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Smart Recycling Bin

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Final Design Report

DT 14

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1. Abstract

Author(s): BTB, SOQ, KRS

The Smart Recycling Bin was designed around the idea that recycling should be common practice across the globe. In order to make an impact on the recycling industry, the system needs to make disposing of recyclable materials relatively convenient for users as well as reduce the amount of overall recycling contamination. This would result in the recycling industry becoming a more profitable sector. To accomplish this, the device will accept four types of materials, each of which are identified and sorted into four different bins. This affectively reduces the overall number of contaminated recyclables well before the materials reach a recycling center. The detection of materials begins with the pressing of a start button that indicates that an item has been inserted into the device. Then, a picture will be taken by the visual detection software to determine whether the item is a bottle or a can. If the item is detected as a bottle or a can, an inductive sensor will identify if the item is metal and a load cell will be utilized to distinguish between glass and plastic and generate detection signals for the appropriate material. These signals are received by the microcontroller and passed on to the stepper motor located at the bottom of the device in order to determine which way to redirect the

incoming object. By achieving a sorting accuracy of at least 85%, The Smart Recycling Bin will be able to increase recycling rates and improve the recycling sector.

- The system can determine if a material is a bottle, can, or neither using visual detection.
- The system will sort the determined recyclables into four bins while tracking bin capacity.

PROBLEM STATEMENT

1.1 Need

Author(s): SRP

The Environmental Protection Agency estimates that, although roughly 75% of waste generated by the U.S. is recyclable, only about 30% of that waste is recycled. According to Waste Management, an American garbage collection company, the contamination rate among recyclables is roughly 25%.[1] Due to such a high rate of recycling contamination, China, which is one of the largest locations to outsource waste generated in the U.S, decreased the number of recyclables purchased by approximately 27%. At the start of 2018, China further distanced themselves from contaminated U.S. recyclables by banning the import of recyclable waste by way of the National Sword Policy, leaving more waste to be sorted by facilities in the U.S. According to Mitch Hedlund, the executive director of an organization called Recycle Across America,

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[1] Sinai, Mina. "Surprising Recycling Statistics." *RecycleNation*, RecycleNation, 4 Dec. 2017, recyclenation.com/2017/11/surprising-recycling-statistics/.

improper recycling causes equipment used by recycling centers to break very frequently.[2] Often, recycling bins designated for different materials are located in inconvenient locations or are far away from one another. There are also no measures taken to prevent the wrong material from being inserted into a bin designated for a particular material. A system is needed to prevent the contamination of recyclable materials and to also make recycling more convenient in public places. A system needs to be able to accept plastic, aluminum and glass bottles, while also having an above average capacity to encourage recycling.

1.2 Objective

Author(s): BTB

The objective of this project is to design and prototype a device that accepts plastic, aluminum, and glass bottles, mixed with other miscellaneous items of trash, and automatically sorts the materials into separate containers. The device will be able to differentiate between acceptable and unacceptable materials and sort them accordingly in order to prevent recycling contamination. Reducing the amount of recycling contamination before the materials reach a recycling plant could help to increase profitability within the recycling industry as a whole.

1.3 Background

I. Author(s): SOQ

[2] Germain, Anne. "Recyclables: Changing Markets." *National Waste & Recycling Association*, vol. 7, Feb. 2019, p. 1.,

In terms of analyzing the practicalities of a Circular Economy, the main goal in generating greater resource productivity is to make the recycling process profitable. To do this, one must tackle the Herculean task of sorting the stream of waste from human consumption to find materials that can be reused or recycled profitably. Colloquially called “The Big Sort”[3], many different methodologies are in use today to recycle and reuse different types of materials from waste that cannot be reused or recycled. The most commonly used in the US today is single stream recycling (SSR) wherein all types of recyclables are consolidated into a single stream of recyclable waste. Almost 77% of all Materials Recovery Facilities (MRF) are designed to process SSR[4]. This introduces the unwanted side effect of cross-contamination, whereby waste that cannot be recycled, or could potentially damage the recycling equipment, enters the recycling stream. Therefore, this contamination directly affects the profit margins that MRFs can achieve. Old and new technologies have been put in place to raise the MRFs’ sorting accuracy, though they can be costly, and impractical.

The need arises for the recycling stream to be standardized, by which consumers and corporations disposing of their recyclables can guarantee that when their stream of materials arrives at the MRF, it will contain a maximum percentage of contamination, so that the MRFs can lower the overall contamination in the single stream of recycling that arrives at the Facility. This could be achieved through the implementation of a smart

[3] Shapiro, Ari. “The Big Sort.” *NPR Science Friday*, 11 July 2016, https://www.sciencefriday.com/wp-content/uploads/2016/07/TheBigSortTranscript.pdf.
[4] Damgacioglu, H., et al. "Recovering value from single stream material recovery facilities – An outbound contamination analysis in Florida." *Waste Management*, vol. 102, 2020, pp. 804-814. 2019.11.020.

device that can sort the waste that has just been disposed of for recyclable materials before it reaches the MRF.

