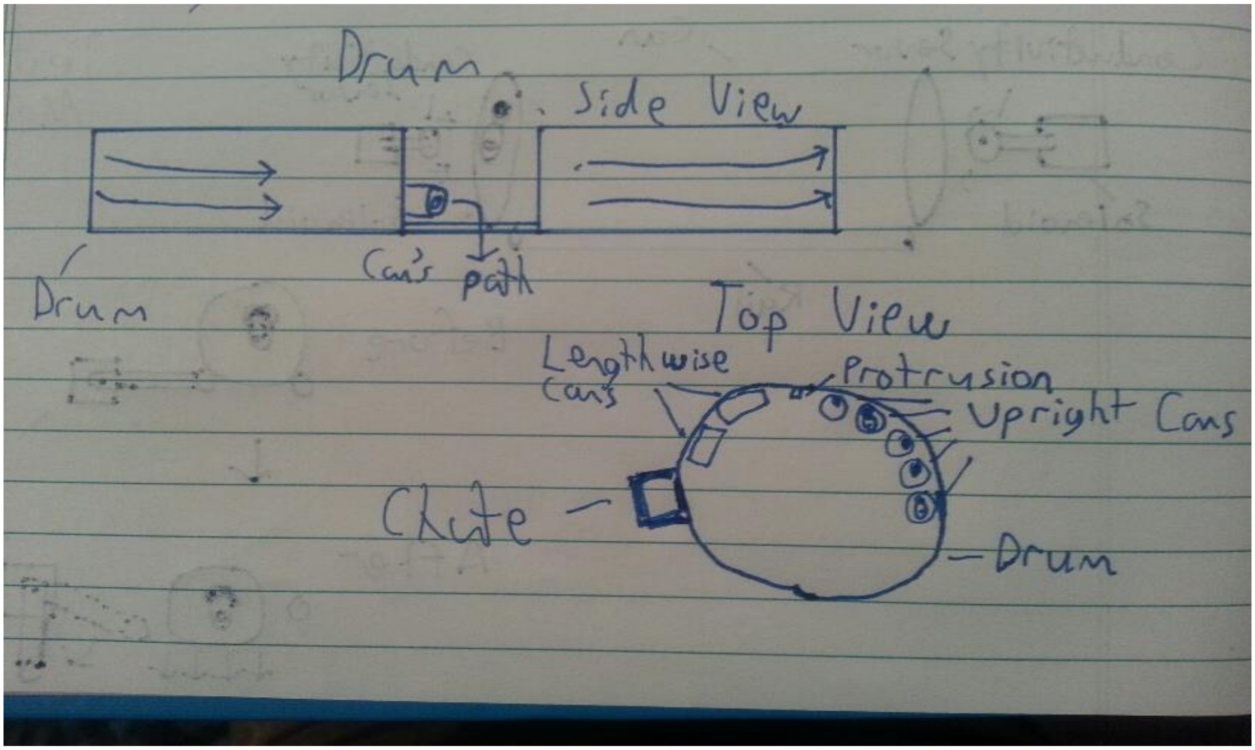

Figure 14: Birds-Eye View and Side View of Drum Mechanism

Chute and Limiting Actuator

A chute will be used to transport the cans from the drum to the testing area. In order to ensure that the cans are rolling rather than sliding, plywood will be used for this chute, as it is easy to work with. There will be an initial vertical drop for the chute, and a shallow angle ramp at the bottom of this small pitfall. The width of the ramp should be slightly larger than the length of the cans, in order to accommodate them while still preserving their orientation.

The limiting device to be used consists of a 12V Bipolar Stepper and an x-flap made from a material as of yet undetermined. The stepper will be attached to the x-flap, and will turn the x flap by 90 degrees when it receives a signal. The can inside of the x-flap will tumble into the testing area below, while the next can will be at the top of the x-flap. The x-flap and chute are demonstrated in Figure 15 below:

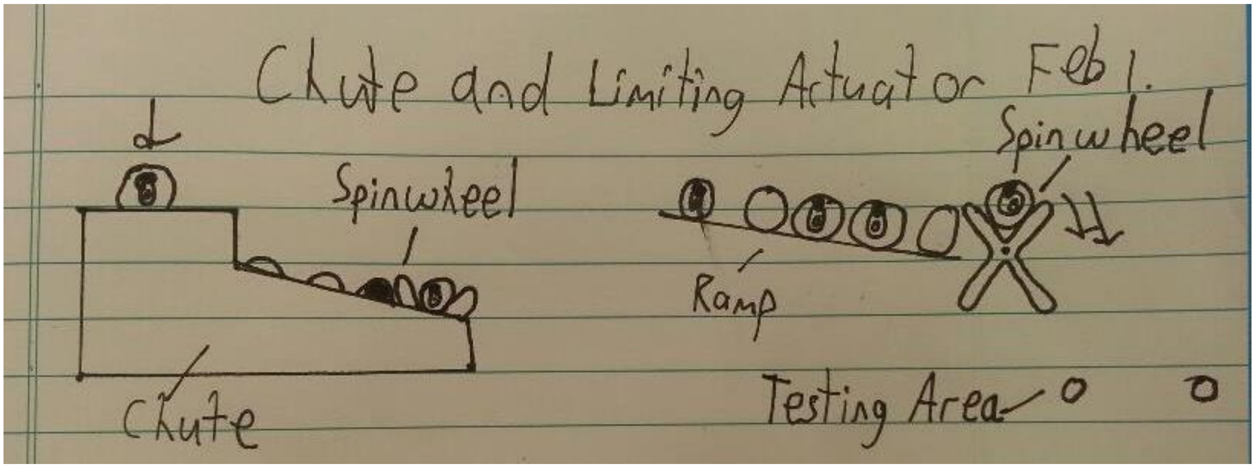

Figure 15: Transport Chute and Limiting Actuator Diagram

Testing Area

Two 5V Solenoids will be used to extend the conductivity arms into the can. With a stroke length of 6 mm, they will be able to apply the conductivity test on the can by extending the metal testers. Due to their low price of 6.60 CAD and their small size, these solenoids are well suited for the conductivity test.

A stepper will be used for the rotating arm that moves the rail due to its precision in movement and its ability to retract the rail as well. The model we will use will be a 12V Bipolar Stepper Motor, due to its relatively high torque for a stepper, consistency with the other 12 volt motors, and its 1.8 degree precision. This will allow use to support the rails and get them in accurate positions. Additionally, using a stepper will give us holding torque, which is necessary for supporting the rail when it is extended. The testing mechanisms are shown in Figure 16 below:

