510 INNOVATIONS

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March 11, 2010

Andrew Rawicz
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**RE: ENSC 440 Design Specifications for the Enhanced Recycling Bin System**

Dear Dr. Rawicz,

Enclosed in this document is the design specification for our ENSC 440/305 Project. Our objective is to design a “Green Bin” System that automatically detects and separates recyclables that are disposed in to the bin.

This document outlines the high level system design for the Green Bin System. The design specifications for all hardware and software components, as well as packaging and user interface will be featured. The design specifications explained in this document will be used by the members of 510 Innovations to direct design, development and testing efforts. And if necessary, further design optimization will be implemented before the final product is completed.

510 Innovations is comprised of five innovative and dedicated engineers – Scott Hsieh, Michael Kume, Fritz Lapastora, Jeremy Lau and David Leung. If you have any questions or concerns regarding the attached document, please feel free to contact David at 604-767-6108 or DBL1@sfu.ca.

Sincerely,

David Leung

David Leung
Chief Executive Officer
510 Innovations

Enclosure: Design Specification for the Enhanced Recycling Bin System

# 510 INNOVATIONS

SEE green . THINK green . DO green .

March 11, 2010
Revision 1.9

## Project Team:

CEO – David Leung
CME – Jeremy Lau
CEE – Scott Hsieh
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Design Specifications for an Enhanced Recycling Bin System

## Submitted to:

ENSC 440 – Dr. Andrew Rawicz
ENSC 305 – Steve Whitmore
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ENSC 440/305

## Executive Summary


510 Innovations is looking to provide the world with real solutions on environmental issues. Through innovation and new technologies, our engineers are constantly thinking of ways to achieve a more sustainable lifestyle.

The number of landfills is increasing and although awareness on a greener perspective is spreading, recyclables are still making their way into these landfills. 510 Innovations is proposing the Green Bin, a system that will ensure a significant decrease of recyclables diverted into landfills. We strongly believe the technology and the know-how to accomplish this exists today; there is a growing potential with RFID technology which will be paramount in the development of the Green Bin.

The development of the Green Bin will be designed under two models; the conceptual model and the production model.

The conceptual model will meet minimum requirements and only achieve the essential functions of the system. The conceptual model is not intended for public testing. For the purpose of ENSC 440, it is important that this model be completed by April 2010. The full development of the conceptual model will fall well within the proposed schedule and the devoted funding towards the project. Some functions to be developed under this model include:

- **sensing and sorting**
- **power and self-sustaining options**
- **user interface**

The production model will meet designed requirements and achieve all functions of the system. The production model is intended for public use. The full development of the production model will be followed according proposed schedule and devoted funding. Further functions to be developed under this model include:

- **cell compartments**
- **designed exterior casing**
- **display options**
- **safety requirements and standards**

Further details into the model requirements, their respective functions, the system test plan, and proposed concept designs can be reviewed within the rest of the documentation. Decisions on the design specification of the Green Bin System were made in accordance to the system requirements that were outlined in the Functional Specification document.

## Table of Contents

## Table of Contents

## List of Figures

## List of Tables

## Glossary

| | |
|---|---|
| **Bin** | Refers to the 'Green Bin' product. |
| **BFO** | Beat Frequency Oscillator – used for metal detection. |
| **Cell** | The storage compartment for the recyclables and garbage. |
| **Chamber** | The section of the Green Bin that houses the identification sensors and sorting mechanism. |
| **Garbage** | Objects that may be found within a garbage can that are not recyclable. An object that is not a glass container, plastic container, or aluminum container. This includes garbage that is misplaced in recycling bins. |
| **LiPO** | Lithium Polymer |
| **NiCd** | Nickel Cadmium |
| **NiMH** | Nickel-Metal Hydride |
| **Object** | Refers to any expected recyclable or common garbage placed in the bin. |
| **Orifice** | Refers to the mouth of the bin where object will be placed. |
| **Refuse** | Mixture of recyclables and garbage; any inputs of the Green Bin. |
| **Scanning Chamber** | The upper portion of the system. It houses both the test chamber and sorting mechanisms. |
| **SLA** | Sealed Lead Acid |
| **Test Chamber** | The housing which encapsulates all four chosen sensor types. |
| **Typical User** | People with a minimum height of 80 centimetres, aged 4 and above. |

# 1. Introduction

In a world where social and environmental needs are a climbing interest in the public eye, the merits of recycling are ever increasing. While recycling bins are widespread, the typical user is simply not motivated to make use of them; bottles and cans are often lost in the trash. Likewise, the contents of recycling bins remain unsorted, and contaminated with the inclusion of non-recyclables.

510 Innovations is currently developing an enhanced recycling bin system, the Green Bin. The proposed design will automatically sort and separate recyclable bottles/cans composed of glass, plastic and aluminum from everyday garbage. It will be designed for use by the typical consumer within office buildings, malls, and other high traffic locations.

Not only will it be an effective replacement for recycle bins, but it is expected to sufficiently capture its target audience: consumers who do not recycle. Motivating users to recycle and become more interested in sustainable technologies, the Green Bin will be an essential component of any society implementing initiatives to become more environmentally-friendly.

The design specifications act as technical descriptions of the various components and inner workings of the Green Bin.

***1.1 Scope*.** The design specifications build upon the ***Functional Specifications for an Enhanced Recycling Bin System*** [1], detailing the design of a proof-of-concept model for the Green Bin. Focus will be placed on the functions and features pertaining specifically to the concept model and requirements essential to both concept and production models. Respectively, only the functional specifications labelled as **[R#, C]** or **[R#, B]** will be implemented into the system. Each component will be characterized by its functionality and how they accomplish the established requirements. This document will also include circuit diagrams, flow charts and SolidWorks designs for significant elements.

***1.2 Intended Audience*.** The design specifications are written for the members of 510 Innovations. They will serve as the guidelines that will be followed during the construction and programming of the Green Bin. It will also continue to act as a reference for crucial components and features during development of the production model. Likewise, a system test plan has been included. It will provide the necessary procedures to ensure that the features of the concept model function properly and optimally.

## 2. System Specifications

In order to accomplish its goals, the Green Bin essentially performs two independent functions:

**Operations**

1. Identify the inserted refuse
2. Sort the refuse into the correct cell

The sorting function simply relies on the use of servo motors which manipulate a chute, directing the refuse into the corresponding cell. The identification process is more difficult. In part, this is due to the various orientations and conditions which the recyclable containers may have when inserted into the Green Bin. Possible orientations and conditions:

**Orientations**

- Right-side up
- Upside down
- Sideways (only applicable to small containers)

**Conditions**

- Emptied out
- Containing liquid
- Stained labels
- Removed labels
- Crushed (only applicable to metal cans)

Aside from these variables, the refuse themselves present varying characteristics that can be used to differentiate them. A variety of sensors will be employed to measure and detect these characteristics. Such sensors must be able to provide definitive results as to the composition under all aforementioned circumstances.

***2.1 Test Cases*.** The sensors must be configured correctly to perform under realistic scenarios. In order to do this, various recyclables were gathered and characterized to determine the defining qualities of each grouping. Recyclables with peculiar shapes and sizes were obtained to account for uncommon cases. Their physical properties also provide constraints and requirements which shape the overall construction of the testing chamber. On the following pages, four groups are analyzed:

1. Glass bottles
2. Aluminum Cans
3. Plastic Bottles
4. Garbage

## 2. System Specifications

### *2.1.1 Glass Bottles*. Glass bottle characteristics:

**Labelling** – Typically branded with paper or plastic labels
**Metal** – Does not disrupt magnetic fields
**Pressure** – Cannot be easily deformed by low applications of pressure

The glass bottles analyzed and used in our testing are characterized in table 2.1 and figures 2.1 and 2.2:

| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|  | **Mike's Hard Lemonade** | 355 | 20.4 | 6.2 | Neck extrusion | No |
|  | **Dole Apple Juice** | 240 | 14.6 | 6.4 | Neck extrusion | No |
| Average | | **297.5** | **17.5** | **6.3** | | |

Table 2.1 – Characteristics of glass bottle test cases.

## 2. System Specifications

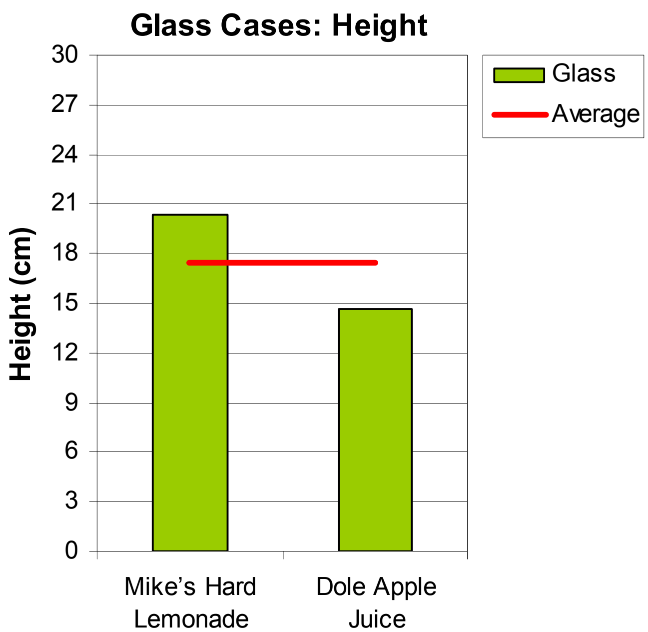



Figure 2.1 – Heights of Glass Bottles.

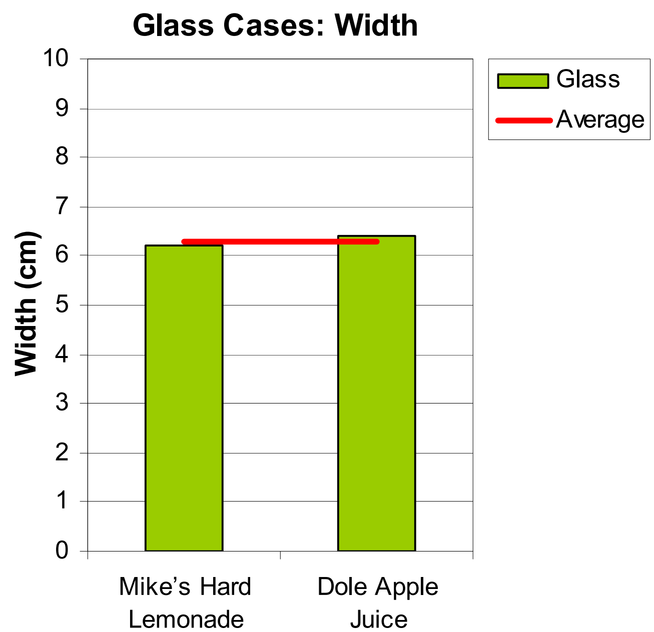



Figure 2.2 – Widths of Glass Bottles.

It is impractical for a glass bottle to carry less than 200mL, and will weigh too much if made too tall. Thus, as shown above:

**Height/Width** – Glass bottles typically reside within a certain height range

## 2. System Specifications

***2.1.2 Aluminum Cans***. Aluminum can characteristics:

**Labelling** – Printed labels and imprinted designs
**Metal** – Disrupts magnetic fields
**Pressure** – Can be easily deformed by low applications of pressure, but does not return to its original shape

The aluminum cans analyzed and used in our testing are characterized in table 2.2 and figures 2.3 and 2.4:

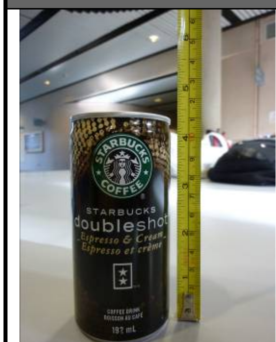
| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|   | **Starbucks Doubleshot** | 192 | 11.0 | 5.3 | N/A | No |
|   | **Pepsi Mini** | 237 | 8.7 | 6.6 | Diameter ≈ Height | Yes |
|   | **Arizona Ice Tea** | 695 | 19.4 | 7.2 | N/A | No |

Table 2.2 – Characteristics of aluminum can test cases.

## 2. System Specifications

| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|  | **Sprite** | 355 | 12.3 | 6.5 | N/A | No |
| **Average** | | **369.8** | **12.9** | **6.4** | | |

Table 2.2 – Characteristics of aluminum can test cases. (continued)

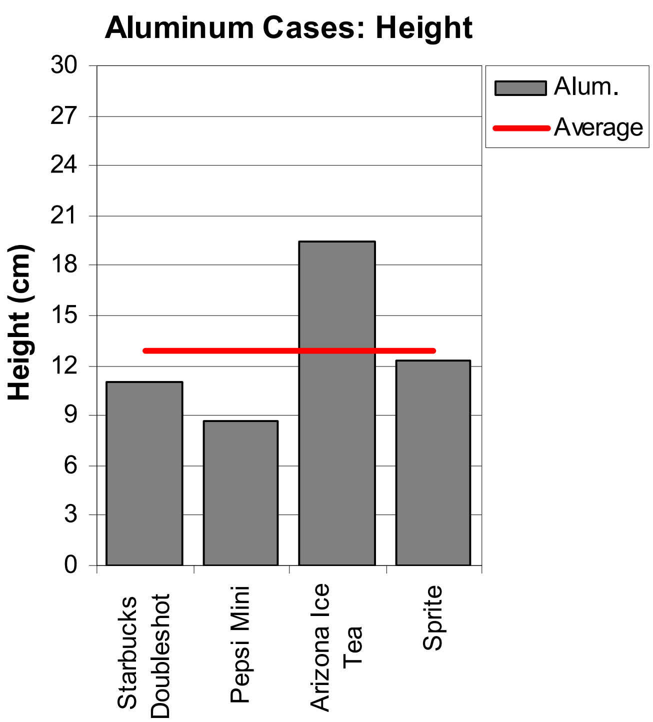



Figure 2.3 – Heights of Aluminum Cans.

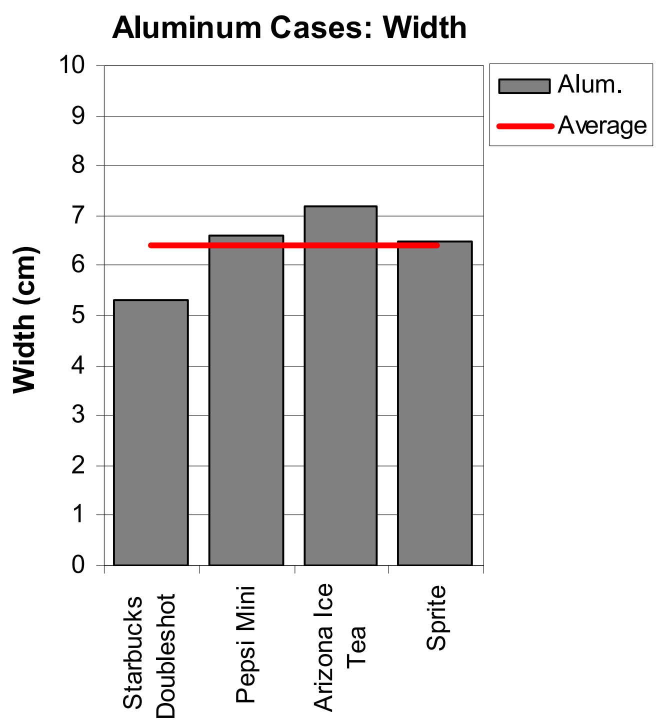



Figure 2.4 – Widths of Aluminum Cans.