The input and output capabilities of the device in question should be relatively straight forward. The proposed device would need just two inputs. A single 120 VAC plug, and unsorted trash containing recyclable bottles. Once the trash is inserted into the device, a multitude of methods could be used to determine whether the current item of rubbish inside of the device is either a plastic, or glass bottle, an aluminum can, or miscellaneous trash. Therefore, the outputs of this device are the four categories set out beforehand: glass bottles, plastic bottles, aluminum cans, and miscellaneous trash. The device would use two sensor modules, one for capacitance sensing to detect aluminum, and one as a pressure sensor to detect whether the given item is a plastic or glass bottle. A third module will be used as an Image Recognition System to recognize bottles and cans from other waste. If the device in question were to be implemented on a wide scale, so that the streams of recycling have at least some standardization in plastic bottle streams, that would directly target the biggest problem MRFs have in recycling materials, contamination. To better understand how this proposed device could tackle such a problem, the next section describes what type of contamination exists in the recycling stream, and how it affects the profit margins of MRFs.

CONTAMINATION

II. Author(s): SRP, KRS, SOQ

More MRFs use single stream recycling versus any other because it is easier for people to contribute all recyclables to one bin, rather than manually sorting it ahead of

time. Even though this leads to more material getting recycled, it increases the total amount of contamination in the recycling stream that arrives at the MRF. Contamination can be non-recyclable materials, residual glue on the packaging, uncleaned material, etc. This increase in contamination causes recycling plants to lose revenue because of the loss of material. This problem has increased to such a degree that some major recycling plants have stopped operating their facilities including Recycle America, Republic Services, and ReCommunity.[5] Another problem that occurs from excess contamination is that the machinery in MRF can be damaged. One example of this is if plastic bags aren't sorted out in the earlier stages, they can get stuck in the gears of machinery and even cause them to break.[3] If materials like cans and bottles are flattened or partially destroyed it can be harder for the material to get automatically sorted correctly even causing some materials to be labeled incorrectly.

Contamination has become more of an issue in recent years because China (and others), who used to buy most of our bulk recycling materials, has changed their requirements pertaining to contamination percentages. The US was exporting approximately 40% of its recyclables (to places such as China, Thailand, Malaysia, and Vietnam), due the lack of waste management infrastructure (in the US) to process domestically collected waste.[6] Over the last couple years those countries of export have become extremely stringent on contamination standards at first and have more recently even banned many (if not all) waste recyclables from import. These restrictions have

[5] Damgacioglu, H., et al. "Recovering value from single stream material recovery facilities – An outbound contamination analysis in Florida." *Waste Management*, vol. 102, 2020, pp. 804-814.2019.11.020.
[6] Damgacioglu, H., et al. "Recovering value from single stream material recovery facilities – An outbound contamination analysis in Florida." *Waste Management*, vol. 102, 2020, pp. 804-814.2019.11.020.

caused major impacts to the waste management companies in the US by causing costs to go up and revenues to go down. In order to adjust, many MRFs have had to incur capital expenditures towards new technologies in an attempt to produce a “cleaner”, higher quality product.[7] Those MRFs that could not afford such endeavors have had to close their doors due to unprofitability.

If the stream of recycling became a little less contaminated, then MRFs would not need to justify purchasing expensive equipment to boost the sorting efficiency of their facilities. While having redundancy is advantageous, the addition of more sorting modules will eventually yield diminishing returns. MRFs could instead spend that money on expanding their current capabilities to handle a higher volume of recyclable waste. The proposed device, if implemented at a large scale, could drastically reduce the incoming waste coming to facilities by sorting it before it reaches the facility, ensuring that the waste being delivered has a maximum amount of contamination that could be considered trivial by the MRF. In order to understand how the nuances of running MRFs as a business, the next section will illustrate how sorting and profitability are correlated.

SORTING & PROFITABILITY:

III. Authors(s): SRP, KRS

The current process in the recycling industry tends to be a single-stream service. In a single-stream recycling cycle, all “recyclables" are commingled when picked up by

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[7] Germain, Anne. “Recyclables: Changing Markets.” *National Waste & Recycling Association*, vol. 7, Feb. 2019, p. 1.,

the materials handling facilities. They are then processed by machines, as well as by hand, along conveyor systems in order to try and sort out the recyclable materials. An example can be observed in US Patent 20140131488A1, Figure 1.A.[8]

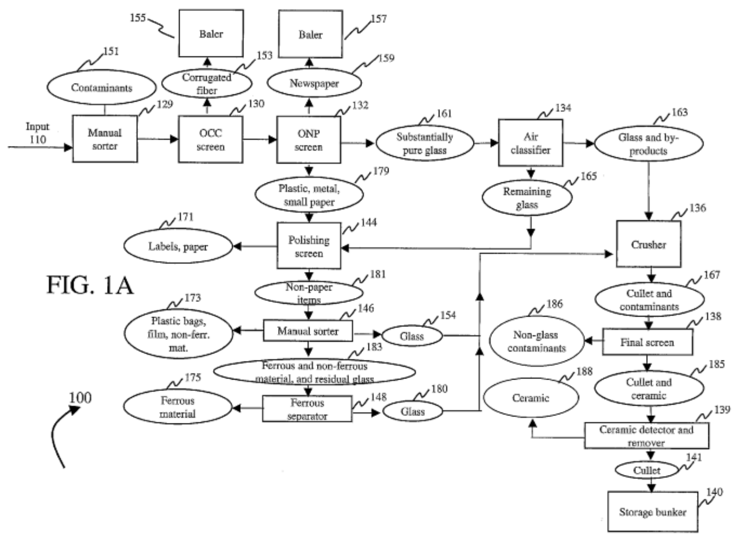


Figure 1A. The directive 146 requires a manual sorter to sort out left-over glass, plastic bags, film, and any other non-ferromagnetic material