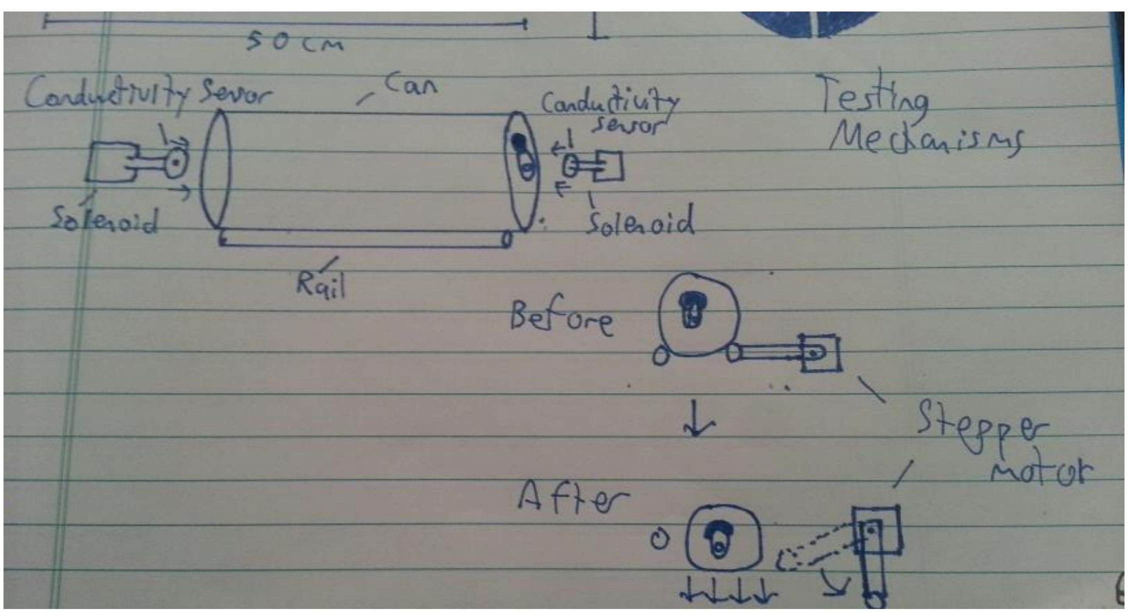

Figure 16: Depiction of Conductivity Test and Subsequent Can Sorting

Can Retrieval and Sorting Area

A 12V High Torque Stepper Motor will be used to drive the turntable that rotates the bins into position. This motor was chosen due to its properties of a stepper; it is able to spin in both directions easily and has precision capabilities. The turntable will be circular and made out of a rigid plastic of some kind. It’s diameter will be half a meter, pushing the limit of the volume envelope. The bins themselves will be represent a quarter circle perpendicular to two lines, as shown below. There will be a slight indent in the plastic in the shape of the bins to keep them in place, as shown in Figure 17.

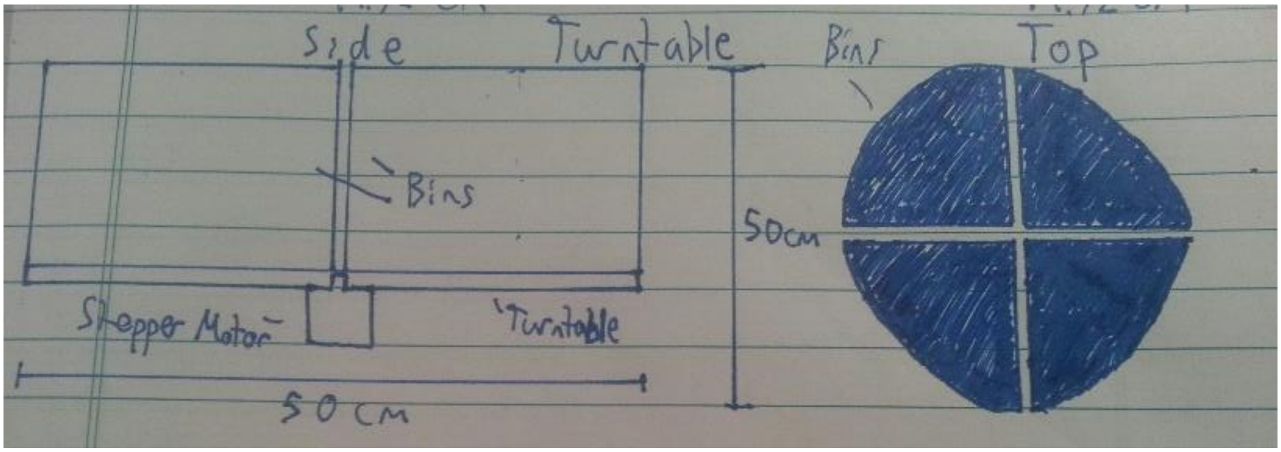

Figure 17: Sorting Bin Configuration

Frame

The frame will consist of four upright support beams with three support platforms spaced out vertically. The support beams will be located in the corners of the robot, and will be exactly 50 cm in length in order to meet the sizing constraints. They will be made of square PVC tubing, chosen for its low price and density (1.48 g/cm^3) [6].

There will be three platforms; one to support the drum, one for the turntable at the bottom, and one in the middle. The middle platform will support the chute, testing area/actuators, and the electronics and microcontroller. The top and bottom platform will span most of the horizontal plane, while the middle platform will span about a third of the area and thus will require additional supports. These supports will be 1’’ by 1’’ wood planks attached to the upper platform. Spruce plywood was chosen for the platforms, for both its low density and price. The plywood will be attached to the PVC by brackets and screws as shown in Figure 18.

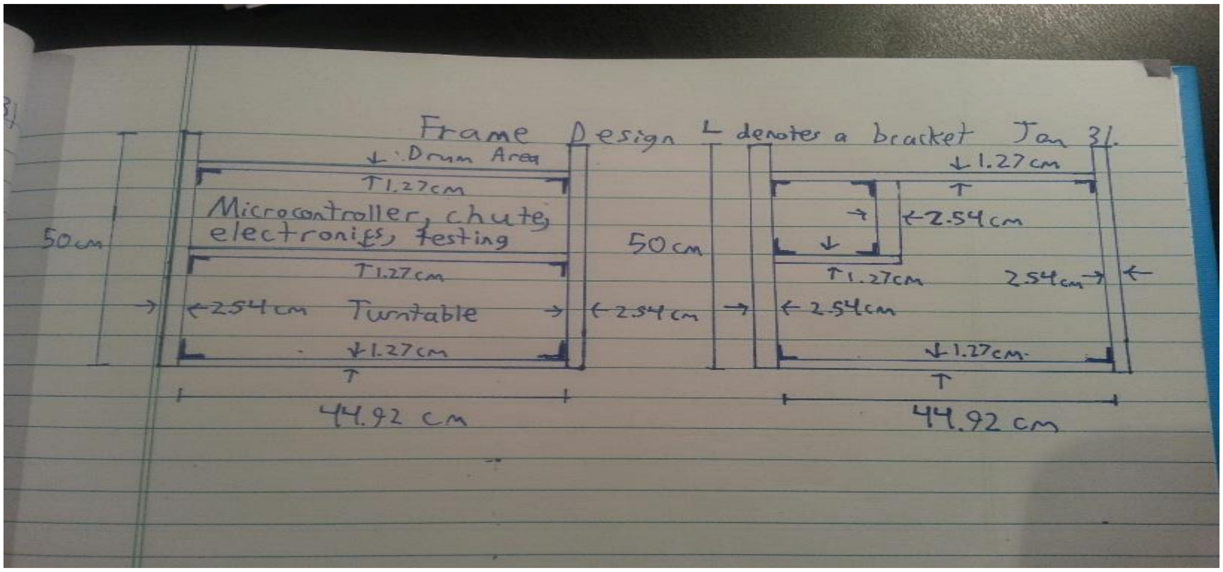

Figure 18: Robot Frame Design

Circuits and Sensors

The overall design of the robot requires:

- 1 emergency switch
- 1 magnetic switch
- 2 break beam sensors
- 1 continuity sensor circuit
- 1 DC motor
- 3 stepper motors

The machine will be plugged into a wall outlet, which will supply 120V of alternating current at 60Hz. The first component of the robot circuitry is a standard wall adapter, which converts the AC to DC, and then provides 12V of DC voltage. This can be used by the motors without needing any additional voltage divisions. The adapter could theoretically be replaced by a soldered circuit consisting of a full bridge rectifier to convert to DC, as in Figure 19, and voltage dividers to supply the desired voltage. However given that it fits within the budget, the difficulties avoided by purchasing the off-the-shelf product make it worth the cost for the design.