Due to the thin walls of aluminum cans, they can carry more liquid while remaining small in shape. As shown, there are 2 size ranges:

**Height/Width** – Aluminum cans are potentially the smallest, with a distinct alternative larger-scale model.

## 2. System Specifications

***2.1.3 Plastic Bottles*.** Plastic bottle characteristics:

**Labelling** – Typically branded with paper or plastic labels
**Metal** – Does not disrupt magnetic fields
**Pressure** – Can be easily deformed by low applications of pressure, and returns to its original shape

The glass bottles analyzed and used in our testing are characterized in table 2.3 and figure 2.5 and 2.6:

| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|  | **Evian Le Petits** | 330 | 16.0 | 6.4 | N/A | No |
|  | **Dasani** | 591 | 22.4 | 7.4 | Curved Neck | No |
|  | **Voss** | 500 | 21.5 | 6.1 | N/A | No |

Table 2.3 – Characteristics of plastic bottle test cases.

## 2. System Specifications

| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|  | **Bolthouse Farms** | 450 | 18.0 | 6.1 | Round to square extrusion | No |
|  | **Milk 2 Go** | 500 | 20.3 | 6.5 | Curvy extrusion | No |
|  | **Gatorade** | 950 | 20.5 | 9.3 | N/A | No |
|  | **Powerade** | 710 | 26.4 | 7.8 | Lid height notably tall | No |
| Average | | **628.9** | **21.1** | **7.2** | | |

Table 2.3 – Characteristics of plastic bottles test cases. (continued)

## 2. System Specifications

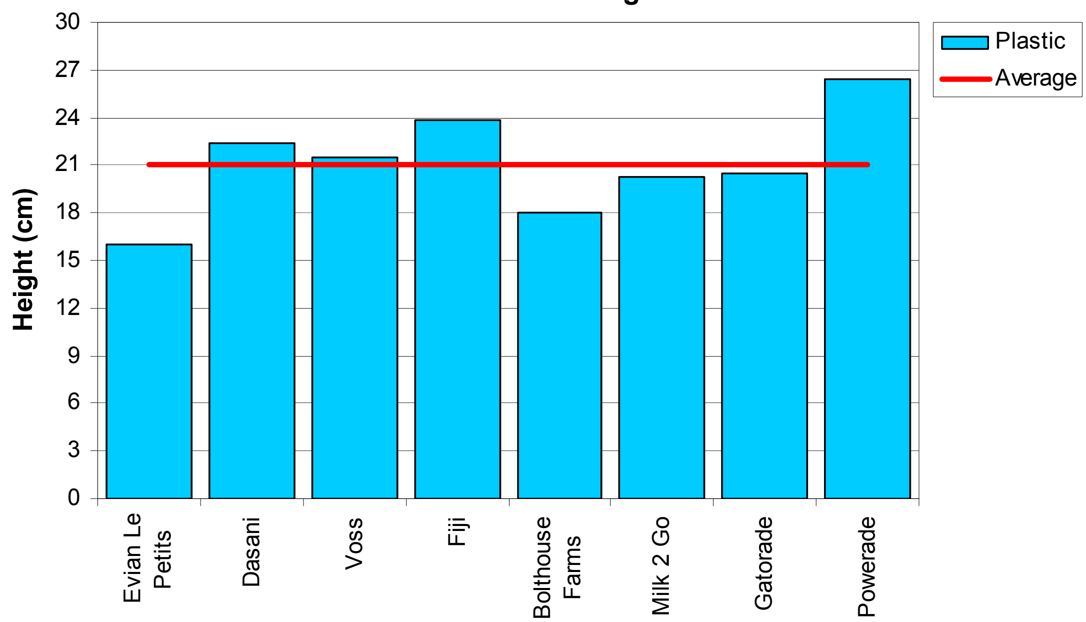



Figure 2.5 – Heights of Plastic Bottles.

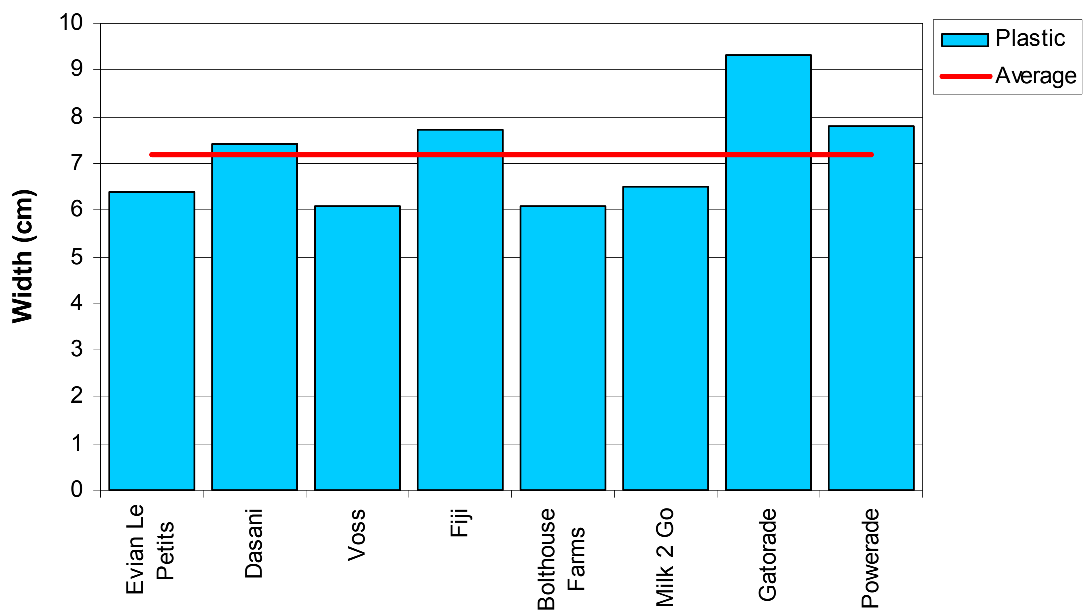



Figure 2.6 – Widths of Plastic Bottles.

Plastic bottles can withstand being dropped, tend to retain their original shape and often have reusable lids. As such, they can be made in a variety of sizes:

**Height/Width** – The average height and width of various plastic bottles are larger than other recyclable container groupings.

## 2. System Specifications

***2.1.4 Garbage*.** Garbage characteristics:

**Labelling** – Unspecified, unlikely to contain a label
**Metal** – Unspecified, unlikely to disrupt magnetic fields
**Pressure** – Unspecified, likely to be deformed under low applications of pressure
**Height/Width** – Unspecified, can be smaller or larger than recyclables

The arbitrary sample to represent garbage is a typical paper coffee cup. This was chosen, because we noticed that it is the most common non-recyclable found in recycle bins. The coffee cup analyzed and used in our testing is characterized in table 2.4 below:

| Sample | Description | Capacity (mL) | Dimensions (cm) | | Notable Features | Invertible |
|---|---|---|---|---|---|---|
| | | | Height | Width | | |
|  | **Ecotainer coffee cup** | 473 | 15.0 | 9.2 | Not recyclable | No |

Table 2.4– Characteristics of garbage test cases.

***2.1.5 Height and Width Comparisons*.** The average height of plastic bottles is taller than other recyclables, while aluminum cans are much shorter. There is no particular distinction in width across recyclables, but there are a few outliers. Nothing is shorter than **7cm** or thinner than **5cm**. The combined tables are presented in appendix figures A.1 and A.2.

# 2. System Specifications

***2.2 Sensor Selection.*** The sensors used in the identification process are chosen based on the characteristics of each grouping, and is aimed to provide optimal results given unknown conditions of the refuse. Table 2.5 presents the considerations made for each sensor (highlighted sensors are used in our project).

| Group | Sensor | Advantages | Disadvantages | Justification |
|---|---|---|---|---|
| Direct Identification | RFID Receiver | • Does not require direct contact/visual | • Refuse must retain label or anodized RFID tag<br>• RFID tags do not currently exist on all products | • Sufficient evidence that products will adopt RFID technology [2]<br>• Not used by any recycle bin on the market |
| Direct Identification | Barcode Scanner | • Barcodes exist on all products | • Refuse must retain label<br>• Label must be directly visible and unmarked<br>• Slower detection relative to RFID | • Refuse must be correctly orientated<br>• Already employed by several recycle bins [3] |
| Metal | Beat Frequency Oscillator (BFO) | • Does not require direct contact<br>• Sensitive to all metal types | • N/A | • Not impeded by plastic casing, easily affixed around test chamber |
| Metal | Conductance | N/A | • Requires direct contact | • Requires mechanical application of contacts<br>• Non-conductive paint on aluminum cans |
| Height & Width | Laser Grid | • Simple sweeping algorithm<br>• Easily scalable | • Rectangular outlines | • Inexpensive<br>• Simple, low power solution |
| Height & Width | Image Processing | • Accurate, precise outlines of the refuse | • Complex detection method requiring complicated algorithms<br>• More processing power is required | • Equipment required is too expensive<br>• Can be easily done by alternative methods |
| Glass vs Plastic | Pressure (Tactile Rod) | • Intuitive | • Requires mechanical implementation<br>• Requires custom construction<br>• Draws more power to apply sufficient pressure | • No feasible alternatives available<br>• Most component are readily available at lower cost |
| Glass vs Plastic | Ultrasound | • Does not require direct contact | • Conditions of refuse are large factors | • Unreliable<br>• Equipment is expensive |
| Glass vs Plastic | Piezoelectric Scale | N/A | • Requires heavy objects to enter useful range | • Recyclables may contain liquid, altering expected weight |
| Glass vs Plastic | Light Spectrum Analysis | • Accurate analysis of materials | • Impeded by labels and liquids | • Unreliable<br>• Equipment is expensive |

Table 2.5 – Sensor selection for identification process.

# 3. Overall System Design

The System Specifications clearly provide parameters which the Green Bin must meet, as well as the basis to form a testbed. The Overall System Design will present an abstract discussion of how the identification and sorting processes are performed, without technical explanations of how each sensor functions. This section will also describe the physical design of the Green Bin itself and the interface which the user will interact with. Technical details will be provided in the Scanning Chamber Unit section.

***3.1 System Operations*.** The various components that will combine to perform the operations of the Green Bin are presented in figure 3.1:

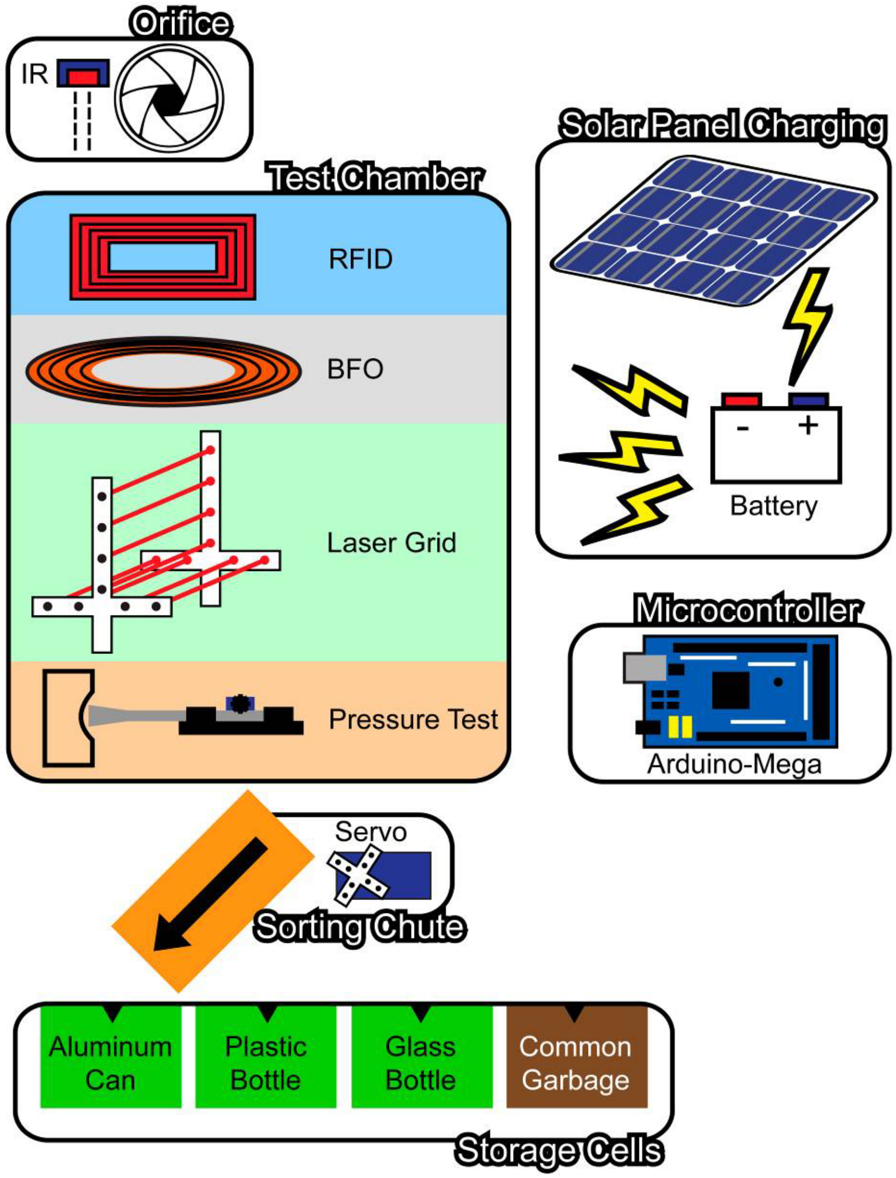



Figure 3.1 – Green Bin components.

# 3. Overall System Design

***3.1.1 Components Characterization.*** The individual functions of each component are briefly characterized in table 3.1:

| Component | Function |
|---|---|
| **Orifice** | The user interface, which opens when refuse is placed near it. It also protects the Test Chamber and prevents the refuse/sensors from being tampered with during the scanning process. |
| **Test Chamber** | Determines the composition of the refuse:<br>1. **RFID Test** – provides direct identification by detecting the RFID tag and referencing a database of stored refuse data.<br>2. **BFO** – detects whether the refuse is composed of metal.<br>3. **Laser Grid** – determines the height and width of the refuse.<br>4. **Pressure Test** – determines the stiffness of the refuse. (chief sensor to differentiate glass and plastic) |
| **Sorting Chute** | Directs the identified refuse into 1 of 4 storage cells. |
| **Microcontroller** | Controls the various electronic systems |
| **Storage Cells** | Stores the recyclables and garbage |
| **Solar Panel Charging** | The power source of the system |

Table 3.1 – Green Bin components.

***3.1.2 Flow of Operations.*** The tests are performed in the following order.

1. RFID Test
2. BFO
3. Laser Grid
4. Pressure Test

***Accuracy.*** The pressure test occurs last in order to ensure that the refuse is not deformed before the height and width test. The remaining 3 sensors are ordered by accuracy. The RFID test is the most precise as it reads the RFID tag attached to the refuse and matches it with the correct recyclable stored within the microcontroller's database. Secondly, the BFO can readily determine the presence of metal, thus differentiating aluminum cans from plastic and glass bottles. The pressure test is used to differentiate glass bottles from plastic bottles and aluminum cans. However, as the pressure test is mechanical, it is susceptible to variances in the orientation of the refuse. The laser grid is the least reliable, because there are profiles that match all categories. It simply identifies objects that are outside of the expected height and width range of recyclables.