This process allows for much contamination of the materials via both errors in sorting as well as undesirable materials getting mixed in because they are either difficult to remove efficiently, or through cross-contamination of "trash". Information obtained through presentations by Summit Reworks (Andrew Linebarger -Planner, and Marcie Kress - Executive Director) at the University of Akron (9/28/2018), as well as both a tour and presentation at KIMBLE's Twinsburg, Ohio facility (10/9/2018) have pointed out that the current technology is limited due to several factors.

First, for the MRF (Materials Recycling Facility) to be profitable, the materials must be sorted as quickly as possible. Also, for the MRF to be profitable the materials must contain as little contamination as they can achieve in the little time allotted for

[8] Bohlig, James W., and Sean P. Duffy. "Modification of Polymer Surfaces by Two-Step Reactions". *United States Patent US20140131488A1*. *United States Patent and Trademark Office*. 11 Nov. 2013.

sorting. Single stream recycling mixes together materials that may have been pre-sorted by the disposer(s), thereby contaminating the materials, thus they will need to be re-sorted. Co-mingled, single-stream recycling introduces unwanted materials (contaminates) to the mix (such as plastic bags into paper bundles, oils to paper and cardboard bundles, all plastics are mixed together) which can lead to much waste (ending up in the landfill.)[9] Current recycling streams rely on people to sort their own trash, and many people end up throwing whatever they feel like into them, thereby further contaminating the materials.

The process of separating materials in single stream recycling at a MRF is extremely complicated. Even though there are a lot of parts to separating the material they are usually separated out one by one. Once the materials get to the MRF the oversized objects are separated by a crane and the rest are sent to a conveyor belt. Then, problem objects such as plastic bags, coat hangers, and big objects, are taken out manually by workers to prevent the machinery from getting jammed. Then, another stage of sorting is done by workers to remove smaller contaminants. At this point the only process removing contaminants is human workers. This can lead to human error. In the next phase a star screen is used to filter out paper. After, glass is sorted out by gravity. Since it is heavier than plastic and aluminum, glass falls through a screen into bins. This can lead to other damaged or pieces of material to fall through. Next a magnet pulls out all metals. Once this is done an eddy current separator is used to filter out the aluminum with bursts of air. Last infrared lasers are used to separate different grades of plastic into different bins. These are the technologies currently in place, however, the next section

[9] PEEK, KATIE. "Single-Stream Recycling." *Popular Science*, vol. 283, no. 2, Aug. 2013, pp. 68–69.

will delve into technologies currently being developed that might benefit the functionality of the device, as well as MRFs in general.

LEADING EDGE & FUTURE TECHNOLOGY

IV. Author(s): BTB, SOQ, KRS

Currently, methods for separating plastic materials using electrostatic separation, froth flotation[10] and gravity have proven to yield high rates of error. There is at least one patented device that uses EM radiation to separate and sort common consumer plastics. This method uses a sensor array to capture readings from an EM radiation transmitter and the readings are used to classify different types of plastics, as shown in US Patent 5318172A.[11] The goal of this device is to provide an accurate and cost-effective method for classifying plastic materials such as bottles and other variations of packaging. The device can ignore things like labels and residue contamination in order to produce an accurate result. Another technique for identifying and sorting recyclable

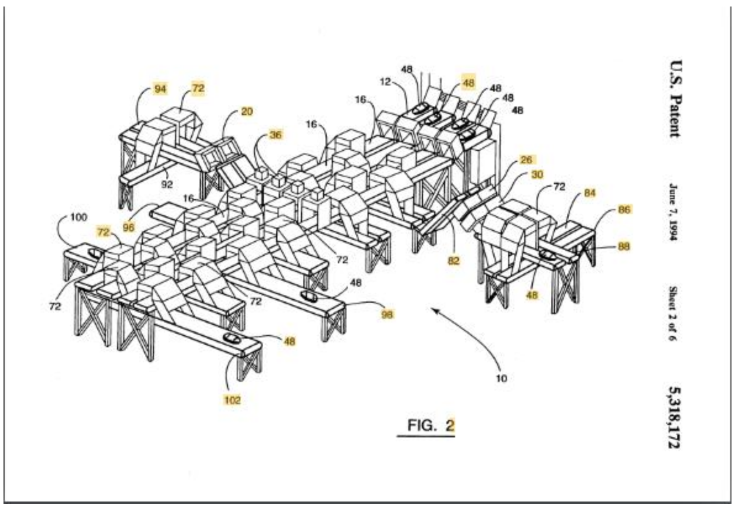


Figure 2: A perspective view of the plastic separation system of the present invention.