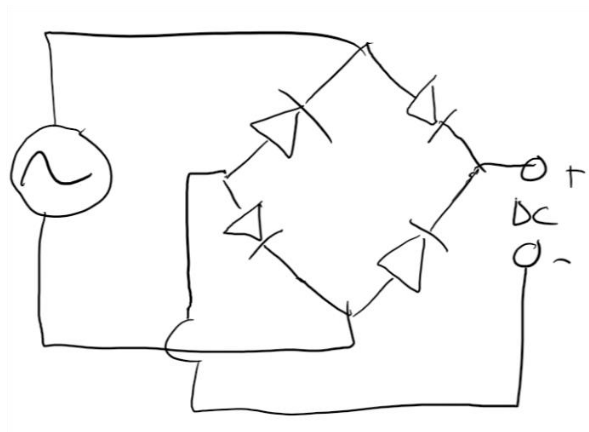

Figure 19: Full Bridge Rectifier

Power

The PIC microcontroller board can take an input of 7.5 - 17.5V [7]. While the voltage range is quite wide, 12V coming supplied by the adapter will be sufficient without any additional regulation or division. Additional current dividers from the initial adapter will be used to power the motors, as well as to send 5V signals to the PIC board.

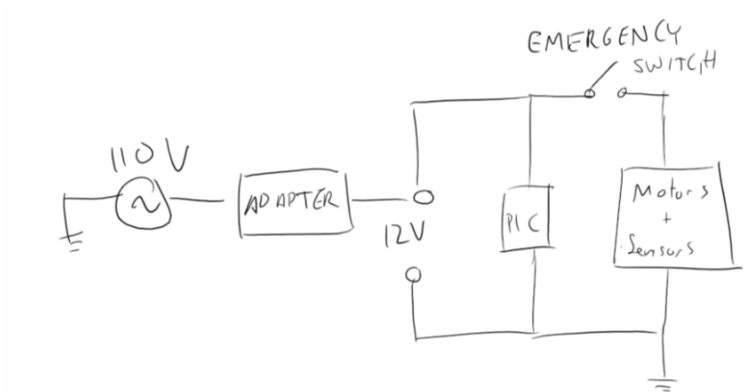

Figure 20: Circuit Diagram Depicting Overall Circuit Structure in the Project

Signals

The PIC board's input and output pins use 5V signals, however these signals are not sufficient to power the motor components as an output. Transistors will be used to amplify the current by connecting two wires to complete a subcircuit when the signal is received. This is because the board's outputs do not supply enough current to power the motors, so the current has to be drawn directly from the wall adapter.

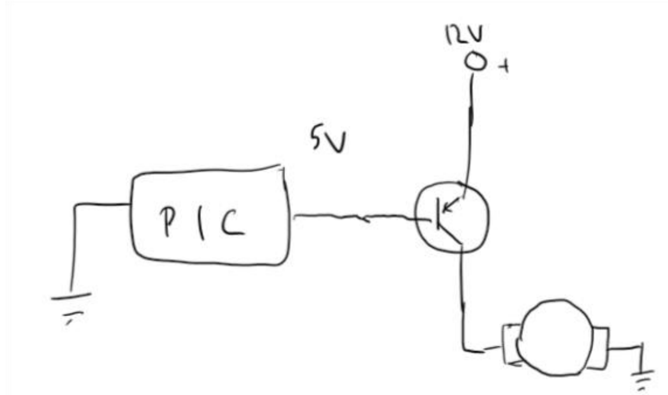

Figure 21: Basic Circuit Diagram for Amplifying Microcontroller Output

When signalling the stepper motor, a driver board will be utilized between the PIC and the motors. This board allows for the stepper to be fed two inputs to determine the angle to which it will move, and it also reduces the pin assignments required on the board to two. The DC motor does not require a driver board, however a full H-bridge will be used to allow for the use of rotation in both directions [Figure 22]. This could be a useful feature for dislodging cans from the drum, if needed.

The board inputs will all be digital 5V signals that can be connected to the PIC pins. Although the voltage provided by the adapter is 12V, L7805 voltage regulators, in addition to current divider branches will ensure that only 5V, 25mA signals are sent to the PIC pins.

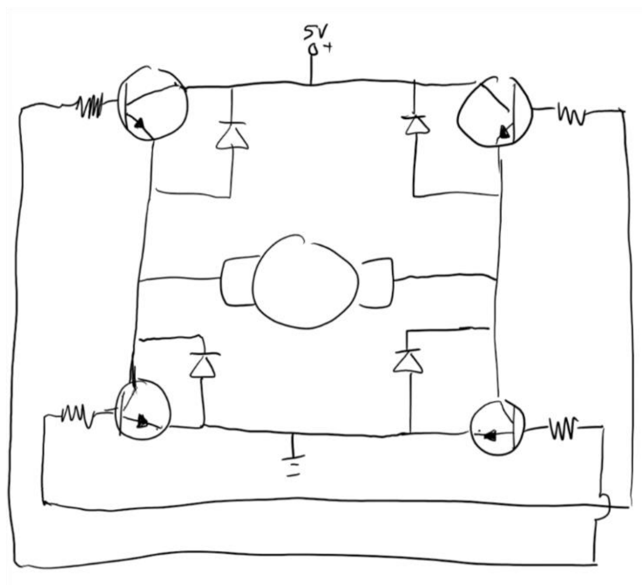

Figure 22: Circuit Diagram for H-Bridge

Break Beam Sensor

The first break beam sensor will be located at the turnstile, at the front of the queue of cans lined up for testing. The sensor will be constructed using a light emitting diode (LED) and a phototransistor, which will control the branch of the subcircuit that sends the signal to the microcontroller. Once the break beam is triggered, the microcontroller can then signal to activate the other subcircuits to test the can. At the testing site, a second break beam sensor will be used to identify the presence of a can.