## 3. Overall System Design

There are two possible flow charts that the software may follow.

***Garbage Bin Flow Chart***. The first flow chart determines the composition by strictly relying on the information provided by the RFID. The RFID provides the system with the expected parameters of the refuse and the subsequent sensors verifies them. The object is discarded as trash if any of the tests fail. This will simulate a garbage bin, because it can accept all types of refuse, including those that may mimic a recyclable object's shape, metallic presence, and rigidity. While this will reject a few recyclables, it is capable of filtering out all the non-recyclables without exception. Thus, this will act as an adequate replacement for both garbage bins and recycling bins. The flow chart is presented in figure 3.2.

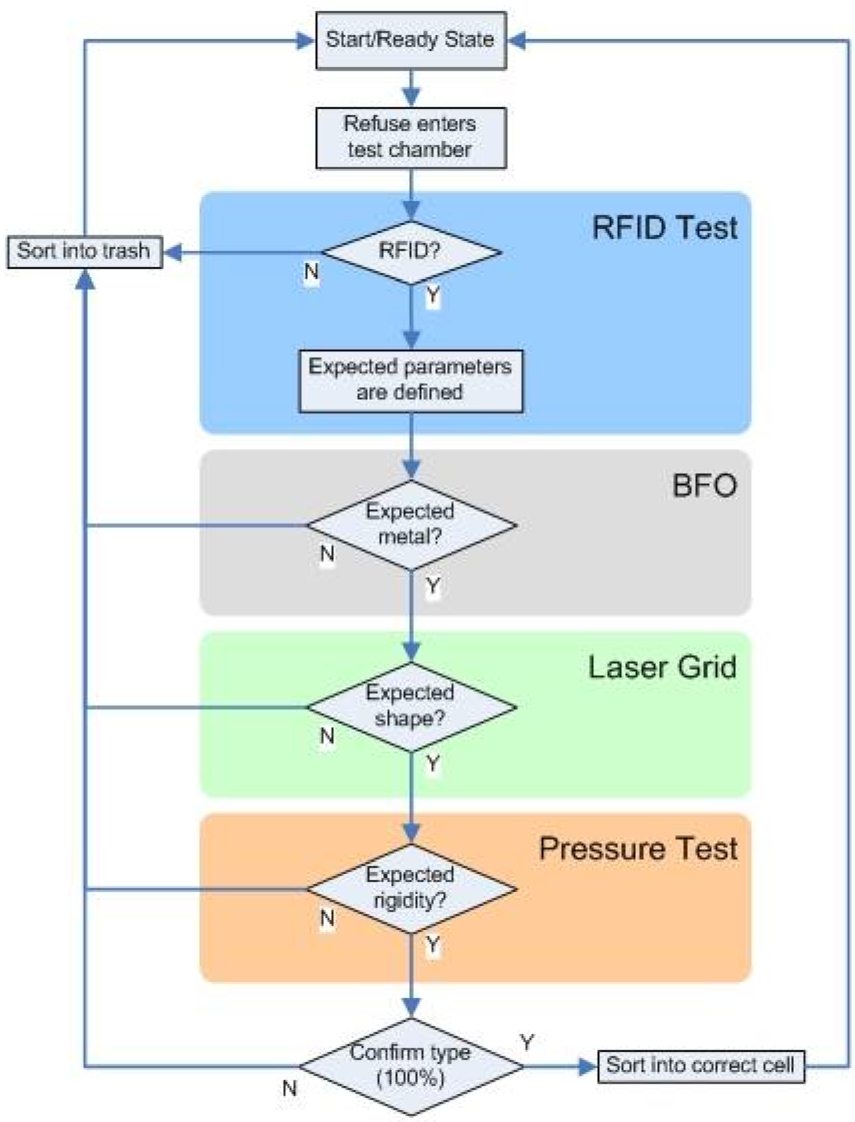



Figure 3.2 – Garbage bin flow chart.

## 3. Overall System Design

***Recycling Bin Flow Chart***. The second flow chart determines the composition by utilizing all 4 tests. A point system, out of 100, is utilized. Each sensor speculates what the object may be, and adds points to the corresponding category. The microcontroller combines the results and performs an action based on the yielded majority (60% or more). Relating to the discussion on accuracy, each test provides the following amount of points:

1. 40% – RFID Test
2. 30% – BFO
3. 10% – Laser Grid
4. 20% – Pressure Test

After each test, the system checks to see if any of the 3 recyclables' categories have acquired or exceeded 60%. This allows 3 distinct possibilities:

- If an RFID tag is not present, the 3 subsequent tests can still determine the composition of the refuse, but only if they all agree.
- If the RFID test identifies the object but the other 3 tests disagree, the other 3 tests total 60% and take priority.
- If an aluminum can is crushed, but the RFID tag remains intact, it will be identified by the RFID test and will also test positive for metal by the BFO. After the second test, it will accumulate 70% and be sorted into the aluminum can bin.

This flow of operations will simulate a recycling bin as it will accept all recyclables. However there may be garbage that perfectly mimics a recyclable object's shape, conductivity and rigidity. This flow of operations cannot properly filter those objects out. Therefore, it will only act as an adequate replacement for recycling bins, but will not be sufficient enough to replace garbage cans.

The flow chart is presented in figure 3.3 on the following page.

# 3. Overall System Design

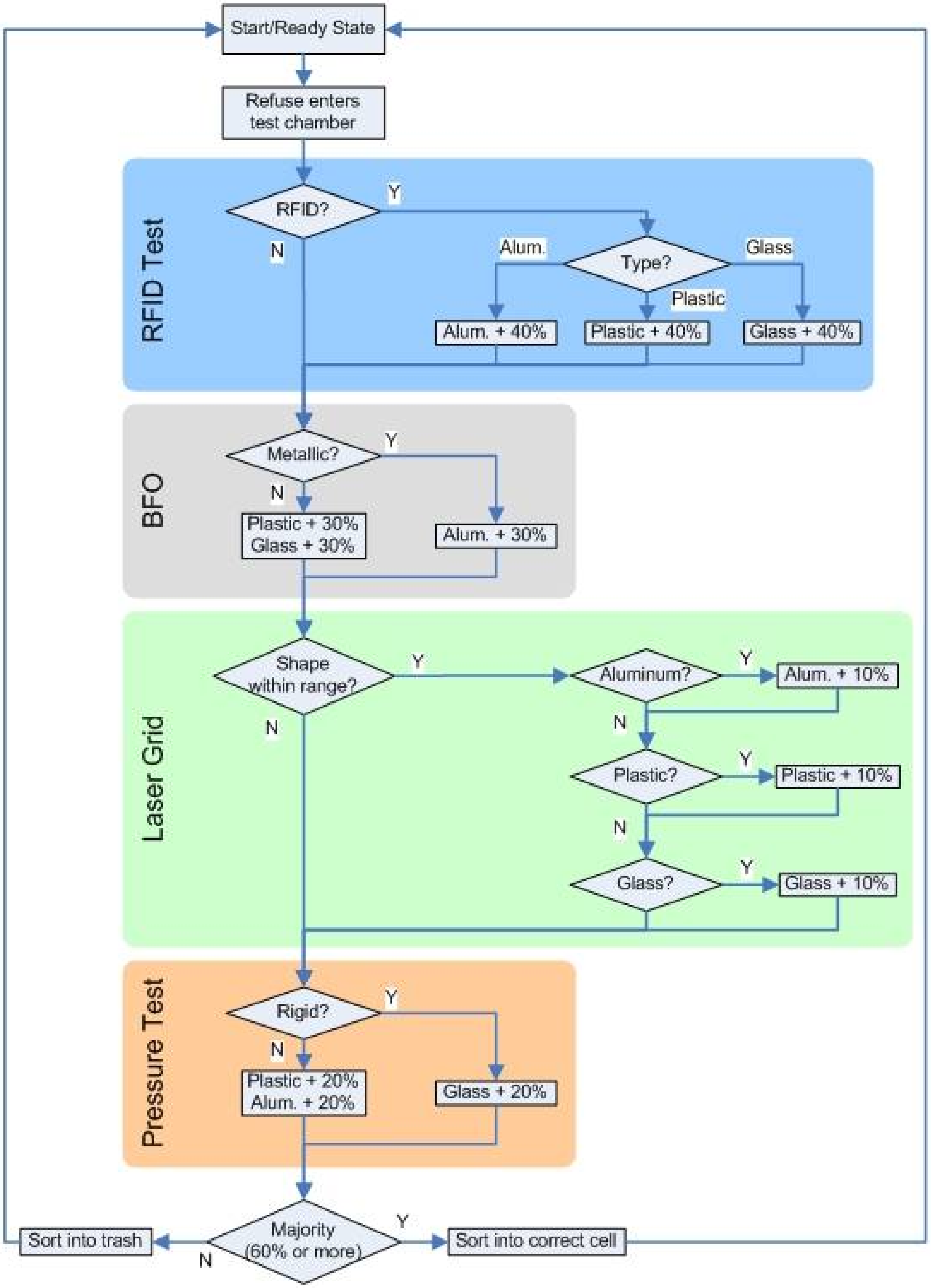



Figure 3.3 – Recycling bin flow chart.

# 3. Overall System Design

***3.2 Physical and Mechanical Design*.** The outer casing of the Green Bin System will be shaped cylindrically with a height of **150cm** and a width of **70cm**. The casing will cover all three major components of the Green Bin System; the Scanning Chamber, Sorting Chute, and Cell Unit used to hold disposed objects. The space requirements for each component can be seen in table 3.2 below.

| Component | Height (cm) | Width (cm) |
|---|---|---|
| Scanning Chamber | 30 | 50 |
| Sorting Chute | 30 | 50 |
| Unit Cell | 80 | 60 |

Table 3.2 – Space requirements for each component.

While the three major components will require a total vertical height of **140cm**, the total height of the Green Bin System is designed to be **150cm**. The extra **10cm** will be for the outer casing as well as room for flexibility and error margins. For example, room must be left so that the unit cell containers can be easily removed when full.

Half the height of the Green Bin System will be allocated for the Unit Cell. This was done to maximize the holding capacity of disposed objects.

For the conceptual model, high density polyethylene (HDPE) and acrylic is used. This was decided due to its ease of machining, as well as the low cost of purchase for HDPE and acrylic. For the production model, to fulfill our objectives, a more environmentally friendly material will be used.

In addition to the orifice, the proximity sensor, status lights, and the solar panel will be located at the top of the Green Bin System. To protect from vandalism and environmental conditions, all components will be covered with UV stabilized polycarbonate.

***3.3 User Interface*****.** The Green Bin is designed to be easy and intuitive to use with minimal interaction. The only required action from the user should be to place the refuse in the bin. Any information should be visible and any other actions should be touch-free and automatic.

***Orifice.*** The bin orifice is circular with a diameter of **11cm** to **12 cm**; less than the diameter of the chamber. This ensures that objects placed in the bin will be small enough, and not become lodged within the chamber. A simple sliding door will be placed at the orifice. The purpose is to protect the chamber from the environment and from any damage. Along with the door, there will also be a laser diode – photo resistor pair at the top of the chamber. This provides a means to indicate any obstruction of the chamber entrance, whether it is a user's hand or an object still being placed in. The door will be programmed so that it will not close when obstructed.

A servo motor will serve as the actuator for the door. It will provide enough angular rotation, torque, and speed to open the door. The motor operates between **4.5V** to **6V** DC, well within operating limits of the entire system. The motor will be not be powered by the microcontroller. Only one output pin from the microcontroller will be used to control the motor.

An infrared proximity sensor will be mounted on the exterior of the bin near the orifice. As required by the functional specifications, the entire system must remain in sleep mode when not in use; only the sensor will remain continuously active. When the sensor produces a signal from an incoming user, it will act as an interrupt for the microcontroller to power the rest of the system. This will also be the relay signal to activate the servo motor for the orifice door.

***Status Indicators.*** Along with the proximity sensor, two or three light emitting diodes will also be mounted. These will indicate the status of the system to the user; vacant, full, or malfunction. The initial design to detect the current capacity of each cell was to use a laser diode-photo resistor pair near the top of each cell. However, since the size of each cell is sized to the estimated amount of expected recyclables of each type, a simple software solution is used instead. An easier design would be using a software counter for each type of recyclable. This method will work for glass bottles, plastic bottles, and metal cans since their sizes and shapes are predictable. However, this will not be practical for garbage since it is not as predictable. Instead, the laser diode-photo resistor method will be used.

Of course, this entire process will remain hidden from the user. These designs will ensure simplicity, ease, and safety for any user.

## 3. Overall System Design

***3.4 Test Chamber***. The test chamber was designed to house all sensors that will be used to detect and differentiate recyclables that are disposed into the Green Bin System. As soon as an object is dropped into the Green Bin System, the opening orifice closes and the scanning process begins.

The test chamber must be designed and positioned such that every time an object is placed into the Green Bin System during the insertion process, the object will land in the same place within the chamber. Positioning the disposed object at the same place all the time is necessary because a set reference point is required to complete proper measurement and pressure tests. As seen in figure 3.4, the test chamber will be oriented at an angle to insure that disposed objects will rest up against the wall of the black pipe at the designated position in the proper orientation.

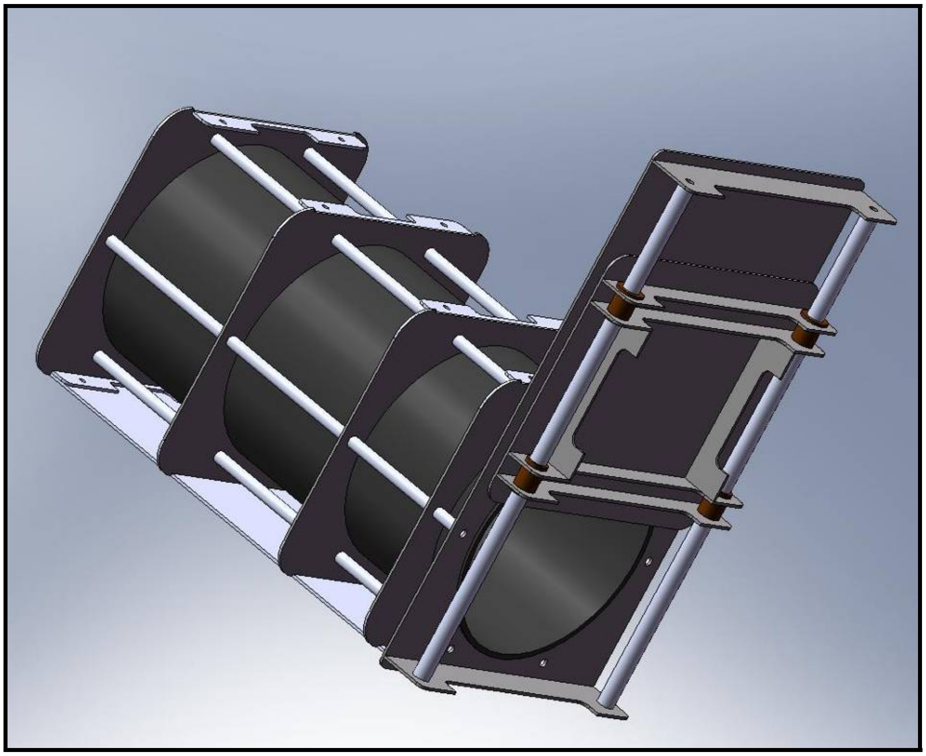


Figure 3.4 - Scanning Chamber of Green Bin System.