[10] L. M. Kumar, K. Shankar, K. H. Shah, T. Chinnu and V. Venkataraman, "Embedded wireless-enabled low cost plastic sorting system for efficient waste management," *2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS)*, Trivandrum, 2013, pp. 154-158.
[11] Kenny, Garry R., et al. "Process and apparatus for identification and separation of plastic containers" *United States Patent US5318172A. United States Patent and Trademark Office.* 7.6.1994

plastics involves near-infrared reflectance spectroscopy (NIRS). This method is cheaper than alternative sorting methods that involve X-rays, optics and Hyper-Spectral Imaging (HIS). NIRS can detect unique signatures produced by common plastics and differentiate between different polymers. It can also be used for chemical analysis which can be used to further decrease contamination among recyclables. Common consumer plastics most likely to be recycled that the spectrometer aims to detect include Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP) and Polystyrene (PS). The resulting data may be used by an embedded system to separate the plastics from the stream of materials. The same concept could be utilized to detect cardboard and paper contaminated by oils and grease based on the chemical information obtained by the spectrometer.[12] The NIRS approach is a cost-effective solution since sorting the many different polymers from each other is normally very labor intensive. This makes NIRS technology a valuable tool to improve the profitability of the recycling industry. NIRS isn't the only tool that could prove to have a positive effect on the industry.

Recently, many models working with Deep Neural Networks (DNN) analyzing life feed from a camera have achieved great accuracy in classification tasks. Indeed, many industries now rely on visual detection algorithms to sort out defective products in their production lines. Furthermore, there are industries such as the MRF which might benefit from the performance of these models through the classification and detection of certain recyclables from the live feed of a camera. While not directly relating to

[12] M. Bonaccorsi, G. Rateni, F. Cavallo and P. Dario, "In-line industrial contaminants discrimination for the packaging sorting based on near-infrared reflectance spectroscopy: A proof of concept," *2017 IEEE SENSORS, Glasgow*, 2017, pp. 1-3

recyclables, in their research paper, A. Costa et al used three different DNN models to determine the best performing model in the detection of defects in tomatoes.[13] They achieved a validation average precision of 94.2% using the ResNet50 model.

One of the drawbacks associated with DNN is their tendency to overfit small datasets. The authors relied on the live feed from cameras placed in field machines that harvest the tomatoes, the defective ones would be sorted by humans to allow the dataset to be labeled as having or lacking defects accordingly. Thus, the data collection and labeling tasks are quite trivial, which therefore allows for the accelerated accumulation of a large dataset. A similar DNN model could be used in the classification of plastic/glass bottles and cans, however the only issue would be how to create a labeled dataset with enough images to train a DNN model without running the risk of overfitting the data. The labeling of the data must be done manually with already sorted cans and bottles.

The Chinese patent CN106670122A[14], describes an "Automatic recognizing, sorting and recovering system for household rubbish", in other words, a machine for installation in the household that automatically sorts trash. In the described system, there are several technologies including photo identification devices, x-ray identification devices, computer control system with cloud server database connection, as well as conveyor systems, collating units, and mechanized hands (sorting devices). This device proposes a system that first pretreats rubbish for liquid-solid separation, dries the solids in a sealed negative-pressure unit (to contain/limit atmospheric pollution), and then begins

[13] Costa, Arthur Z. Da, et al. "Computer Vision Based Detection of External Defects on Tomatoes Using Deep Learning." *Biosystems Engineering*, vol. 190, 6 Dec. 2019, doi:10.1016/j.biosystemseng.2019.12.003.

[14] 邸建军臧瑜鑫, et al. "Automatic recognizing, sorting and recovering system for household rubbish" *Chinese Patent 106670122A. People's Republic of China Patent Office.* 5.7.2017

the sorting process for the solid waste. Through a series of redundant checks utilizing the x-ray and photo devices as well as the data sets in the cloud server, the system then automatically sorts the refuse into categories such as recyclables, organics, and suspected junk (mixed products needing hand sorting for materials of potential value – such as items containing both plastic and metal parts). These sort routines can be further expanded to classify and sort materials into separate bins for metal, plastics, cloth, glass, and paper (or even further into ferrous metals, copper, aluminum, etc.).

While this undertaking far exceeds the parameters of the device being proposed in this document, it demonstrates that presorting early in the recycling process is advantageous to both energy conservation as well as to efficiency in reclaiming valuable materials; it also shows that a relatively small sized recycling sorting device can be feasibly implemented (even for the home).

SMART RECYCLING BIN

V. Author(s): SOQ

Throughout the research on this project, it became quite clear early on which technologies would be useful in the Smart Recycling Bin project, and which were not within the realistic scope of the design. For example: the vast majority of modern MRFs use spectroscopy to determine plastic waste. Not only that, this system can also detect which types of plastic are in the stream of waste (PET, ABS, etc.) However, these systems rely on technology that is quite expensive. So much in fact that only large-scale operations are able to utilize these systems profitably. The Design Team did not see this type of technology as being attainable in this project. Likewise, most MRFs use manual

sorting operators, which is not only prone to errors, but would defeat the purpose of engineering and design in this project. This left a collection of technologies to be explored that the Design Team determined to have the highest chance of success in the sorting of waste for recyclable bottles and cans.