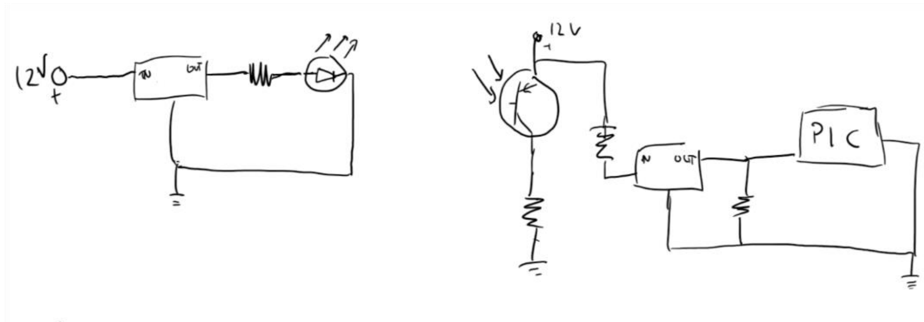

Figure 23: Circuit Diagram for the Break Beam Sensor

Magnetic Microswitch

The first break beam sensor will be located at the turnstile, at the front of the queue of cans lined up for testing. The sensor will be constructed using a light emitting diode (LED) and a phototransistor, which will control the branch of the subcircuit that sends the signal to the microcontroller. Once the break beam is triggered, the microcontroller can then signal to activate the other subcircuits to test the can. At the testing site, a second break beam sensor will be used to identify the presence of a can.

Continuity Test 1:

This continuity test will be used to check for the presence of a label on the tin can. Once the magnetic switch has been activated, this circuit will be completed by a transistor receiving a signal from the PIC board. Since tin is a conductor, a can without a label will act as a wire to complete a circuit. The contact pads, made of aluminum foil or bare wires, of the two sides are attached to the support rails that hold the can in place. This eliminates the need for another moving part to bring the testing "mechanism" into place.

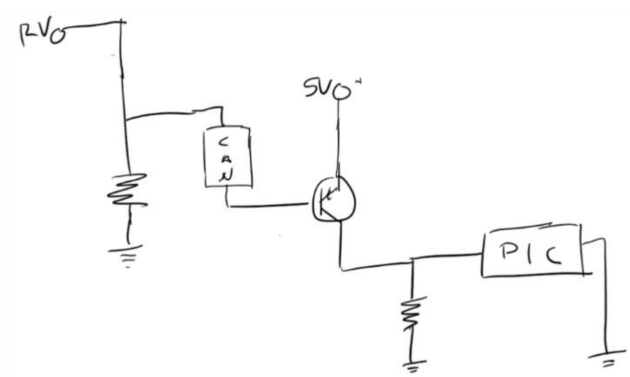

Figure 24: Circuit Diagram for a Continuity Sensor

Continuity Test 2:

Using a similar circuit as the previous continuity test, this one will test for the presence of a pull tab on aluminum cans. If the magnet switch isn't triggered, as in it rests in the normally closed arrangement, the microcontroller will send a signal to move the ring shaped pads in with two solenoids facing in at the ends of the can. If no pull tab is present, the circuit will not complete, and the transistor will not signal the PIC board.

This is a versatile test, as it allows for the detection of lids on the tin cans. This is an additional feature that was not outlined in the RFP, however it demonstrates the potential of the design. By adding a 5th bin, or dividing one of the existing ones, it is possible to activate this feature by making slight modifications to the microcontroller code.

Microcontroller

Description

The microcontroller subsystem enables programmable functionality of the robot and acts as the interface between the robot and its operator. The primary component of the subsystem is the PIC18F4620 microcontroller, a programmable system on chip that controls robotic operation. The PIC18F4620 is an 8-bit RISC-based microcontroller on a 40-pin DIP manufactured by Microchip Technology Inc. It is considered to be among the more high-end microcontrollers offered by Microchip, with significant support for peripheral features, making it suitable for general purpose work.

A sophisticated comparison of potential microcontrollers for this project was not conducted. However, the PIC18F4620 was chosen based on three factors: significant support for peripherals, extensive instruction set, and wealth of technical support. This PIC features up to 36 I/O ports, as well as support for up to 5 PWM outputs and I2C, SPI, and EUSART data interfaces [7]. The RISC-based instruction set features 75 instructions, including 8 instructions for tabling that are not included on lower-end PIC modules. Furthermore, the PIC18F4620 is the microcontroller discussed in Emami's Multidisciplinary Engineering Design. A great deal of sample code and online resources are available for this PIC. For more technical specifications of the PIC18F4620, please refer to the data sheet referenced in the bibliography.

In addition to the PIC18F4620, the microcontroller subsystem is comprised of an auxiliary PIC 18F2550 microcontroller, LCD, keypad, simple configuration board, and AC-DC power adaptor. The simple configuration board, offered by UTIAS, holds each of these components together. It houses the PIC18F4620, connecting it the AC-DC power adaptor and various peripherals. The LCD communicates with PIC via the HD44780 protocol, acting as the primary means of output to the robot operator. The auxiliary PIC functions as an encoder for the keypad, the primary source of operator input. The PIC is also connected to a real-time clock (RTC) for accurate timekeeping [7].

Although not a component of the final design, the PIC18F4620 will be programmed on the UTIAS-offered PIC Dev Bugger board. Due to a host of debugging features and easy peripheral access, the Dev Bugger is a suitable choice for PIC programming, experimentation and preparation. Microchip's MPLAB X software will be used for software development. Though coding in C and compiling to machine code with Microchip's XC8 compiler is possible, this project will be entirely coded in assembly language, and compiled with Microchip's MPASM. This decision was made to minimize the level of abstraction from the PIC, enabling easier debugging. Additionally, more resources are available for assembly language programming than for XC8 functionality, further supporting the decision to use assembly.