During the scanning process, the sliding trap door at the very bottom of the test chamber will be in the closed position. Thus during the scanning process, the placed object is expected to be resting on top of the trap door. Once the scanning process is complete, the trap door will slide open and the scanned object will slide down the sorting chute.

# 3. Overall System Design

The opening and closing of the trap door will be completed through the use of a servo motor as seen in figure 3.5.

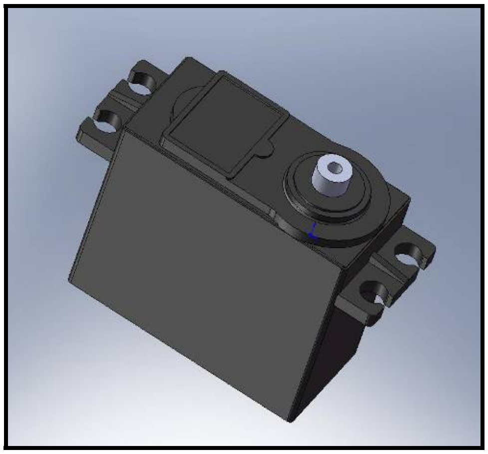


Figure 3.5 – Servo motor.

The current design of the test chamber has numerous ribs and threaded rods that act as support for the entire system. They add strength and provide a mounting solution for the pipe to the rest of the mechanics such as the sliding doors and the deflector. The distance separating the ribs can be easily adjusted via the threaded rods to allow the coils from the metal detector and RFID(s) to be positioned. In addition it allows the laser and photodiode assembly to be mounted directly to opposing plates on top of the ribs. The mounting plates can be seen at the very right of the scanning chamber in figure 3.6. Holes will be drilled into both the mounting plates and the pipe to allow the placement of the laser and photodiode assembly.

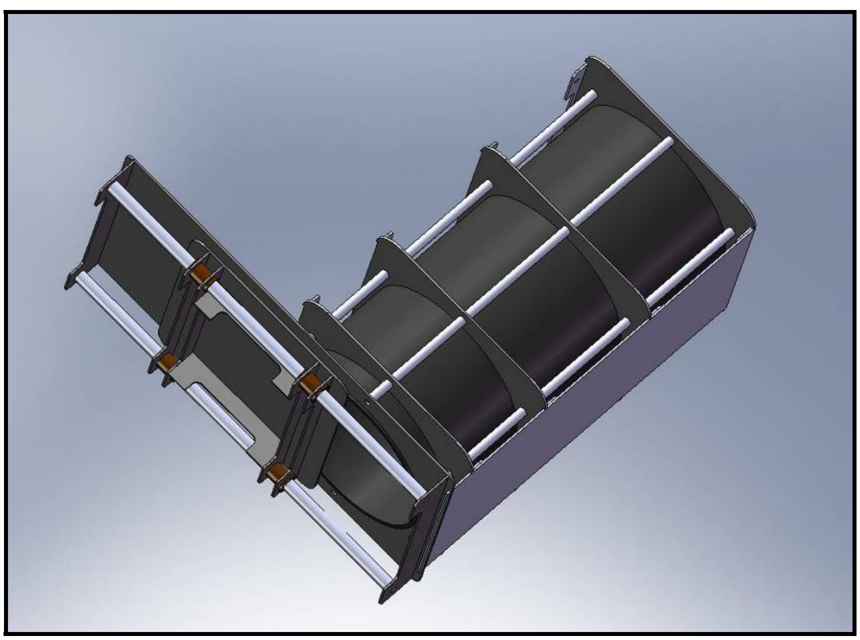


Figure 3.6 – Support System.

# 4. Scanning Chamber Unit

The identification and sorting processes are both performed within the scanning chamber unit of the Green Bin. This is done in two distinct stages, and their operations are unified by a microcontroller.

***4.1 Sensor Components*.** The four chosen sensor types (RFID receiver, BFO, laser grid, and pressure sensor) are all housed within the first stage: the test chamber. The construction and functionality of each type is discussed in greater detail below.

***4.1.1 RFID Receiver [4]*.** The RFID reader chosen for this project is sensitive to RFID tags at **125kHz**. The **125kHz** reader and tags operate at a lower frequency range in comparison to other types of RFID combinations. The **125kHz** system has a lower range of detection, however, this type of RFID is cheaper to implement and is less sensitive to noise caused by humidity and surrounding metallic objects. The RFID reader acquired is SeeedStudio RDM630. This particular model has an external antenna which allows us to fabricate our own customized design. This gives us a flexible antenna shape for placement and increased detection range. The custom antenna has a circular shape with a diameter of **13.8cm** and inductance of **467µH**. This detection range is approximately **±10cm** above and below the antenna coil, while the manufactured antenna has a range of **±4.5cm** for **50mm** diameter tags.

***4.1.2 Beat Frequency Oscillator (BFO) [5]*.** In order to detect aluminum and steel cans, a simple beat frequency oscillator circuit is utilized. This detection method is based on the principle of magnetic induction. Two identical oscillators are used to create two alternating currents operating at the same frequency. One circuit however is comprised with a fixed inductor while the other uses a large coil of magnetic wire, both with matching inductances. If a metallic object is near the coil, it alters the magnetic field and thus changes the frequency of the alternating current.

In order to be compatible with the microcontroller, a rectifier and a passive integrator are coupled in series with the oscillator circuit. This effectively transforms the AC signal to a DC signal. This sensor method remains the most passive among the four. It will only require one microcontroller input pin. The design only operates at a supply voltage from **5V** to **9V** DC and will not be driven by the microcontroller. Any operational amplifier in the design only needs a positive supply.

# 4. Scanning Chamber Unit

Figure 4.1 below is the prototype circuit design for the metal detection sensor.

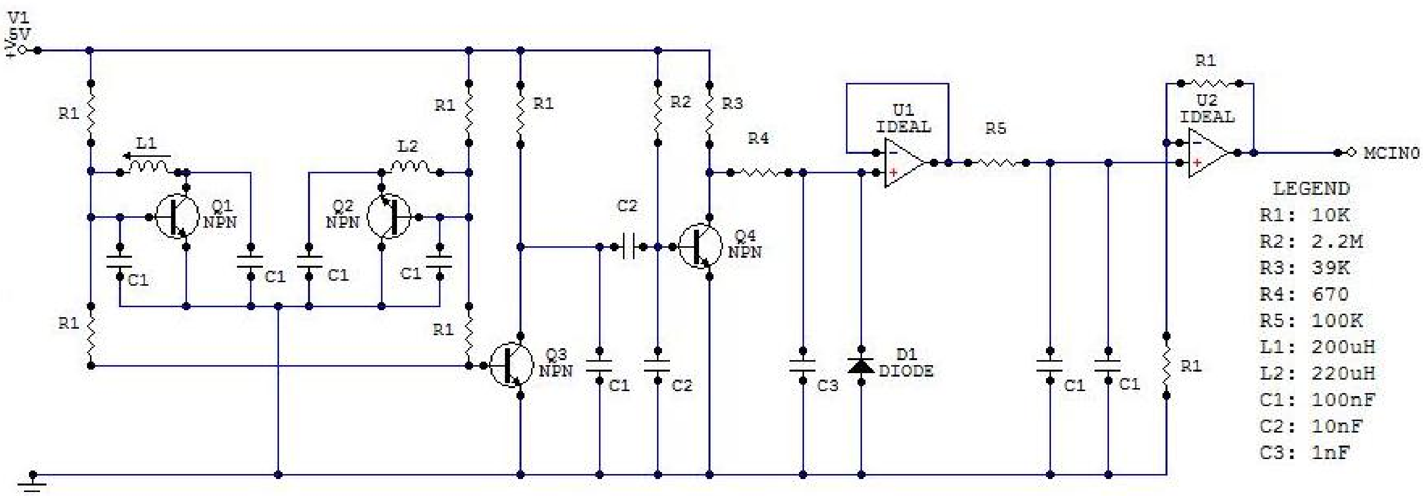



Figure 4.1 – BFO Metal Detector.

The coil is constructed with **32 gauge** magnetic wire so a more precise value can be achieved to match the fixed inductor. The coil has a diameter of **13.5cm**, slightly greater than the diameter of the chamber. The purpose is to be able to wrap the coil around the chamber and have the refuse move smoothly through it. The placement of the coil is chosen to be at the bottom of the chamber. This design maximizes sensitivity and ensures that it does not interfere with the RFID antennas. The range is within **10cm** from the center of the coil. The thickness and material of the testing chamber does not affect the sensitivity. Other than the coil, all other components will be place and soldered onto a single universal printed circuit board. The circuit is to remain separate from the chamber.

This sensor meets all the functional specifications required to complete the metal detection test. It remains non-intrusive, non-audible, and does affect other sensor systems within the chamber or the environment outside.

***4.1.3 Laser Grid*.** The laser grid sensor we designed uses 12 lasers, arranged in a cross pattern, to perform dimensional measurements.

***Emitter [6].*** It is inefficient to dedicate 12 input pins and 12 output pins to control each individual laser diode. Therefore, a Charlieplexer or multiplexer is required to control the laser diodes using fewer I/Os.

# 4. Scanning Chamber Unit

Figure 4.2 shows the schematic of the Charlieplexer implemented for the project.

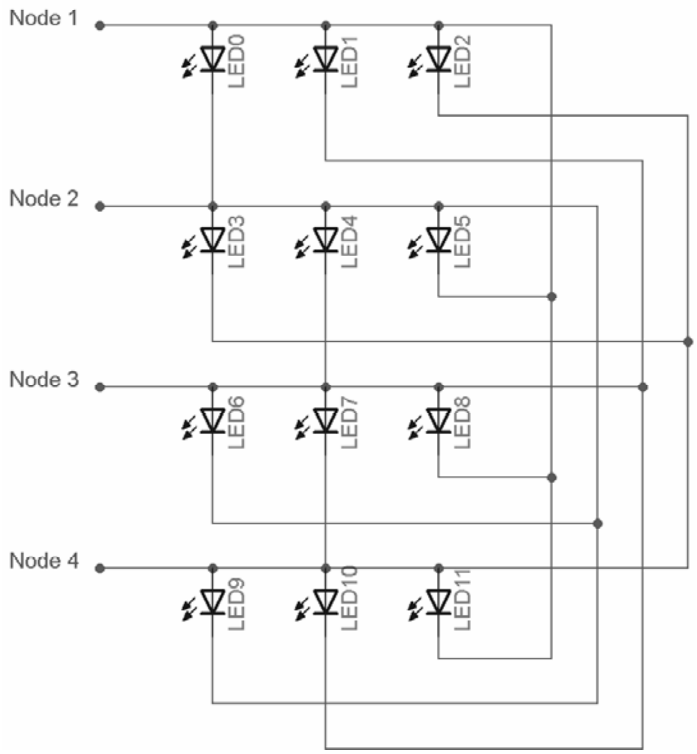



Figure 4.2 – Charlieplexer Schematic.

The Charlieplexer's relationship between number of inputs, *n*, and number of laser diodes, *d*, is given by equation 4.1:

$$d = n(n-1) \qquad 4.1$$

In contrast, the multiplexer's relationship is

$$d = \left(\frac{n}{2}\right)^2 \qquad 4.2$$

Hence, using a Charlieplexer with 4 input pins, we have the ability to control 12 laser diodes. In comparison, a multiplexer with 4 input pins is only capable of controlling 4 laser diodes.

Charlieplexer requires the I/O pins to have tri-state logic:

1. low impedance High ($V_{cc}$) mode
2. low impedance Low (GND) mode
3. high impedance open circuit mode

## 4. Scanning Chamber Unit

Referring to figure 4.2 for instance, turning on LED 0 requires Node 1 to be HIGH, Node 2 to be low, and Nodes 3 & 4 to be in the high impedance state (open circuit). Current will then flow from Node 1 to Node 2 powering LED 0. Another constraint for Charlieplexer is if one laser diode fails then the whole system collapses. However, for the project, a Charlieplexer is sufficient and not overly complicated to design and implement.

***Receiver.*** The laser diodes, placed in a Charlieplexer configuration, form the emitter. The emitter then interfaces with the receiver as shown in figure 4.3.

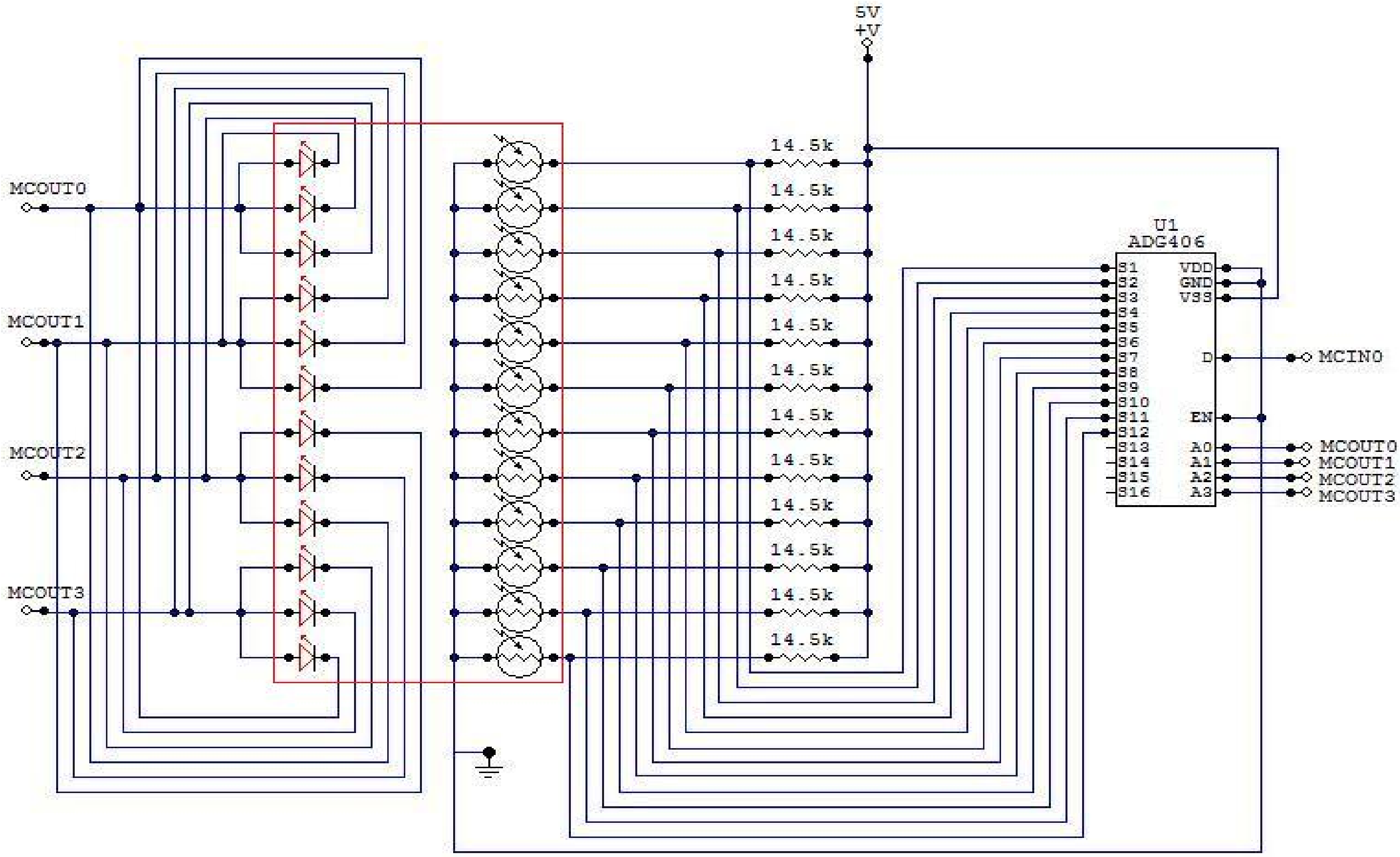



Figure 4.3 – LED profiler circuit.