To start off, the device will have three stages. The first stage will consist of two modules, a capacitance sensor, the Bottle/Can Recognition System (BCRS), as well as a conveyor belt to transport the item to the second stage. A capacitance sensor should be able to detect any material that contains the property of high electric conductance. The conductivity of Aluminum is higher than most metals, at around 10^6 S/m, while the conductivity of glass and plastic are around 10^{-11} and 10^{-12} S/m respectively. A sensor measuring the capacitance within a plate being hovered over the input of the device would immediately detect a larger capacitance than normal across the sensor’s electrodes, thereby detecting when an aluminum can has entered the device. Furthermore, the sensor might also be able to detect the capacitive effects of glass and plastic, since the electric conductivity of air is around 10^{-15} S/m, but the change in capacitance would be much greater for aluminum cans, giving a wide margin for detection. The second module dubbed BCRS is tasked with determining whether the item introduced in the device is a bottle or a can. There are many image recognition algorithms built for classification with high accuracy, and some are very resource efficient. But as previously mentioned, the biggest issue is coming up with a large enough dataset to prevent overfitting the model. To circumvent this issue, the Design Team has already started the collection of photographs of bottles and cans to start training the model as soon as possible.

The second stage of the device will contain two more modules. A needle-tipped pressure sensor, and a directional chute to direct the item to the third stage. The pressure sensor will use a needle to poke at the item and graph its pressure response curve. An elastic material like plastic would absorb some of the pressure and store it, while glass, which is not an elastic material, would reflect back all of the force that the needle applied. The difference in pressure response graphs would yield a nice margin of the detection of plastic versus glass. Finally, the system should make a decision based on what the sensors and the BCRS module determined the item to be. The directional chute would then direct the item of rubbish to a particular container in the third stage where four containers pertaining to the four designated categories are located. Many details still need to be determined before any attempt at determining the accuracy of the system can be quantified. However, these design principles will function as the foundation of what the Design Team hopes the device will be able to achieve.

VI. Author(s): BTB

Overall, the recycling industry struggles regularly with contamination issues which negatively affects MRFs and the employees working for them. Methods involving single-stream recycling have proven to be inefficient when considering the rates of contamination of an average MRF. Contamination among recyclables is one of the leading causes of lost profit in the industry because the inability to sort materials leads to recyclable items being thrown away. There is an obvious need for improvements in the recycling industry that may involve more efficient ways to detect and separate desired materials. These new methods that MRFs may adopt could include the use of Deep Neural Networks (DNNs) and near-infrared reflectance spectroscopy (NIRS) and could

greatly improve efficiency and, in turn, profitability. Our smart recycling bin aims to target the prevention of recycling contamination long before the materials reach an MRF. This decrease in contamination could potentially make recycling more profitable as a whole. The device will utilize an image sensor much like the DNN described above in order to differentiate between bottles and cans being inserted and dispose of garbage in a separate bin. For redundancy, a capacitor will be implemented in order to identify aluminum. To filter glass bottles from aluminum and plastic, the device will gauge the pressure response of the bottle. If the bottle is able to withstand pressure up to the max set threshold, the device will know it's dealing with glass and if not, the material must be plastic. The materials will then be separated into their respective containers

1.4 Marketing Requirements (KRS):

1. The system shall be able to accurately detect materials
2. The system shall be able to accurately sort bottles and cans from mixed recycling
3. The system shall be intuitive for the user
4. The system shall detect and sort in a timely manner
5. The system shall provide feedback of the detected material to the user

2. Engineering Analysis:

2.1 Circuits

2.1.1 Power (KRS & SRP)

Power will have an AC/DC converter to convert the 120 V AC into useable DC voltages. Power must be distributed using a circuit with 12-, 5-, and 3.3-Volt rails. The voltage rails will be established using a 12 VDC power supply, which will supply the 12 VDC voltage rail. The Explorer 16/32 microprocessor board will be powered by the 12 Volt rail and then perform the needed DC/DC step-down transformations to supply the 3.3 and 5 VDC voltage rails. These are the expected needs to power all the electronics in the system.

2.1.1(a) Power Revisions 1 (KRS)

The power requirements for this project have changed due to the addition of servo motor(s) and an oversight on the requirements to supply power the Jetson Nano. The Jetson Nano requires a 5 VDC source capable of 2 A service, which is beyond the supply limits of the Explorer 16/32 board. Therefore, a DC/DC converter will be required to act as a voltage regulator/power supply for this unit. The main power supply for this project is a 12 VDC, 5 A supply, which is more than adequate for the system's needs (as per earlier engineering analysis). The Explorer board will still be utilized as a 5 VDC and 3.3 VDC supply source for other units in the system. The Monolithic Power Systems Inc. part number MEZD71202A-G (Digi-Key part 1589-1465-ND) is a single output 5V, 2A, 6.5V

- 24V Input DC/DC converter sufficient for supplying the power needs of the Jetson Nano and will be supplied with 12 VDV from the main power supply unit.