Workflow

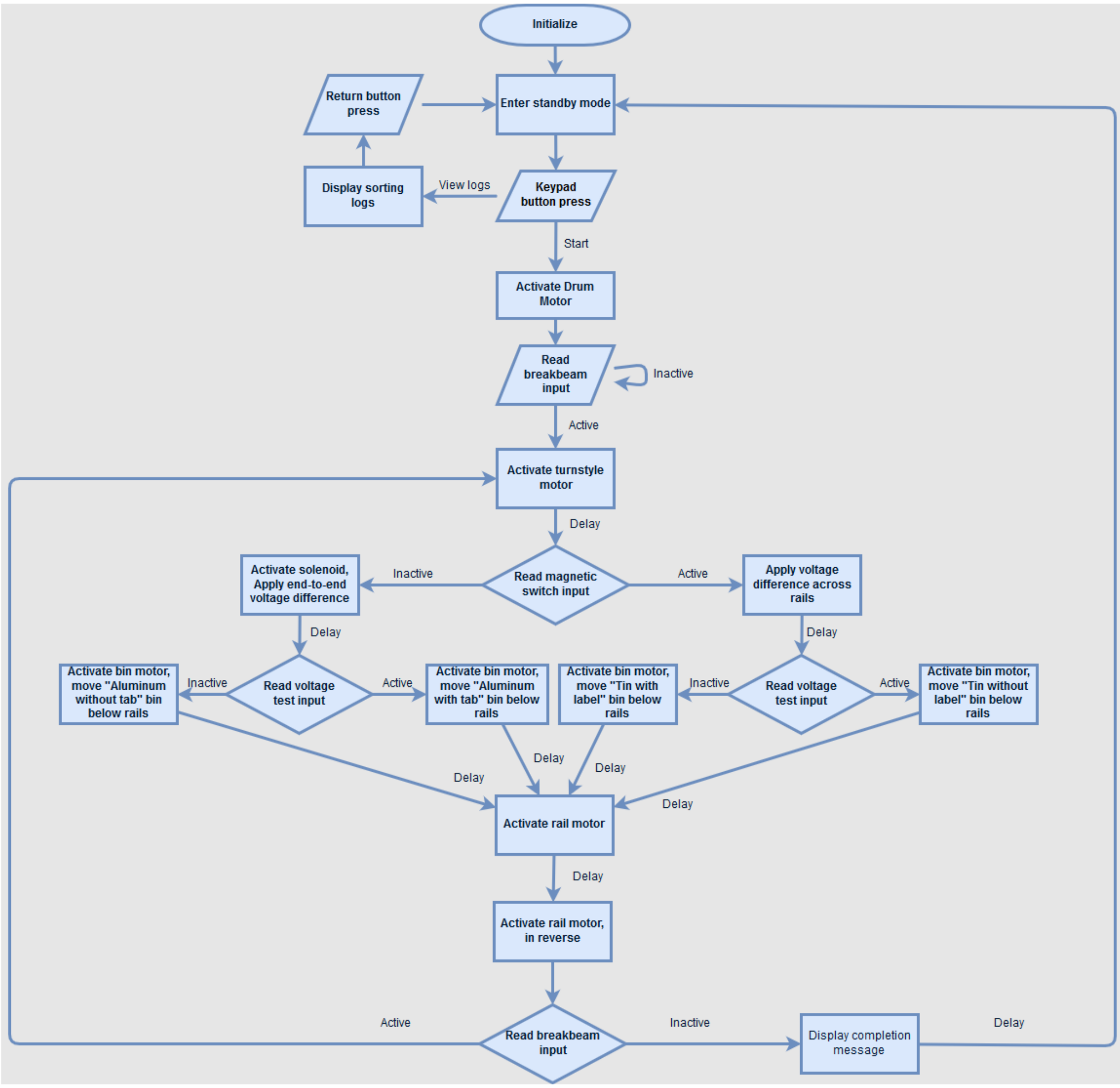

Figure 25: Flowchart Describing Program Operation. Note the similarities between this diagram and the flowchart provided in the design overview.

The overall process, with respect to the microcontroller, is outlined in Figure 25. Minute tweaks and changes to this process are to be expected over the development period. Appropriate delays will be determined during the development period, as required by the physical implementation of the design.

Interface Design

The LCD is capable of displaying two lines of sixteen characters at a time. There will be five possible display states, as detailed in Table 2. Of particular note is the innovative ticker feature used in log viewing mode. The screen content will change dynamically, with the bottom line slowly shifting left to display more information about the log being viewed. In addition, the RTC module will be used to display the current date and time in standby mode.

Table 2: Potential LCD Display States. Delays and keyboard inputs are subject to change.

YY/MM/DD START>A HH:MM:SS LOGS>B	Standby mode. Current date and time are displayed.
IN OPERATION.	Operation message. No user inputs are available at this time, besides the emergency switch.
OPERATION COMPLETE.	Termination message. Displayed for 5 seconds upon completion of a run. No user inputs are available at this time, besides the emergency switch.
NEXTLOG>A BACK>B PREVLOG>C	Log viewing instructions. Displayed for 3 seconds upon "B" press in standby mode.
LOG #1 YY/MM/DD TotalCans:12 Alu	Log viewing mode. The bottom line displays a ticker of information, slowly moving left to reveal more information about the particular log.

The keypad will be the primary method of gathering input from the robotic operator. Keyboard interrupts will be enabled, in order to attain more flexibility in program structure. In addition to the keyboard, an emergency switch will be included in the design. When activated, the emergency switch will cause the PIC to immediately cease all active electromechanical outputs and reset itself using MCLR. The switch is a critical safety feature of the design, and will be rigorously tested to ensure perfect functionality.

Pin Assignments

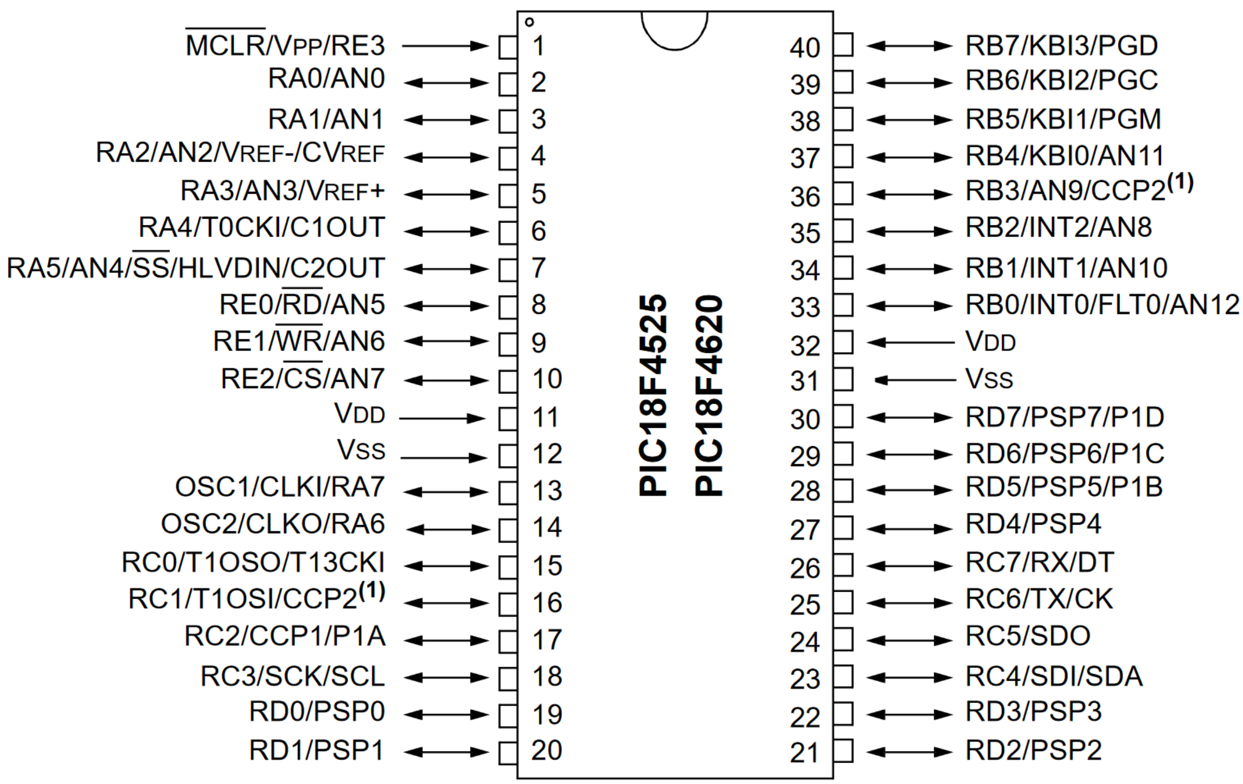

Figure 26: Pin Schematic for the PIC18F4620 Microcontroller. Courtesy of Microchip

Table 3: Proposed Pin Assignments for the Project. Bold entries are free to move to other pins, as their location is not restricted by the simple configuration board