On the opposite side of the laser diode bank, there is also a bank of twelve photo resistors. Each laser diode will pair off with its respective photo resistor. Each photo resistor has a nominal range from **10kΩ** to **120kΩ**, from lowest to highest light intensity, respectively. Each is then connected to a fixed resistor, thus creating a simple voltage divider. All twelve voltages between resistors will effectively act as the profiling signals and needs to be fed into the microcontroller for processing. The supply voltage to the photo resistor bank operates from **5V** to **9V** DC. Do note that the photo resistor bank will not be driven by the microcontroller.

# 4. Scanning Chamber Unit

For efficiency, the design is to have each pair firing individually to minimize the output signal of the photo resistor bank to only one analog I/O pin on the microcontroller. The original design was to have all pairs junction into a summing amplifier. But after further analysis, we realized the single amplifier output would always produce the same value and distinguishing each pair would be impossible. A more suitable design was to have all pairs junction into an analog 16:1 multiplexer. Any of the pairs can then be selected using only four selection signals to the multiplexer. With this design only four output pins and one input pin of the microcontrollers I/O bank would be necessary, as opposed to twelve input pins if all the photo resistors were directly fed into the microcontroller.

The Charlieplexing and multiplexing circuits will be placed and soldered on separate universal printed circuit boards (PCB). These circuits are to be separate from the testing chamber. A third PCB will be placed on the chamber and act as a junction point between laser diode and photo resistor banks, the first two circuits.

This sensor meets all the functional specifications required to complete refuse profiling. It remains non-intrusive, non-audible, and does not affect other sensor systems within the chamber or the environment outside. With the microcontroller, the firing time between each pair can easily be modified such that the entire scanning process is well within time constraints and without any sensitivity loss.

***4.1.4 Pressure Sensor.*** In order to differentiate between glass and plastic bottles, a pressure sensor will be used. As seen in figure 4.4 a device similar to a rack and pinion gear set will be designed and used to press up against objects that are disposed into the Green Bin System.

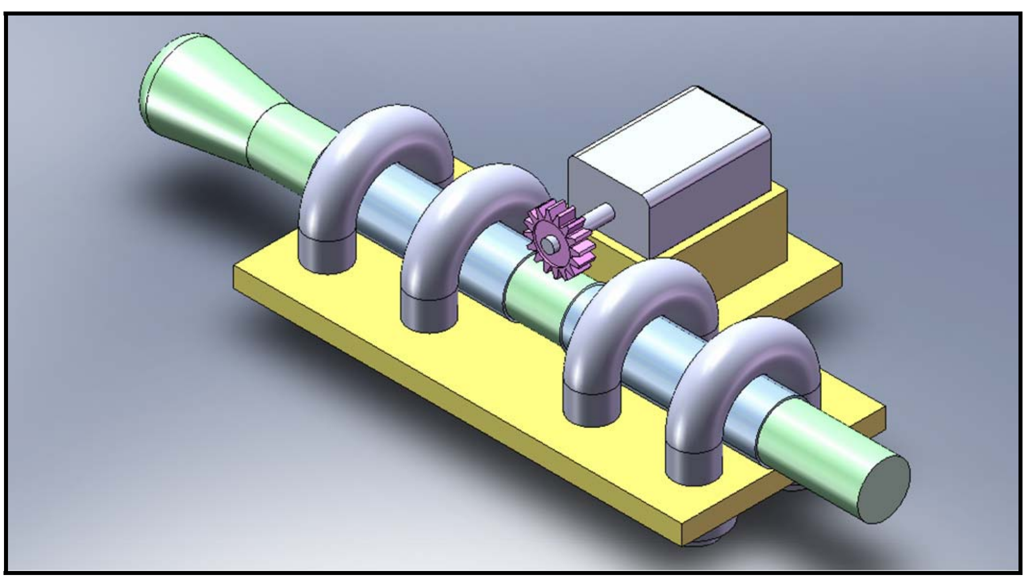


Figure 4.4 – Pressure sensor system.

# 4. Scanning Chamber Unit

***Pressure Application.*** Depending on the hardness of the placed object, the threaded rod will act differently when contact is made. Harder objects such as glass bottles will completely stop the linear motion of the threaded rod, regardless of how much pressure is applied. On the other hand, objects prone to deformation such as plastic bottles will slow down the threaded rod as it is partially compressed by the applied pressure. The pressure sensor, with the threaded rod extended, is shown in figure 4.5.

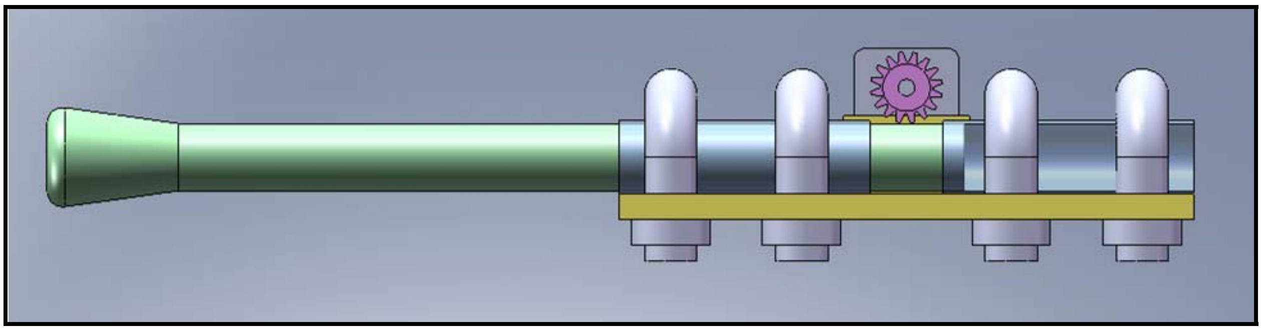


Figure 4.5 – Pressure sensor system with rod extended.

***DC Motor Controller [7].*** Rotational motion supplied by a DC motor will cause the threaded rod to move forward and apply a constant force on the object. The extending and retracting motion require that the DC motor be capable of rotating in both clockwise and counter-clockwise directions. The direction of rotation is dependent on the direction of which current flows through the DC motor terminals; therefore, to achieve the effect in reversing the current flow through the motor, a circuit is implemented to control the polarity of the DC motor. The schematic is provided in figure 4.6 below.

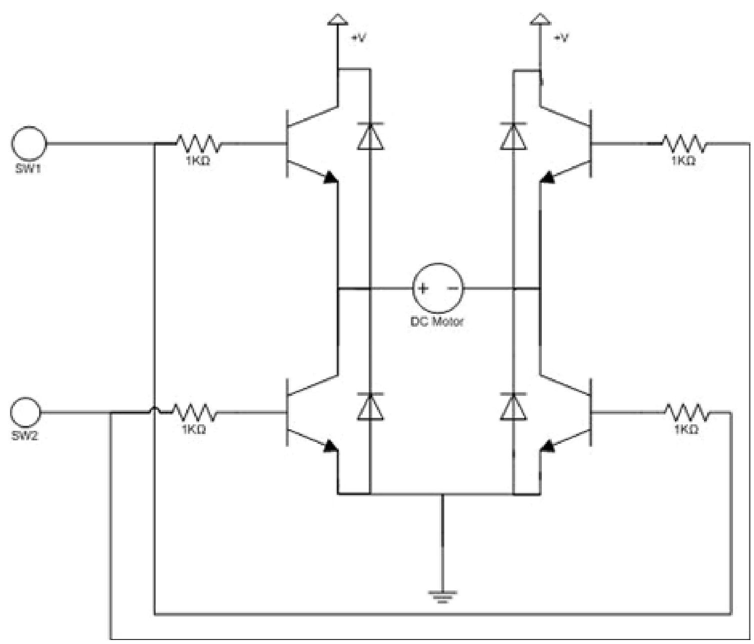
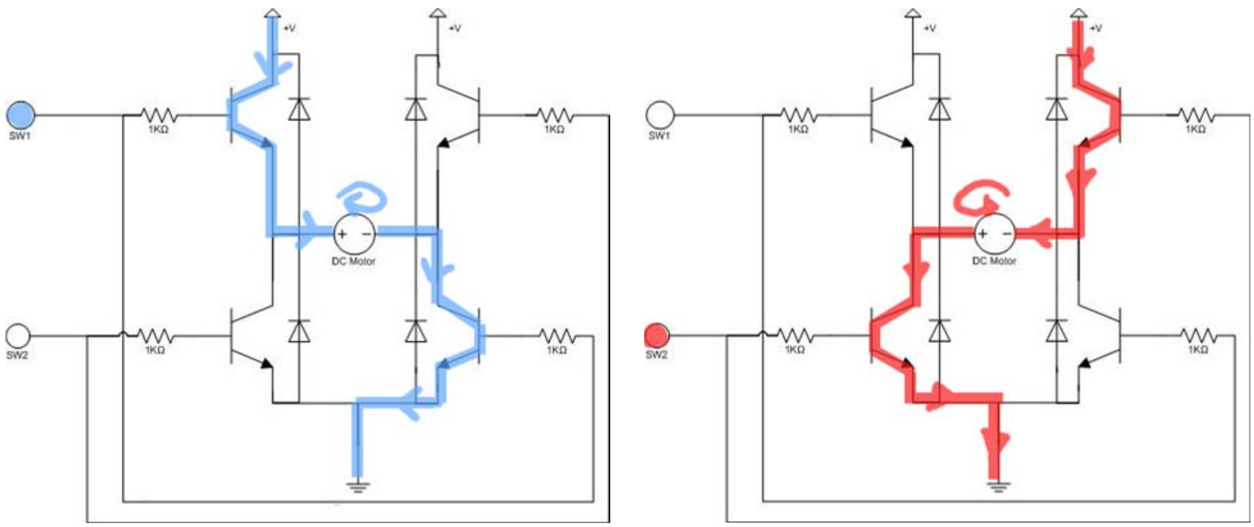



Figure 4.6 – Schematic diagram of the H-Bridge circuit.

## 4. Scanning Chamber Unit

This particular circuit is known as the H-Bridge. The H-Bridge requires 4 transistors to be used as solid state switches. Toggling each of the transistors in different combinations enables us to control the current flow through the DC motor. Figure 4.7 provides a visual representation of the current flow when the DC motor controller is active.




**Clockwise Motion** **Counter-Clockwise Motion**

Figure 4.7 - H-Bridge operation

When a small current is applied to **SW1**, the top left and the bottom right transistors go into saturation mode allowing current to flow from the power source through the DC motor's positive terminal towards the ground. The path of the current is highlight by the blue path and the DC motor will rotate clockwise. Similarly, when a small current is applied to **SW2**, the top right and bottom left transistors are turned on, allowing current to flow through the DC motor from the negative terminal. In this configuration, the polarity on the DC motor terminal is reversed and the motor rotates counter-clockwise, as indicated by the red highlights.

The **1kΩ** resistors between the switches SW1 and SW2 and the base of the transistors are used as current limiting resistors. This ensures that the DC motor is only drawing power from the power source and not from the circuitry controlling SW1 and SW2. The diodes connecting the emitter and collector of all transistors are used to protect the transistors from Back EMF (electromotive force) reverse current and voltage generated by the motor when operating with a load.

The SW1 and SW2 nodes are connected to the digital output pins of the microcontroller. The **5V** DC, low current, digital output pin enables directional control of the DC motor through software.

## 4. Scanning Chamber Unit

***Optical Encoder.*** Through use of an optical encoder attached to the input shaft of the motor, the different linear motions will be analyzed and used to differentiate between glass and plastic bottles. The optical encoder disk is customized to be compatible with the microcontroller while providing reasonable window-to-rotation resolution.

A planetary gear box will be used to provide rotational motion for the pressure sensor at a speed and power (torque) that will be sufficient to fulfill our requirements. The magnitude of speed and power at which our pressure sensor functions optimally at will be obtained through various tests, once the construction of both the pressure sensor and drop-in chamber is complete.

***4.1.5 Sensor Placement.*** Four key sensors will be used to fulfill the task of detecting and differentiating recyclables placed inside the scanning chamber. They will be placed on the pipe and mounting plate of the scanning chamber, as seen in figure 4.8.

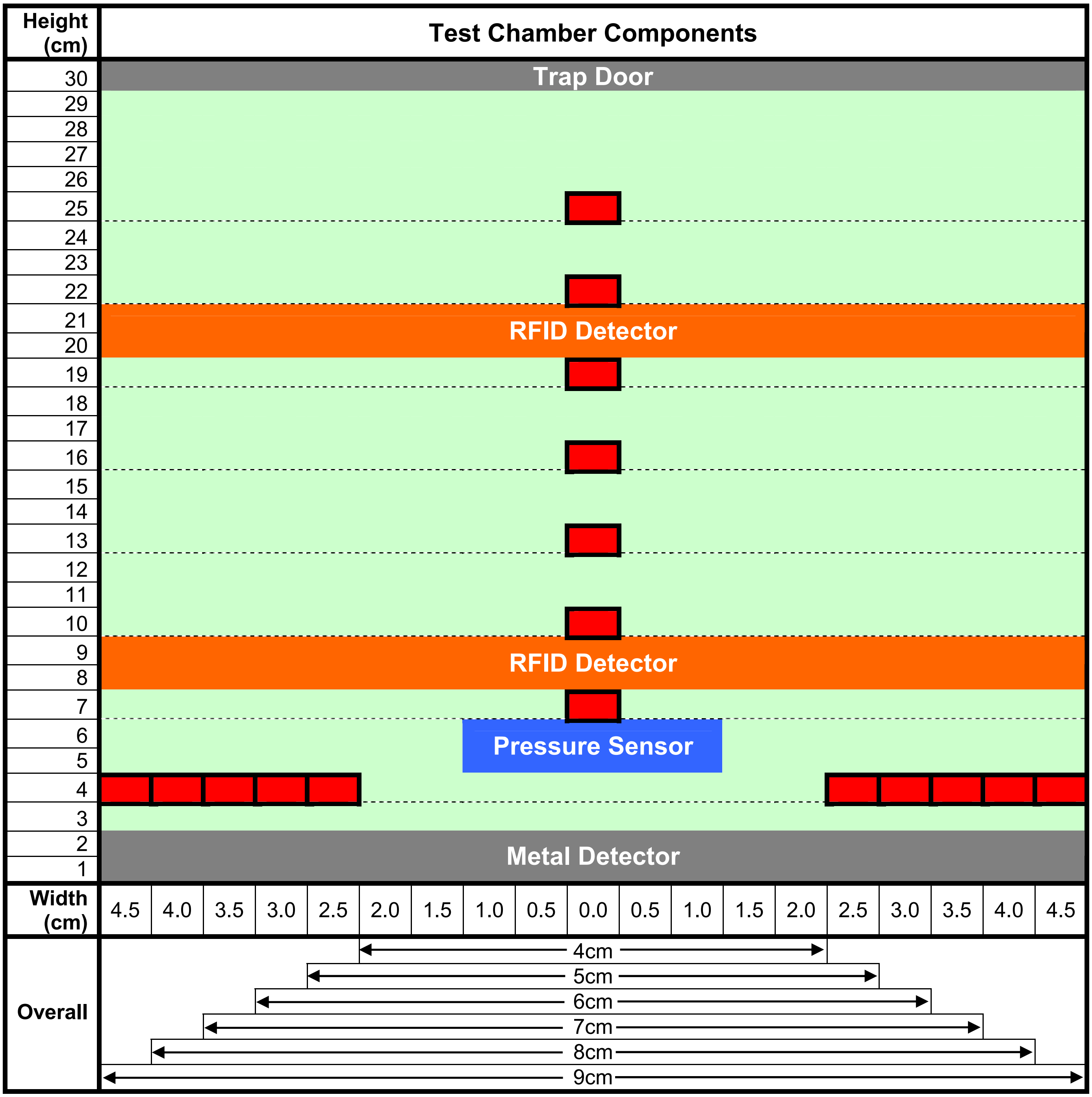



Figure 4.8 – Sensor placement.