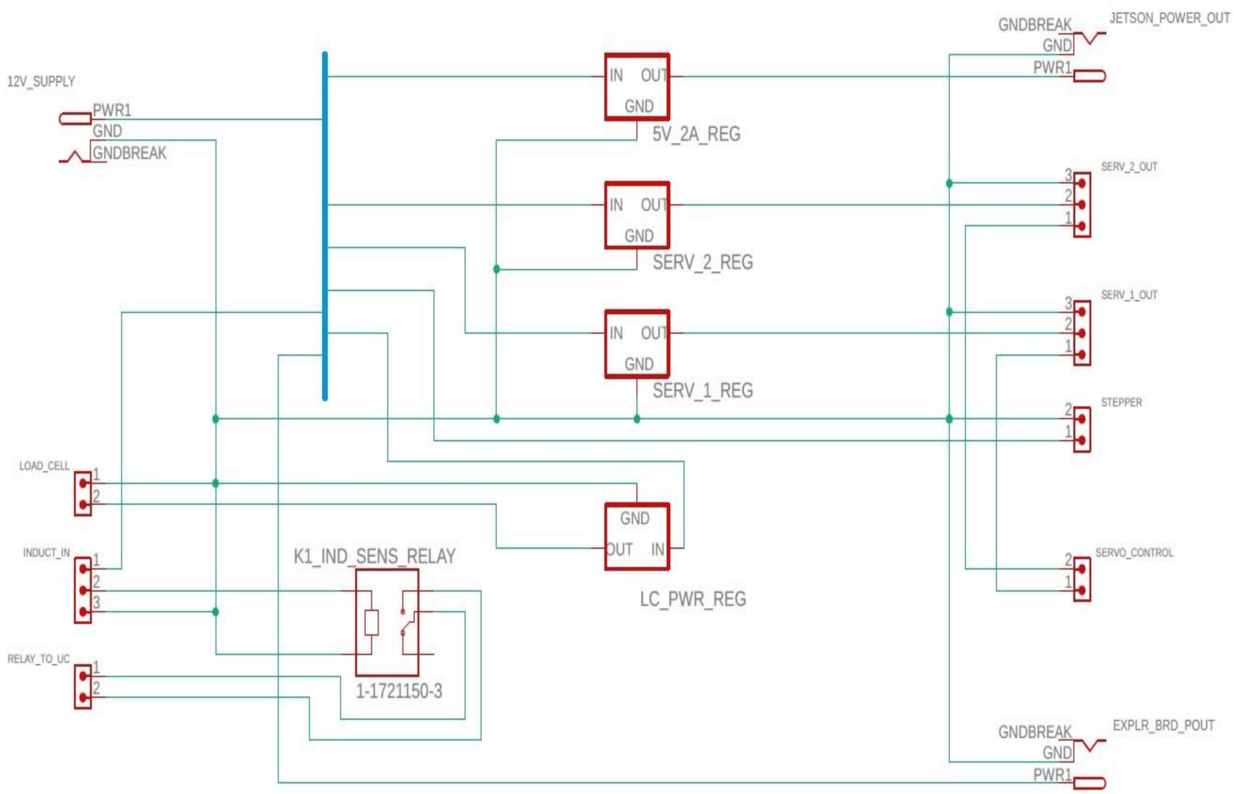
A servo motor (or possibly two) will be utilized to implement the new Transition Stage of the system. The transition stage is mechanically simpler to implement than the original Trap-Door, which was to transition the recyclable materials from the detection/identification stage to the sorting stage of the system. A servo motor will be utilized to actuate a "Sweeper" that will move (or sweep) the recyclable material from the detection area to a shoot that leads to the sorting unit. Note: a second servo may be required to actuate a door to the shoot if it is found that the recyclables can enter the shoot uninhibited prior to the detection and sensing being completed. It is proposed to utilize PARALLAX standard servo motor(s) for this project.

The servo power requirements are: 4 to 6 VDC*; Maximum current draw is 140 +/- 50 mA at 6 VDC when operating in no load conditions, 15 mA when in static state. The manufacturer states not to utilize unregulated power supplies, nor the Vdd pins of a microcontroller because the amperage draw can spike significantly when under load. It is therefore proposed to utilize the XP Power part number VR05S05 (Digi-Key part 1470-VR05S05-ND) to regulate the power for each servo utilized in this project. The VR05S05 is a single output 5V, 500mA, 6.5V - 36V Input DC/DC converter sufficient for supplying the power needs of the Parallax servo motor.

A power distribution circuit was designed in order to implement the desired power supplies and distribute them to the proper units. Due to the fact that

the load cell and its strain gauge network are components that are sensitive to voltage differences and power supply ripple, it was determined that utilizing another XP Power VR05S05 to regulate the power supplied to the load cell would be a prudent decision. The schematic for this distribution circuit is shown in **Figure 2.1.1.1**. It was decided that this circuit was the ideal location to house the inductive sensor relay (discussed in **section 2.1.2**) as well as to serve as the hub for routing servo control signals and the inductive sensor signal as can also be seen in **Figure 2.1.1.1**.