Pin Number	Type	Function	Pin Number	Type	Function
1	Input	MCLR reset	40	Input	Keypad
2	**Output**	**Stepper 1, A**	39	Input	Keypad
3	**Output**	**Stepper 1, B**	38	Input	Keypad
4	**Output**	**Stepper 2, A**	37	Input	Keypad
5	**Output**	**Stepper 2, B**	36	-	-
6	**Output**	**Stepper 3, A**	35	-	-
7	**Output**	**Stepper 3, B**	34	Input	Keypad interrupt
8	**Output**	**Solenoid A**	33	-	-
9	**Output**	**Solenoid B**	32	Power	VDD
10	**Output**	**DC motor**	31	Power	VSS (ground)
11	Power	VDD	30	Output	LCD D7
12	Power	VSS (ground)	29	Output	LCD D6
13	Input	Oscillator 1	28	Output	LCD D5
14	Output	Oscillator 2	27	Output	LCD D4
15	**Input**	**Break beam sensor**	26	-	-
16	**Input**	**Magnetic switch**	25	-	-
17	**Input**	**Electrical sensor 1**	24	-	-
18	Input	RTC	23	Input	RTC
19	**Input**	**Electrical sensor 2**	22	Output	LCD E
20	-	-	21	Output	LCD RS

The proposed mapping of pin assignments is shown in Table 3. This mapping leaves seven pins unused; this is a healthy buffer to have, in case unforeseen difficulties arise and more pins are required.

Long Term Storage

The PIC will store logs for the previous four runs in long term EEPROM memory, available for access by the operator in log viewing mode. Additionally, the PICs EUSART capability will be used to enable PC interfacing, making the logs available for external download. The format for these logs is displayed in Table 4.

Table 4: Log Storage Format in EEPROM Memory. Each line address represents a byte of data. Note that a single log entry requires 16 bytes of EEPROM storage

Address	Value
00	Log Number
01	Total number of cans
02	Number of aluminum cans with tab
03	Number of aluminum cans without tab
04	Number of tin cans with label
05	Number of tin cans without label
06	Year
07	Month
08	Day

09	Start hour
0A	Start minute
0B	Start second
0C	End hour
0D	End minute
0E	End second
0F	Elapsed Seconds

Potential Challenges

Weight will be a concern, as the project is moving forward with portability as an objective. Since the max weight constraint is 5 kg, material functions must be optimized, and a weight balance must be kept under careful scrutiny.

Ensuring that the cans leave the drum at a lengthwise orientation and continue to be in this orientation while rolling down the chute could be an issue as well. Since the system flow and testing procedure depends on this specific orientation, this could potentially be a critical issue if not resolved. The drum and chute are yet to be tested with high fidelity prototypes/final implementations, but if initial drum sorting is producing alternate orientations heavy optimization may be needed.

A recurring occurrence was noticed during testing of various loading and transport mechanisms: aluminum cans frequently slid inside the tin cans. This occurs because of the lack of a lid on one end of the tin cans, as well as the difference in diameter between the two products. In the proposed design, this can only happen within the drum itself, as the queue ramp holds the cans side by side. Potential fixes to this issue were discussed in this report, however higher fidelity prototyping is required to find the correct method to eliminate this issue.

Other foreseeable challenges mostly revolve around the precise contacts for the continuity tests, as these would give false negatives if the contact surfaces aren't precisely oriented.

Schedule

A Gantt chart, seen in Figure 27, was drawn up to plan the project and track its progress. The PERT analysis in figures 28 and 29 is based on this chart, using only the activities that occur after or during the current date (Feb 1). The duration of the critical path is 61.8 days, with a variance of 6.8 days. Interestingly, the critical path consists of just two microcontroller specific activities: software development and iteration and optimization. However, it is worth noting that the worst case estimates yield multiple critical paths, each of 70 days. Hence, it is important for each team member to stay vigilant, and complete their work on time.