## 4. Scanning Chamber Unit

***RFID Detector.*** Two RFID antennas will be placed on the pipe of the scanning chamber at a height of **7.5cm** and **19.5cm**. Each RFID antenna is expected to have a range of **10cm**. Thus the detection range will encompass the entire area inside the pipe with this placement of RFID antennas. All RFID tags will be within detection range, whether the tag is placed at the top or bottom of a recyclable container.

***Metal Detector.*** The coil of the metal detector will be wrapped around the very bottom of the pipe of the scanning chamber. Doing so will allow all conductive materials to be detected, even objects smaller than our minimum test case. With this placement of the metal detector, even crushed aluminum cans are detectable.

***Laser Grid.*** The lasers and photo-diodes for the laser grid will be placed in positions as displayed by the red squares in figure 4.8. 7 lasers will be used to approximate the height of the object inside the scanning chamber. Starting at a height of **7cm**, lasers will be placed at intervals of **3cm**, up to the maximum height of **25cm**. This placement of the lasers will allow the scanning chamber to detect the height of both our minimum test case (**8.7cm**) as well as our maximum test case (**26cm**).

In addition, 5 lasers will be used to approximate the width of the object placed in the scanning chamber. Starting at a horizontal distance of **2cm** from the center of the tube, lasers will be placed at intervals of **0.5cm**, up to the maximum distance of **4.5cm** from the center of the tube. This placement of the lasers will allow the scanning chamber to detect the width of both our minimum test case (**2.6cm** in radius) as well as our maximum test case (**4.6cm** in radius).

The lasers and photo-diodes will be mounted on the mounting plates of the scanning chamber. Holes will be drilled in the pipe of the scanning chamber to allow the laser to pass through.

***Pressure Sensor.*** The pressure sensor will be used to differentiate between plastic and glass bottles. Thus, the pressure sensor must be placed at a position that will allow it to press up against all existing plastic and glass bottles. And because there are plastic bottles as short as **8cm – 9cm**, the pressure sensor must be placed at a height shorter than this. Due to space constraints, the pressure sensor was decided to be placed on the mounting plate of the scanning chamber at a height of **4cm**. A hole approximately **1.5cm – 2cm** in diameter will be cut in the pipe to allow the threaded rod of the pressure sensor to pass through and make contact with the disposed object resting inside the pipe.

## 4. Scanning Chamber Unit

***4.1.6 Production Model*.** The identification components detailed above have been strictly designed to meet the requirements of the proof-of-concept model. As such, the sensors are capable of accomplishing the goals required of a concept model, but the resolution of each sensor may not be adequate for public use. However, several components can be modified and slightly reconfigured to scale up the resolution of each sensor.

***Pressure Test.*** The pressure test will undergo rigorous testing to determine the rigidity of each material. Utilizing the optical encoder, the object can be characterized as it is being pressed upon. The way in which the material bends and the resistance it provides will determine such characteristics. While this can already be done with the proof-of-concept model, the accuracy is dependant on the quality of the system performing the testing. As such, the data yielded from the production model will be more precise, because it will be built with superior motors, gear boxes, and rack and pinions. The optical encoder may also be replaced with a sliding potentiometer or other alternative measuring device.

***Laser Grid.*** The cross shape of the laser grid is sufficient for the proof-of-concept model. The production model will feature a scaled up grid, utilizing more laser diodes, to perform object profiling with increased accuracy. The Charlieplexer and multiplexer designs were chosen because they allow this scalability. The production model's laser grid will resemble a large rectangle, allowing the lasers to detect the varying widths and contours of the refuse. This will provide increased resolution and also allow use to determine if the refuse is symmetrical or not. By performing the height and width test once before the pressure test and a second time afterwards, the laser grid will also be capable of observing if permanent deformations were made. This allows further differentiation of plastic bottles from aluminum cans and garbage, as plastic bottles tend to return to their original shape after pressure is removed.

***4.2 Sorting Components*.** After the composition of the bottle is identified, the bottle is released to the sorting mechanism as shown in Figure 4.9. The sorting mechanism directs the refuse coming out of scanning chamber into the appropriate bin. The entrance of the diverter mechanism always remains on the same axis relative to the exit of the scanning chamber to ensure that refuse will always fall properly onto the diverter.

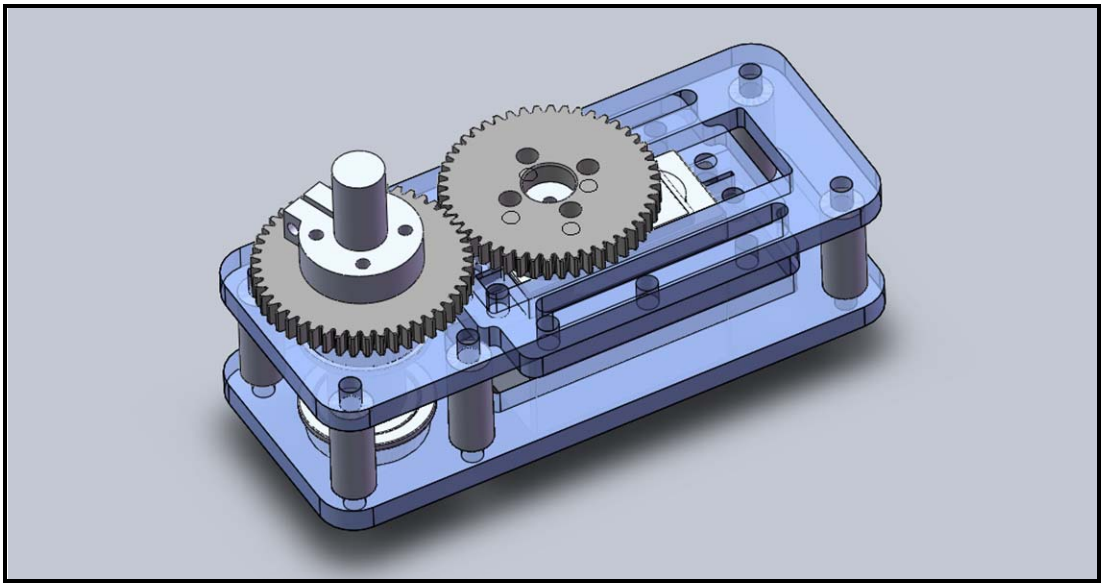


Figure 4.9 – The sorting mechanism along with the diverter output shaft.

The sorting mechanism is actuated using a Hitec HS-625MG servo motor as shown in figure 4.10.

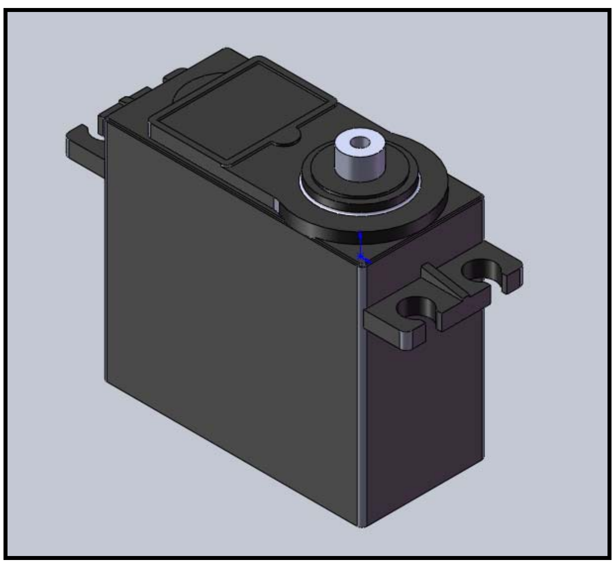


Figure 4.10 – Hitec HS-625MG servo motor.

# 4. Scanning Chamber Unit

To minimize the latency from the time the refuse enters the scanning chamber to the time it gets sorted into its proper bin, the speed of the motor is critical, as the sorting mechanism is only actuated after the scanning is finished. It is important to note that the Hitec HS-625MG is designed only to handle loads radially, not axially, due to the use of radial bearings. Although the radial bearings in the servo are able to handle some minor loads axially, it is prudent not to subject them to such loads overtime. Doing so would to cause creep and damage to the bearings.

To prevent damage to the servo, the diverter mechanism is offset from the actual servo via gears as shown in Figure 4.11; in this scenario, the axial moment caused by the refuse falling on the diverter is not transferred to the servo. The only component of force transferred to and from the servo, and the diverter, is the radial force to which the servo is designed to handle.

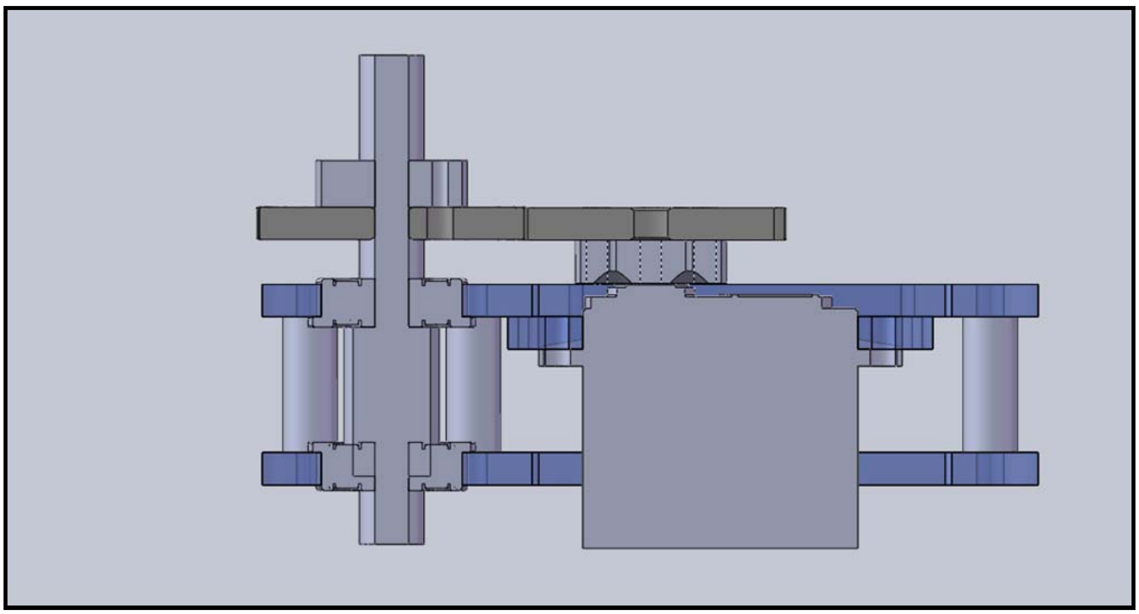


Figure 4.11 – Cross-sectional view of sorting mechanism.

The use of a gearing system between the diverter and the servo also offers the ability to adjust the speed and torque characteristics of the sorting mechanism. The gear ratio between the servo and the diverter can be adjusted to suit the needs of the system; however, the gear ratio will be maximized to decrease latency time while still retaining enough torque to actuate the mechanism.

# 4. Scanning Chamber Unit

The Hitec HS-625MG servo features a military grade potentiometer to provide a negative feedback loop for position response. The potentiometer essentially generates an error signal relative to the expected signal pertaining to the positional error of the output shaft. In essence, the use of the Hitec HS-625MG provides an elegant all-in-one solution for a feedback system not found in a simple DC motor. For a stock servo, this method need not be modified. However, since the Hitec HS-625MG servo is rated for **~180**° of rotation, due to the potentiometer limitation and a mechanical stop, a gear ratio of greater than **1:1** would require the potentiometer of the Hitec HS-625MG to be mounted on the shaft of the diverter. Likewise, the mechanical stop of the servo must be removed.

For specifications on the Hitec HS-625MG, please refer to the datasheet [8].

## 4. Scanning Chamber Unit

***4.3 Microcontroller*.** The microcontroller chosen for this project, Arduino Mega [9] with ATmega1280 chipset [10], is dictated by requirements set by our scanning chamber unit and sorting components. Below are some of the special functions required of the microcontroller that is essential to ensure functionality of the Green Bin.

***Analog to Digital Converter.*** The Arduino Mega has 16 analog inputs that have analog to digital data conversion capabilities. The analog input range is from **0-5V DC**. It is sampled at **1000 kHz** at the maximum clock frequency, and mapped to a **10 bit** digital value from **0** to **1023** integer value for processing.

***Serial Ports.*** The microcontroller has 4 pairs of built in **Rx**(receive) and **Tx(**transmit) pins for receiving and transmitting TTL serial data. The serial data communication is required to interface with the RFID reader. Multiple serial ports enable the implementation of multiple RFID readers for redundancy. There is also an output serial for transmitting processing data to computer for testing and debugging; done via Hyper Terminal.

***Pulse-Width Modulation.*** Arduino Mega has 14 digital output pins which support PWM. However, only 5 will be used to control the angle or rotation for various servo motors used in the system. Also, PWM will provide inputs for variable speed control of the DC motor driver. The output signal modulates at **500Hz** with **8 bits** of control for the duty cycle.

***External Interrupt*.** The external interrupt pin can be mapped to trigger when the external signal is detected to have:

1) High (**5V**)
2) Low (**0V**)
3) Rising Edge
4) Falling Edge
5) Change in value

The interrupt pins allows the system to be in standby mode and activate when a sensor or switch is triggered.