Figure 2.1.1.1: Power Distribution Circuit Schematic (KRS)



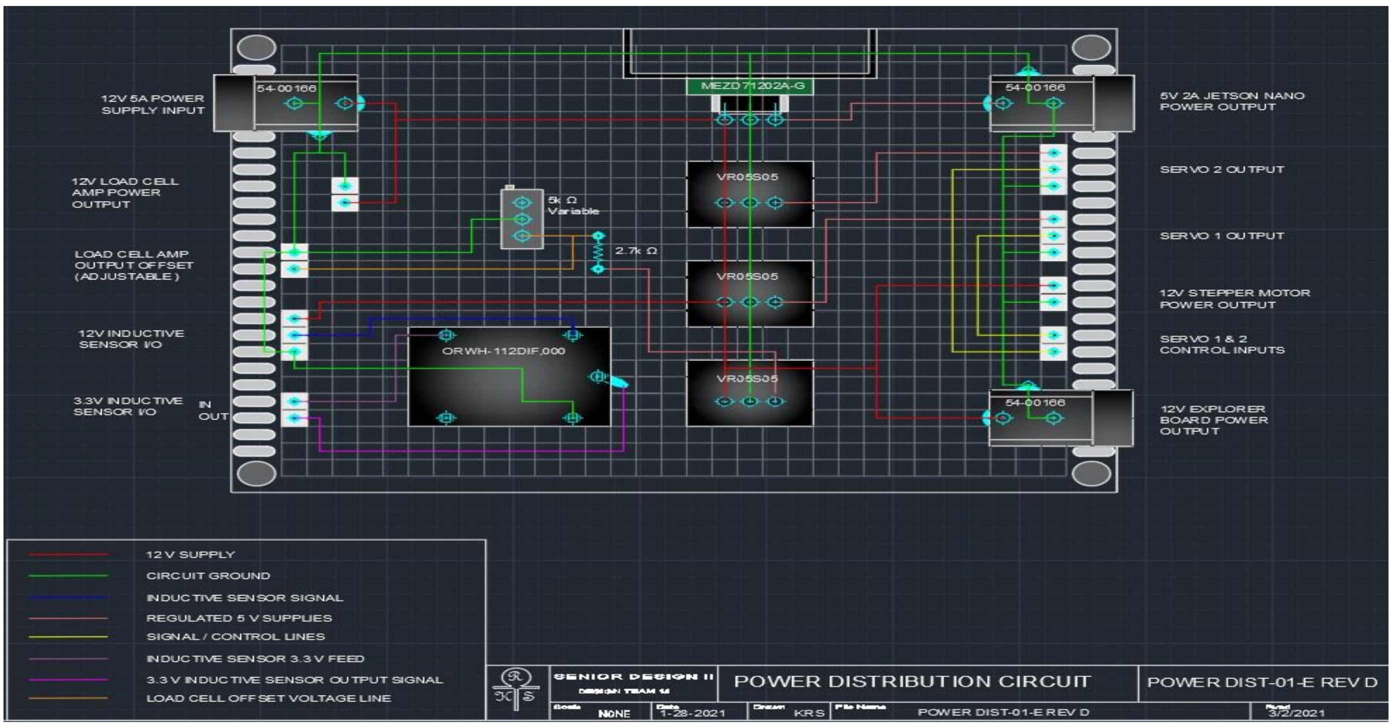
2.1.1(b) Power Revisions 2 (KRS)

During the integration testing between the power distribution circuit and the Jetson Nano, it was discovered that there were two different power supply input options built into the Jetson Nano device; one being the 5VDC, 2A input that the distribution circuit had been designed for, and the other being a 5VDC, 4A input. Integration testing revealed that the 2A supply was not actually enough power for processing the image and the Deep Neural Network (covered in **section 2.2.2**) simultaneously. Therefore, a 5VDC, 4A service will be needed to supply the Jetson Nano. Unfortunately, this results in more total amperage draw for the entire system than the chosen 12VDC, 5A power supply can handle. It was determined that a separate phone style micro-USB power supply unit (utilized by the image recognition personnel during initial programming) would be utilized to supply the 5VDC, 4A power requirements of the Jetson Nano in the final build of the project.

A revision of the load cell amplifier circuit (discussed in **section 2.1.2(a)**) also created a needed change to the original power distribution circuit design. The revised load cell amplifier can be powered by 2.7 to 36VDC and can supply precision voltage references of 1.24-, 2.5-, 5-, or 10VDC. With the parameters chosen for implementation in section **2.1.2(a)**, the power distribution circuit was modified to supply 12VDC to the load cell amplifier. The 5VDC, 500mA regulated supply that was originally slotted to power the load cell, has been altered by adding an adjustable voltage divider network in line with its output in order to supply an offset voltage to the load cell amplifier. This adjustable offset

voltage will be utilized to set a peak output of 3.3VDC at full load for the load cell amplifier in order to satisfy the peak input voltage of the microprocessor's AD converter. The schematic for this redesigned power distribution circuit can be seen in **Figure 2.1.1.2** (Note: the 5VDC, 2A supply was abandoned in-place).

Figure 2.1.1.2: Power Distribution Circuit v.4 Schematic (KRS)



2.1.2 **Sensors** (KRS)

Materials properties will be utilized to identify metals, plastics, and glass for sorting purposes. Initial research into capacitance sensing showed that materials can be discerned by utilizing their relative permittivity (ε_r). The relative permittivity of metals is 1, but plastic (polyethylene) and glass are both dielectrics with relative permittivity of 2.2 and 6.0 (4-7) respectively. While it is possible to utilize capacitive sensing to determine if a material is either plastic, glass, or

metal, the implementation of such a sensor is complex because the capacitances to be detected are small and the changes of capacitance between the material types is even smaller. It would be necessary to first amplify the output of the sensor and then connect the output of the amplifier to an oscillator, and then measure the frequency of the oscillator. Those frequencies would then have to be compared to a look-up table programmed into the microcontroller in order to determine the material type. The look-up table would have to be generated through experimentation with both the sensor and different materials. Because the distance to the bottle/can may vary in this device and the varying sizes of the cans/bottles, utilizing a capacitive sensor to discern material make-up exceeds the threshold of complexity for senior design. The costs of regularly available capacitive sensors are in the area of $200, which is also restrictive.