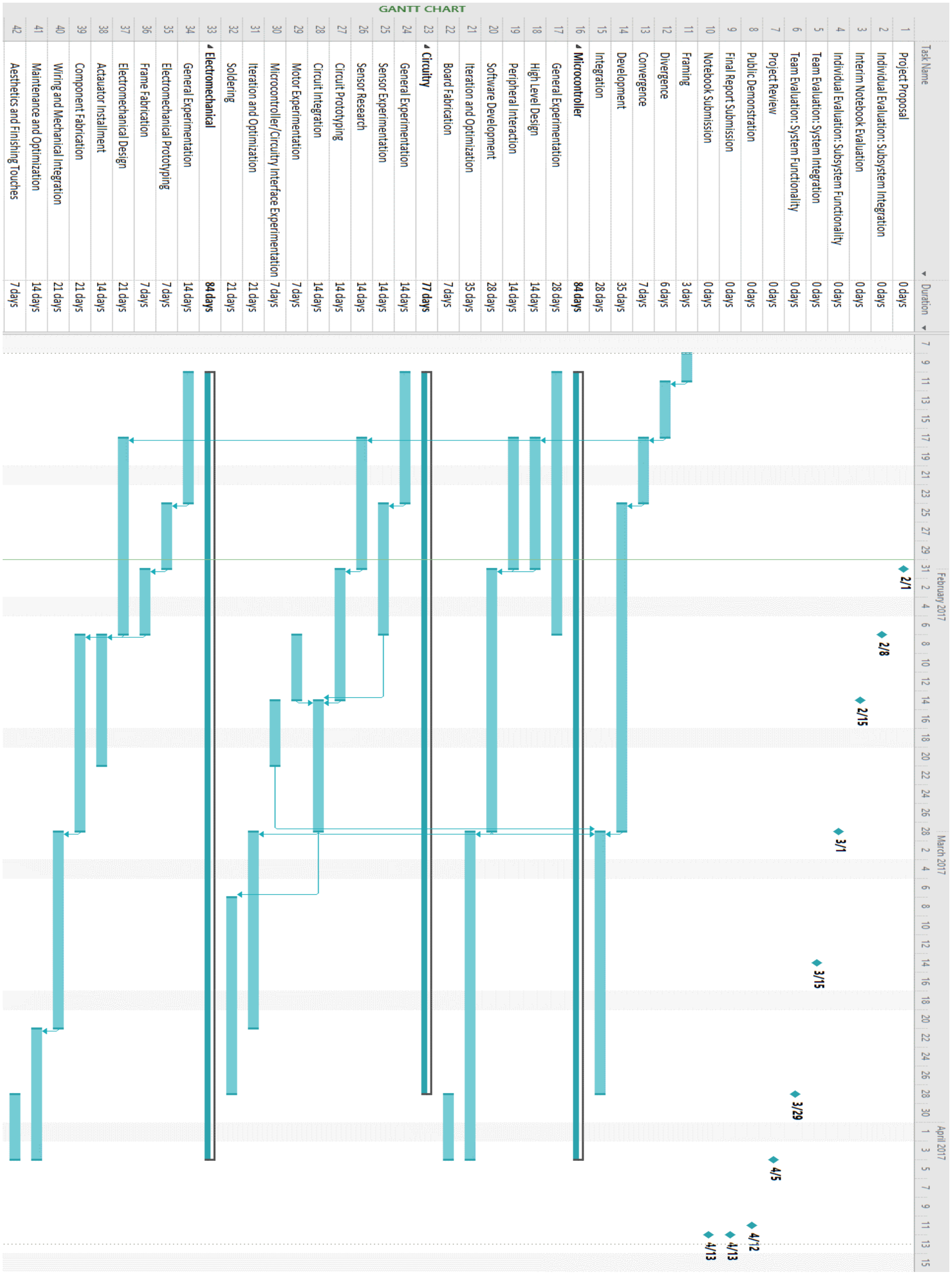

Figure 27: Gantt Chart

Code	Activty	Most likely Estimate	Best case	Worst case Estimate	Preceeded by		Expected Duration	Variance (o2)
A	General Integration	28	21	35	B,I,G,O		28	5.4444444
B	Software Development	28	21	35			28	5.4444444
C	Iteration and Optimization	35	28	35	B		33.8333333	1.3611111
D	Board Fabrication	7	4	7			6.5	0.25
E	Sensor Experimentation	7	4	10			7	1
F	Circuit Prototyping	14	7	21			14	5.4444444
G	Circuit Integration	14	7	21	E,F,H		14	5.4444444
H	Motor Experimentation	7	4	10			7	1
I	Microcontroller/Circuitry Interfac	7	6	8			7	0.1111111
J	Iteration and Optimization	21	18	24	G		21	1
K	Soldering	21	14	28	G		21	5.4444444
L	Frame Fabrication	7	3	10			6.83333333	1.3611111
M	Electromechanical Design	7	4	7			6.5	0.25
N	Actauator Installment	14	7	21	L,M		14	5.4444444
O	Component Fabrication	21	21	28	M		22.1666667	1.3611111
P	Wiring and Mechanical Integratio	21	18	28	O		21.6666667	2.7777778
Q	Maintenance and Optimization	14	11	17	P		14	1
R	Aesthetics and Finishing Touches	7	3	7	A		6.33333333	0.4444444

Figure 28: Estimations and Calculations Required for PERT Analysis

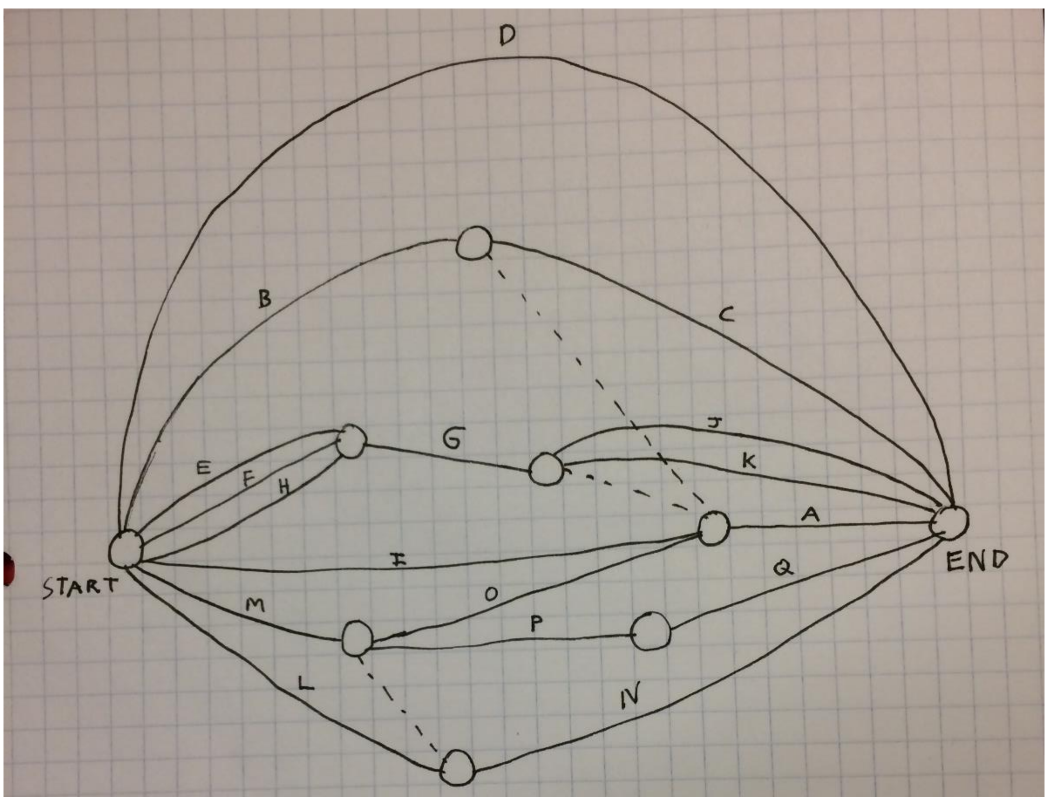

Figure 29: PERT Chart Based on Figure 28

Budget

Table 5: Proposed Project Budget. Miscellaneous circuit component and mechanical component estimates are accounted for. The total proposed budget is $173.61

Product	**Price**
12V, 2A AC/DC Wall Adapter	$14
Stepper Motor Driver x3	$5 (x3)
Simple Configuration Board	$10
LCD+Keypad	$6
Real-time Clock (RTC) Chip and Coin Battery	$5
12V Brushed DC Motor	$17.32
2 5V Solenoids	$6.60 (x2)
2 12V Bipolar Stepper Motors	$4.19 (x2)
12V High Torque Stepper Motor	$20.45
6 ft, 6 and ⅞ inches by 1 inch by 1 inch hollow PVC	$21.95
Misc electrical components	$15
Misc fastener and mechanical components	$15
4' by 4' Spruce Plywood	$12.31
Total	**$173.61**

The proposed budget is $173.61 CDN, considerably short of the $230 CDN budget limit. A simple calculation yields a percentage difference of 24.5%. This is substantially shorter than the 10% industry standard buffer.

Conclusion

In conclusion, the robot proposed will provide a solution to autonomous small-scale can sorting, and the prototype to be constructed will serve as a proof of concept for further implementation. The design will have the benefit of reducing human labour required to sort single stream recycling. The robot will be loaded via a spinning drum and channel them into a single testing area, an unique feature of our design. From there, they will be sorted into easily removable bins by an innovative rotating technique. Finally, all of the relevant information about the process will be readily accessible on a simple LCD interface. The design's strengths are its portability, effectiveness, and accuracy. It's projected cost is $173.61; slightly over three quarters of the maximum budget of $230. The project planning gives adequate time for debugging and the autonomous robot will be completed in no longer than 14 weeks.

The largest bottlenecks for this project are going to be the robot's weight, orientation of the cans during transport, and the possibility of the aluminum can entering the tin can. The weight of the robot could jeopardize

In the future the design could potentially be upgraded in both capabilities and features. One thing that could be done is to scale up the amount of cans the robot could sort at a time, allowing for less units needed and savings in human labour. With a larger design, there would be more room to optimize the process and thus efficiency would improve. One added feature could be the capability to detect whether tin cans have the lid on. Additional features could include the ability to stack cans and remove tabs from aluminium cans.

Appendices

Appendix A - Bibliography

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Appendix B – Analytical Hierarchy Process (AHP)

Sample AHP calculations have been included to offer insight into the convergence process.