# 4. Scanning Chamber Unit

***4.3.1 Signal Types and Interface***. There are a variety of electrical and mechanical components integrated in the system. Table 4.1 summarizes how each of the main components communicate with and are controlled by the microcontroller.

| Component | Signal Type | I/O | Number | Description |
|---|---|---|---|---|
| **Proximity Sensor** | Interrupt | I | 1 | user comes in close proximity of the Green Bin interrupt will start the system |
| **Orifice** | PWM | O | 1 | control trap door servo |
| **RFID** | Serial | Both | 4 | two RFID readers will be implemented for redundancy at 9600 baud |
| **Laser Grid - Charlieplexer** | Digital | O | 4 | controls the laser scanning sequence 1 laser at a time |
| **Laser Grid – Channel Select** | Digital | O | 4 | s0, s1, s3, s4 selection line for selecting which signal to read |
| **Laser Grid – Mux Output** | Analog | I | 1 | the output for selected channel for 16:1 Mux range from 0 to 5V dependent on the object being scanned |
| **Metal Detector** | Analog | I | 1 | when metal is present voltage drops below 5V dependent on quantity of metal present |
| **Pressure Sensor-Motor** | PWM | O | 2 | two channel of PWM for forward and reverse direction |
| **Pressure Sensor – Optical Encoder** | Interrupt | I | 1 | optical encoder outputs PWM, use interrupt for edge detection |
| **Sorting Compartment** | PWM | O | 2 | two servos are being controlled for trap door and sorting mechanism |
| **Status Indicator** | Digital | O | 4 | control Led to display status |
| **Computer** | Serial | Both | 2 | interfacing with computer for debugging and analysing data via hyper terminal at 9600 baud |

Table 4.1 – Microcontroller pin assignments.

# 4. Scanning Chamber Unit

According to table 4.1 the minimum number of pins required for base function of the Green Bin is **27 pins**. More will likely be required once more features are added. While Arduino Mega supports **54** digital I/O and **16** analog inputs, there are sufficient ports remaining for future add-on functionalities. The ATmega1280, provides adequate processing power, speed and memory for the system. It is clocked at **14 MHz**, with **1280 Bytes** of flash memory for storing C-programming code.

## 5. Cell Unit

The storage cells will have the least electronic components and interaction with the rest of the system. The design of the cell unit will mainly focus on physical attributes, as its main purpose is housing refuse; the most passive function of the entire system.

The cell unit will be placed below the test chamber and sorting unit. The cell unit will be cylindrical with a closed bottom and open top, very similar to, if not the same as, an average garbage can. It will be able to fit within the remaining space left in the bin, with a maximum height of **80cm** and a maximum diameter of **60cm**. The cell unit will be sectioned into four different sub cells to house the separated refuse. Each sub cell is removable and serviceable for maintenance through an access door from the back of the bin. Figure 5.1, below, summarizes the sub cell sizes.

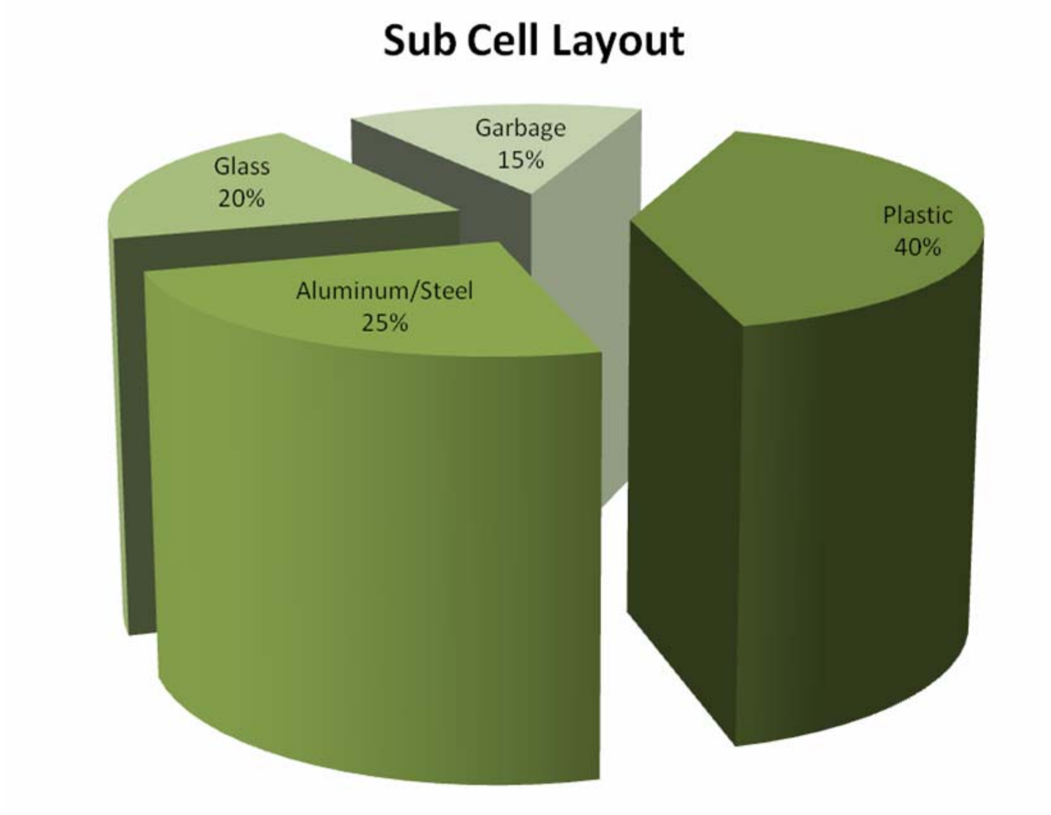



Figure 5.1 – Sub Cell Unit Layout

The sub cell sizes are based on two main factors: probability of being recycled and average size of object. The majority of liquid containers sold in vending machines and off-the-shelf refrigerators are mainly aluminum cans and plastic bottles. The test cases we have gathered reflect this trend. Also, the average size of a plastic bottle is considerably greater than that of aluminum or steel cans. Thus, it is reasoned that the plastic sub cell will have the greatest volume for storage, followed by aluminum, glass and lastly garbage.

## 5. Cell Unit

As mentioned in User Interface, only the garbage sub cell will have hardware monitoring. The monitoring will use the one laser diode-photo resistor pair, the same method employed by the laser grid. The components and their respective values will remain the same. However, there is no need for a Charlieplexer or a multiplexer. Instead, the pair will be connected directly to the microcontroller, utilizing only one output pin and one input pin.

Since the cell unit will be housed within the Green Bin, there is no need to design allowances for vandalism protection. The cell unit will be constructed from high density polyethylene (HDPE), the same material that most municipal curb side garbage containers are made from. This material provides many advantages for this type of application. It is chemically resistant to liquids such as alcohol, acids, and bases. It is also impact resistant, lightweight, low moisture absorptive, and has high tensile strength [11].

# 6. Power Unit

In an effort to promote the green aspects of the Green Bin and to create a viable self-sustaining power source, solar energy has been chosen as a natural source of power.

***6.1 Operating Characteristics*.** The operating characteristics of this system:

- Maximum Current: **5A**
- Maximum System Voltage: **5VDC**
- Can operate on 3-phase **120VAC**
- Regulated Output

***6.2 Solar Panel [12]*.** The system utilizes monocrystalline solar panels. Monocrystalline solar panels are currently the highest density solar panels available on the consumer market. Several smaller panels are used in a series/parallel configuration to provide the ideal power output required for the system.

***6.3 Battery*.** The system needs to be optimized for efficient use of solar panels in order to minimize costs and spatial mounting requirements. The premise revolves around the fact that a battery with a higher voltage would require a larger solar panel than a battery with a lower voltage. Several battery chemistries were considered with such notables as sealed lead acid, nickel-metal hydride, nickel cadmium, and lithium polymer. A single-cell (**3.7VDC** nominal) lithium polymer battery was chosen for several of its favourable characteristics to meet the aforementioned power requirements.

Given the **5VDC** requirement of the system, the nominal **3.7VDC** provides an adequate platform for transforming into a regulated **5VDC** source. A single battery is favourable over several batteries in series. As the single battery is charged, it does not require battery balancing to ensure equal charge distribution over the cells. The nominal cell voltage of nickel cadmium and nickel-metal hydrides is **1.2VDC** and would be less ideal, as the voltage difference with the required **5VDC** is larger. A sealed lead acid battery with a cell voltage of either **6VDC** or **12VDC** would require much higher power requirements; back to the original premise that a higher battery voltage would require increased power requirements, requiring more solar panels and increasing costs.

## 6. Power Unit

Most importantly, lithium polymer cells also have an ideal discharge curve and internal resistance curve as shown in Figure 6.1 [13] and 6.2 [13] below.

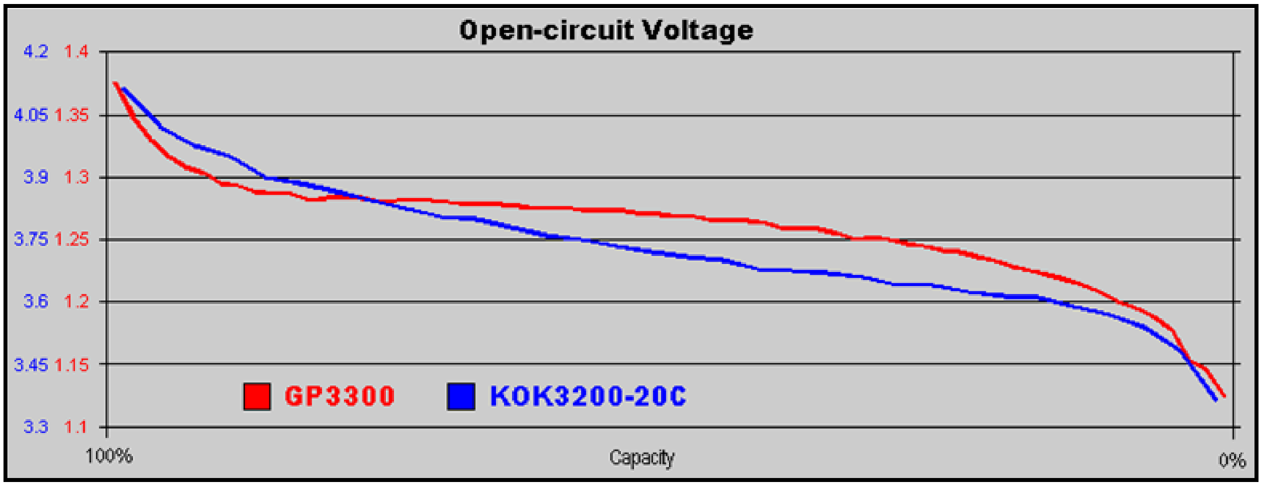



Figure 6.1 – The voltage discharge curve of lithium polymer cells and nickel-metal hydride cells

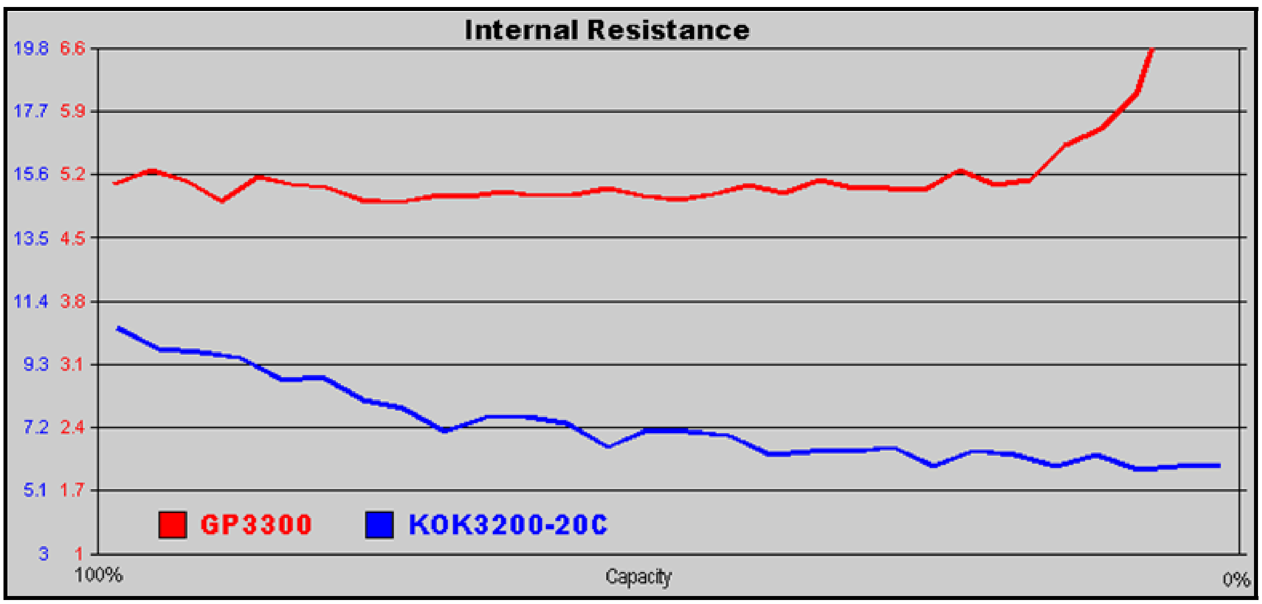



Figure 6.2 – The internal resistance of lithium polymer cells and nickel-metal hydride cells

Lithium polymer cells feature a relatively linear horizontal discharge curve, providing ample usable voltage until the battery is completely discharged. This attribute is not characteristic of other battery chemistries such as sealed lead acid, nickel cadmium, or nickel-metal hydride. These other battery chemistries feature a steep discharge curve which provides less usable voltage range.

# 6. Power Unit

Figure 6.2 shows that as lithium polymer cells are discharged, the internal resistance of the cell decreases whereas battery chemistry such as NiCad increases in internal resistance as it is discharged. The linear horizontal discharge curve coupled with the decreasing internal resistance of the lithium polymer battery chemistry makes it an excellent candidate for use in the solar charging component.

***6.4 Power Unit Design.*** Through natural design iterations, two viable solutions were developed for use as a solar charging unit, both providing regulated **5VDC**.

***Design Iteration A.*** The initial design of the solar charging circuit utilizes two main integrated circuits, the MAX1555 and the MAX756. The architecture of the MAX1555 provides the charging component by accepting a **5VDC** +/- **2VDC** input and providing peak voltage detection, **280mA** constant current charging to a **3.7V** lithium polymer battery. The second stage utilizes the MAX756 in buck-boost configuration to switch the **3.7VDC** of the lithium polymer battery to produce a regulated **5VDC**. The circuit design is given in figure 6.3:

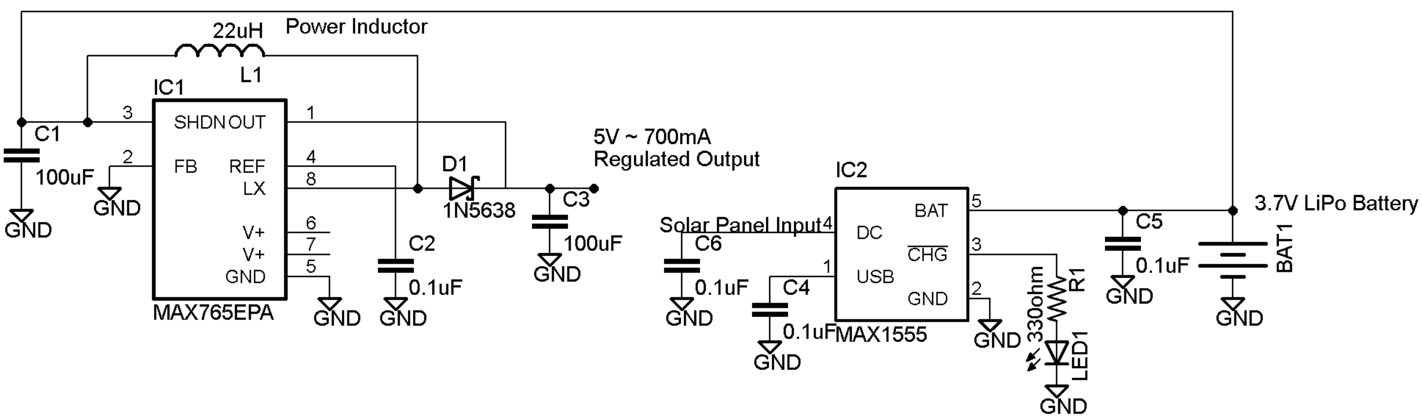



Figure 6.3 – Circuit schematic of design iteration A.

The notable feature in here is that the MAX756 can be replicated in parallel should more channels with an independent draw of less than **700mA** be required; however, this should be kept to a minimum as the superposition of efficiency losses add and becomes significant as the number of channels is increased. A reverse discharge diode is not required on the solar panel input to prevent the solar panel from discharging the battery in a null state. The downfalls of Design Iteration A are as follows:

1. Superposition of efficiency losses added during the buck-boost stage is significant as the number of MAX756's increases.
2. Parallel operation of the MAX756 buck-boost is limited as each additional MAX756 loads the MAX1555.
3. Charge current input to battery is limited to **280mA**
4. Any single channel is limited to regulated **5VDC ~ 700mA**.

## 6. Power Unit

***Design Iteration B.*** The second design of the solar charging circuit utilizes two primary integrated circuits, the MCP7833 and the LTC1700. Unlike the MAX1555 used in design iteration A, the MCP7833 is an integrated lithium polymer battery charging IC which provides variable charging current that can be set by an external resistor. Design iteration B is shown in Figure 6.4 below.

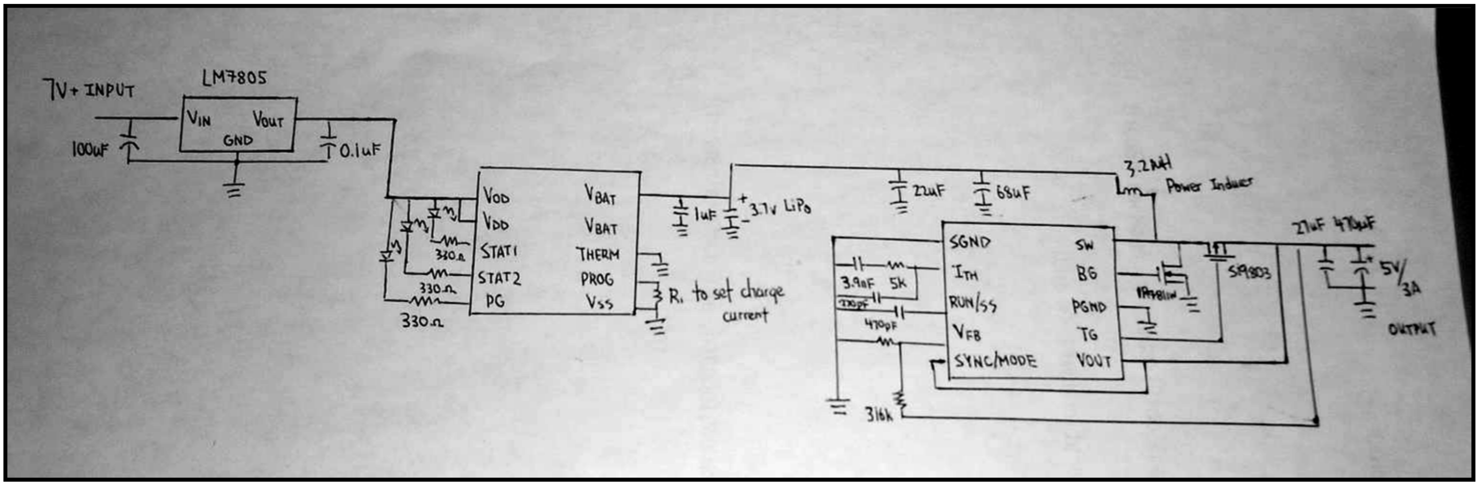



Figure 6.4 – Circuit schematic of design iteration B.

The maximum output of the circuit is regulated **5VDC** and **3A**. To meet the **5A** power requirements of the system, two LTC1700’s would have to be used in parallel to provide **3A** per channel. This addresses the problem faced by Design Iteration A where each channel of the MAX756 could only provide **700mA**.

Design iteration B also makes use of larger monocrystalline solar panels to counteract non-ideal weather conditions such as indoors, shade, and cloudy days. A larger solar panel would ensure that even during non-ideal conditions, the system would still receive enough charge to maintain a usable charge in the lithium polymer battery. As a result of this increased power intake from the solar panels, the power is processed through a **5VDC** regulator (LM7805) in order to protect the MCP7833 from over voltage.

Improvements from Design Iteration A:

1. A single channel utilizing LTC1700 can supply up to a regulated **5VDC ~ 3A**.
2. Charge current is variable by external resistor up to **1A**.

# 6. Power Unit

***6.5 AC Plug-in Power*.** Despite the use of solar panels, there exist some conditions and environments where they are not a viable power source. Indoor conditions with minimal lighting and long winter days are two such conditions where a reliable light source would not be present. To counter this, a secondary option for supplying power to the system is a conventional **120VAC/220VAC** to a **5VDC** switching power supply. This adaptation has also been constructed for the proof-of-concept model.

# 7. System Test Plan

Once the sensor compartment and the mechanical sorting mechanisms are completed and tested individually, these two systems will be integrated together to form the basis for a functional prototype. From this point on, standard operations and extreme cases will be tested extensively to ensure functionality and accuracy of the system under typical operational environments.

***7.1 Unit Testing*.** The prototype system will be tested with small test sample sizes of common cans/bottles of each material (for example: Aluminum pop cans, plastic water bottles, and glass juice bottles). The system will then be tested with a larger variety of test subjects from other manufacturers. Under ideal operating environments, the prototype system must complete the following test to verify the Green Bin's base functions.

1. Monitor the orientation of bottles to ensure correct positioning for all sensor detections.
2. Sequentially verify that the control output signals from the microcontroller behave properly, and ensure sensors and motors are correctly initialized and controlled.
3. Sequentially verify the microcontroller inputs to ensure data are correctly transferred from sensors to microcontroller for processing.
4. Verify the sensor output data to ensure sensors are giving the correct readings.
5. Monitor the microcontroller outputs on HyperTerminal to verify that the processing algorithms are functioning correctly for each of the test cases.
6. Monitor the angle of rotation on servos to ensure servos are correctly positioned.
7. Observe overall system behaviour and performance, based on fully automated sorting, without monitoring intermediate stage of operation.
8. Observe the time required for testing and sorting, and test the optimal delay necessary for each component to achieve best overall performance.
9. Observe the status indicator LED's to ensure proper detection of the status of the overall system.

# 7. System Test Plan

***7.2 Corner Cases.*** In real world operations, there are a few important corner cases that need to be covered in order to ensure the system is robust and safe to use.

**Normal Usage**

| | |
|---|---|
| **Case # 1** | Oddities in container shape and sizes |
| **Condition** | Bottles and Cans inserted are not commonly found and not covered in our test bases. |
| **Expected Result** | Our test will still detect the correct material the bottle is made of and sort accordingly to the correct bins. |

| | |
|---|---|
| **Case # 2** | Crushed cans/bottles |
| **Condition** | The bottles and cans might be deformed before being inserted into the Green Bin. |
| **Expected Result** | If the RFID tags are still intact detection should not be an issue. If aluminum cans are crushed into puck shape, the metal detector should still be able to identify and place into the correct bin. Plastic bottles are dependent upon whether the tags are intact and the severity of deformation. Shattered glass will be considered garbage. |

**Extreme Usage**

| | |
|---|---|
| **Case # 1** | Obstruction in the chamber |
| **Condition** | User inserts his/her arm into the scanning compartment or inserts objects larger than the scanning compartment, obstructing the orifice from closing. |
| **Expected Result** | Laser diode-photo resistor pair placed at the top of the test chamber will be used to ensure that there are no obstructions. If the orifice will not close, no scanning or sorting will be conducted until obstruction is removed and orifice is closed. |

| | |
|---|---|
| **Case # 2** | Small objects |
| **Condition** | Garbage that is smaller than the resolution of the grid sensor is placed into the bin but the system will not know there is an object present inside. |
| **Expected Result** | Before a new object can be placed into the Green Bin, the trap door for the garbage compartment will open to ensure the scanning chamber is empty. |

| | |
|---|---|
| **Case # 3** | RFID tags only |
| **Condition** | Users trying to fool the system by placing only the tags or placing wrong tags onto the bottles trying to trick the system. |
| **Expected Result** | The point system algorithm for material identification should be able to override the points added for the RFID tag only. The bottles will still be placed in the correct bin and the tag will be considered to be garbage. |

## 8. Conclusion

The design specifications provide a means of ensuring that all pertinent functional specifications are available in the proof-of-concept model of the Green Bin. Several components have already been developed and have been detailed according to their functionality. The remaining components will be constructed based on the theoretical models presented in this document. Likewise, the unified system operations will follow the flowcharts provided. The system test plan will act as a basis for testing, but further tests will be conducted if unforeseen adjustments are made.

Although the design specifications are written to construct the concept model, functional specifications of the production model have been considered. Several components are simplified for demonstrating their function, but can be easily scaled up or slightly reconfigured for accuracy. Due to budget and time constraints, the outer casing will be built strictly to work with the concept model.

# 9. Appendix

## *A. Combined Height & Width Charts.*

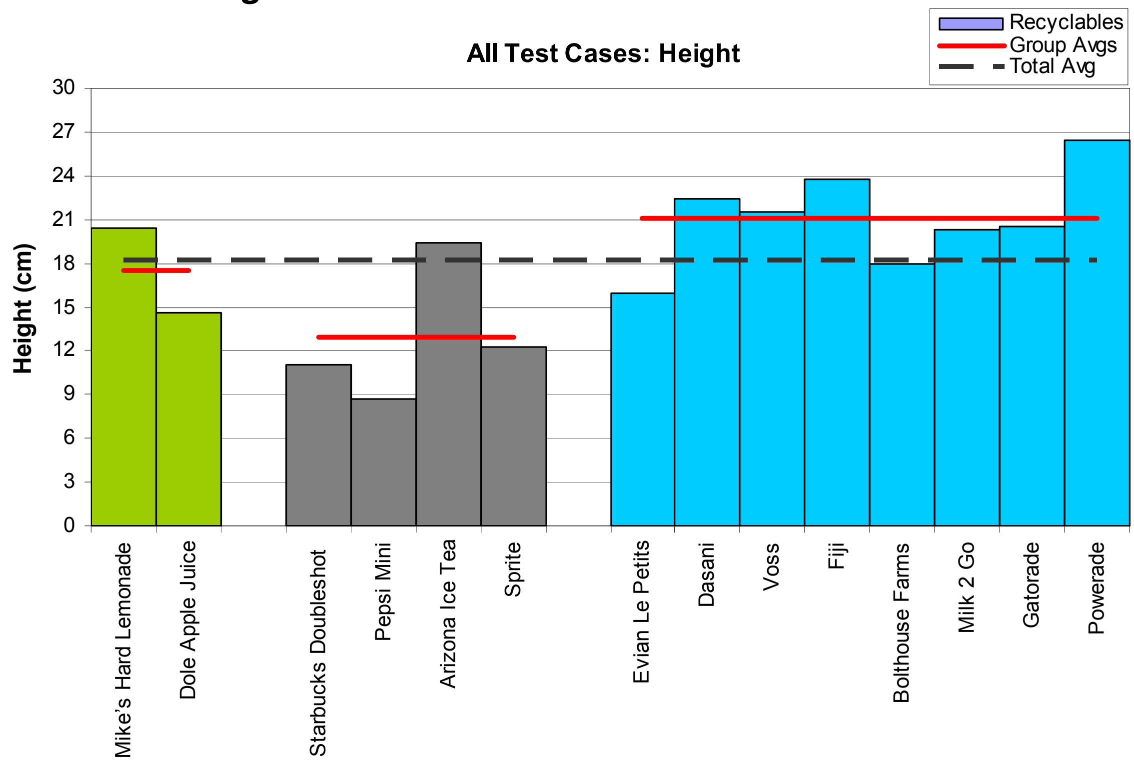



Figure A.1 – Height comparison of all test cases.

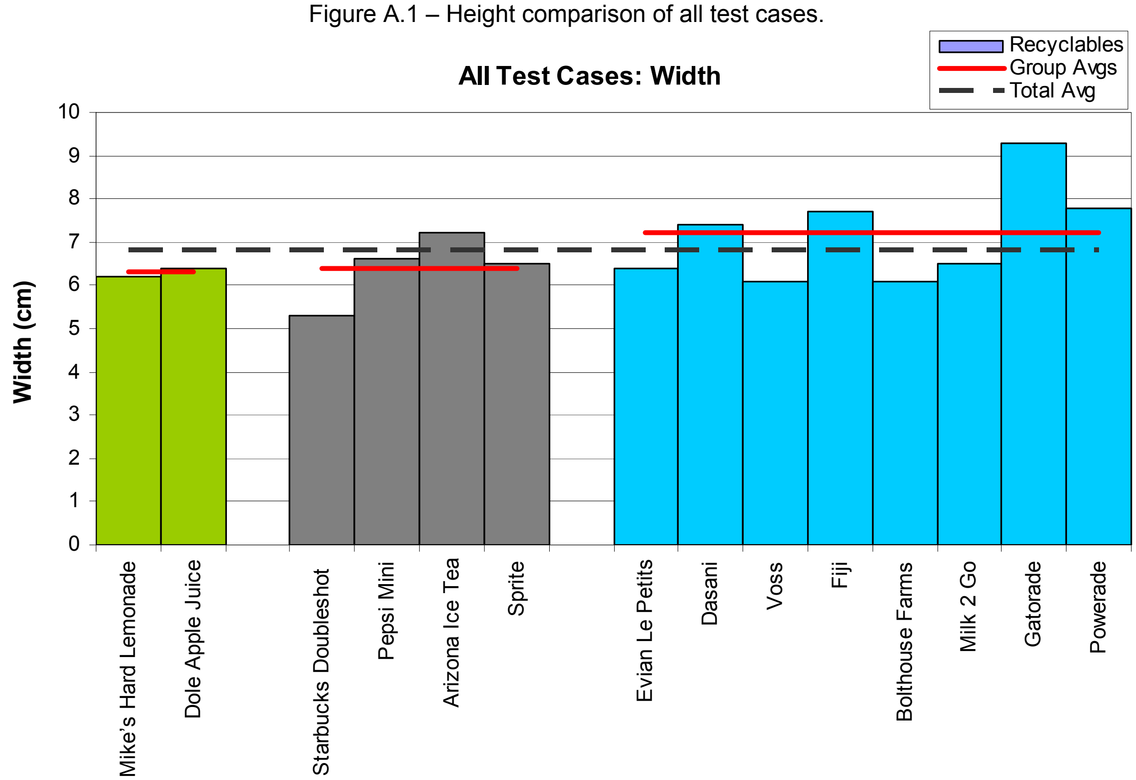



Figure A.2 – Width comparison of all test cases.

## 10. References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