Loading – Relative Preference

Efficiency	Drum	Chute	Ramp
Drum	1	1.3	1.5
Chute	0.77	1	1.15
Ramp	0.67	0.87	1

Safety	Drum	Chute	Ramp

Drum	1	0.33	0.33
Chute	3	1	1
Ramp	3	1	1

Portability	Drum	Chute	Ramp
Drum	1	3	4
Chute	0.33	1	1.33
Ramp	0.25	0.75	1

Accuracy	Drum	Chute	Ramp
Drum	1	7	5
Chute	0.14	1	0.71
Ramp	0.2	1.40	1

Normalized Columns

Efficiency	Drum	Chute	Ramp
Drum	0.41	0.41	0.41
Chute	0.32	0.32	0.32
Ramp	0.27	0.27	0.27

Safety	Drum	Chute	Ramp
Drum	0.14	0.14	0.14
Chute	0.43	0.43	0.43
Ramp	0.43	0.43	0.43

Portability	Drum	Chute	Ramp
Drum	0.63	0.63	0.63
Chute	0.21	0.21	0.21
Ramp	0.16	0.16	0.16

Accuracy	Drum	Chute	Ramp
Drum	0.74	0.74	0.74
Chute	0.11	0.11	0.11
Ramp	0.15	0.15	0.15

Relative Importance Matrix

Importance of objective	Efficiency	Safety	Portability	Accuracy
Efficiency	1	3	1	0.5
Safety	0.33	1	0.33	0.17
Portability	1	3	1	0.5
Accuracy	2	6	2	1

Normalized Matrix and Total Importance

Importance of objective	Efficiency	Safety	Portability	Accuracy	Total importance
Efficiency	0.23	0.23	0.23	0.23	0.23
Safety	0.08	0.08	0.08	0.08	0.08
Portability	0.23	0.23	0.23	0.23	0.23
Accuracy	0.46	0.46	0.46	0.46	0.46

Decision Values for each Solution

Drum: 0.23(0.41) + 0.08(0.14) + 0.23(0.63) + 0.46(0.74) = **0.59**

Chute: 0.23(0.32) + 0.08(0.43) + 0.23(0.21) + 0.46(0.11) = **0.21**

Ramp: 0.23(0.27) + 0.08(0.43) + 0.23(0.16) + 0.46(0.15) = **0.20**

The drum is clearly the winner in the AHP process. This strongly influenced the decision to use the drum during the can loading process.

Tab Test – Relative Preference

Efficiency	Conductivity	Force Sensor	Distance Sensing
Conductivity	1	1	1.2
Force Sensor	1	1	1.2
Distance Sensing	0.83	0.83	1

Accuracy	Conductivity	Force Sensor	Distance Sensing
Conductivity	1	2	3
Force Sensor	0.5	1	1.5
Distance Sensing	0.33	0.67	1

Normalized Tables

Efficiency	Conductivity	Force Sensor	Distance Sensing
Conductivity	0.35	0.35	0.35
Force Sensor	0.35	0.35	0.35
Distance Sensing	0.30	0.30	0.30

Accuracy	Conductivity	Force Sensor	Distance Sensing
Conductivity	0.55	0.55	0.55
Force Sensor	0.27	0.27	0.27
Distance Sensing	0.18	0.18	0.18

Relative Importance Matrix

Importance	Efficiency	Accuracy
Efficiency	1	0.5
Accuracy	2	1

Normalized Matrix and Total Importance

Importance	Efficiency	Accuracy	Total Importance
Efficiency	0.33	0.33	0.33
Accuracy	0.66	0.66	0.66

Decision Values for each Solution

Conductivity: 0.33(0.35) + 0.66(0.55) = **0.47**

Force Sensor: 0.33(0.35) + 0.66(0.27) = **0.29**

Distance Sensor: 0.33(0.30) + 0.66(0.18) = **0.22**

The conductivity test fares best in the AHP process. This supports the decision to use a conductivity test for the tabs. It also shows that the AHP works in a very intuitive case with a clear winner.

Sorting System – Relative Preference

Efficiency	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	1	0.5	1
Ramp with Trapdoors	2	1	2
Rotating Ramp	1	0.5	1

Cost	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	1	1.5	1.2
Ramp with Trapdoors	0.67	1	0.8

Rotating Ramp	0.83	1,25	1

Portability	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	1	2	1
Ramp with Trapdoors	0.5	1	0.5
Rotating Ramp	1	2	1

Normalized Tables

Efficiency	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	0.35	0.35	0.35
Ramp with Trapdoors	0.35	0.35	0.35
Rotating Ramp	0.30	0.30	0.30

Cost	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	0.55	0.55	0.55
Ramp with Trapdoors	0.27	0.27	0.27
Rotating Ramp	0.18	0.18	0.18

Portability	Rotating Bins	Ramp with Trapdoors	Rotating Ramp
Rotating Bins	0.4	0.4	0.4
Ramp with Trapdoors	0.2	0.2	0.2
Rotating Ramp	0.4	0.4	0.4

Relative Importance Matrix

Importance of objective	Efficiency	Cost	Portability
Efficiency	1	1.2	0.8

Cost	0.83	1	0.67
Portability	1.25	1.49	1

Normalized Matrix and Total Importance

Importance of objective	Efficiency	Cost	Portability
Efficiency	0.32	0.32	0.32
Cost	0.27	0.27	0.27
Portability	0.40	0.40	0.40

Decision Values for each Solution

Rotating Bins: 0.32(0.25) + 0.27(0.4) + 0.40(0.4) = **0.35**

Ramp with Trapdoors: 0.32(0.5) + 0.27(0.27) + 0.40(0.2) = **0.31**

Rotating Ramp: 0.32(0.25) + 0.27(0.33) + 0.40(0.4) = **0.33**

The rotating bins have the highest value in this case, and thus should be adopted for the design.

Sample Utility Function Calculation

Objective	Parameter	Scale	Unit
Inexpensive	Material costs	Ratio	CAD
Small	Volume of design	Ratio	m^3
Flexible design space	Rigid design space, options for direction, location, orientation	Ordinal	rank
Controlled	Number of controlled motions	Interval	number
Fast	Time taken to orient cans	Ratio	seconds

Table : Objectives and their details for the design of the top loading and orienting mechanism. These objectives were used in the utility calculation below.

		A		B		C		
Objective	Weight	Estimated value	Utility value	Estimated value	Utility value	Estimated value	Utility Value	Utility function
Cost	1	20	0.000335350 13	25	0.000002260 32	10	0.88079707797	1/(1+e^(x-12))
Volume	2	0.025	0.498750002 6	0.015	0.501249997 39	0.03	0.49750002083	1/(1+e^(x-0.02))
Rigidity of space use	3	1	0.731058578 63	4	0.119202922 02	3	0.26894142137	1/(1+e^(x-2))
Controlled motions	1	2	0.622459331 2	3	0.817574476 19	0	0.1824255238	1/(1+e^-(x-1.5))
Time	1	15	0.999664649 87	30	0.000911051 19	20	0.95257412682	1/(1+e^(x-23))
Totals			4.81309		1.85675		3.8176	
Normalized Total			0.459		0.177		0.364	

Table : Example utility calculations for the selection of the top loading and orienting mechanism. Solutions A, B, and C are the drum, funnel, and ramp respectively. The utility function utilized was 1/(1+e^(x-a)), where a can be any real number and is decided based on the range of expected values. Based on these properties, estimations, and functions, the drum seems to be the most optimal solution.

Appendix C – Resumes and Datasheet