As an alternative to capacitive sensing to determine all the materials, it is proposed to instead separate the materials sensing into two units; one for metal detection and one for discerning between plastic and glass. For the detection of metal cans/bottles, it is proposed to utilize an inductive type sensor. Inductive sensors are governed by magnetic flux density, also referred to as magnetic inductance. The materials property that affects the inductance is permeability (μ). Since both plastic and glass are non-magnetic materials (i.e. $\mu_r = 1$), the inductive sensor will not detect these materials and only sense the aluminum or steel cans/bottles. This sensor will operate on DC power, sense the material property of metal recyclable inputs, and the positive detection signal from the inductive sensor will be utilized in the actuation of the sorting unit as described in **Table**

5.3.1. The proposed inductive sensor for this project is the IMF Efector Model IM5116 whose parameters are shown in **Table 2.1.2.1**.

The inductive sensor's output function is normally open and will output a maximum voltage drop of 2.5 V when metal is sensed. The 'closed' state of the sensor will output a signal of approximately 12 VDC that will be utilized to actuate a relay to send a 3.3 VDC signal to the microcontroller to be processed for actuating the sorting unit.

Table 2.1.2.1: Inductive Sensor IM5116 (KRS)

Supplier/Manufacturer	IMF Efector
Electrical Design	PNP
Output Function	Normally Open
Sensing Range [mm]	35
Dimensions [mm]	40 X 40 X 54
Current Consumption [mA]	< 20
Operating Voltage	10…36 DC
Real Sensing Range Sr [mm]	35 ± 10 %
Operating Temperature (ambient) [°C]	-25…70
Protection	IP 67
UL Approval	Type 1, Class 2, File E174191
Weight [g]	152.5
Housing	Rectangular
Sensing Face	5 Position Selectable
Connector	1 - M12; Locking, Rotatable
Display	Switching Status – 1 Yellow LED Power – 1 Green LED

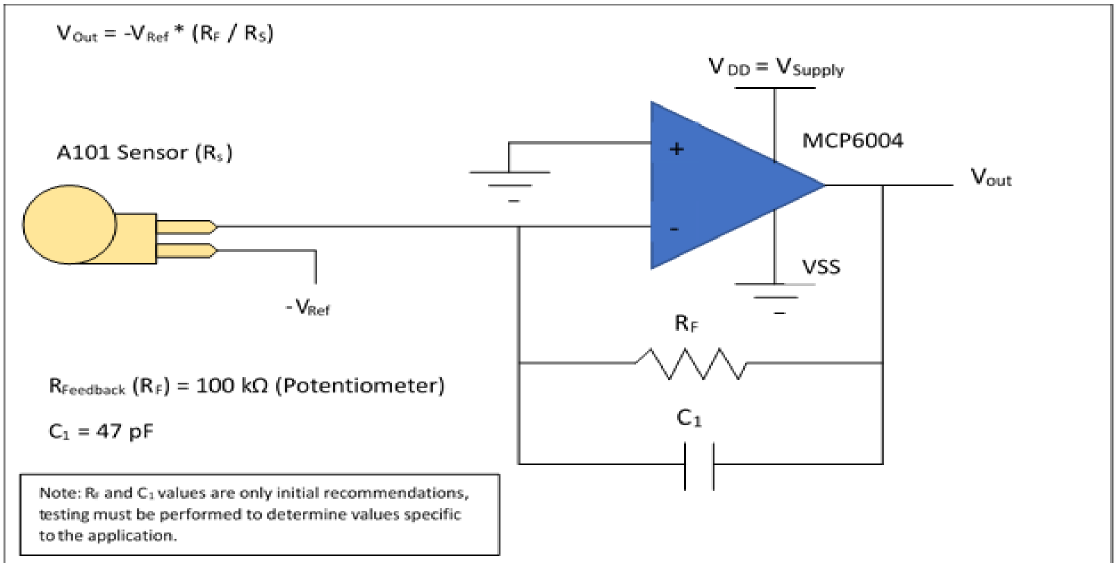
When it comes to materials properties, plastic bottles and glass bottles have an entirely different resistance to pressure applied to the surface (i.e. flexibility). When a pressure is applied to the surface of a plastic bottle, it will flex in comparison to the glass bottle. This is the principle that is planned to be utilized in this project to discern between the two materials. When exploring existing pressure sensor devices, it was discovered that most devices, or sensors, were designed to be implemented on hydraulic and/or pneumatic pipes and tubes. These sensors are not only of the wrong design for implementation in this project, but also come at a high price. Further research into pressure sensing has led to piezo-electric pressure sensors. Piezo-electric pressure sensors are available in various shapes and sizes and are relatively inexpensive. The initial proposal is that a sensor be placed at the end of a linear actuator to act as a pressure probe (see **Figure 6.3**). The actuator will extend out to contact the bottle, then continue to extend/exert force to the surface of the bottle. The pressure sensor will feed-back a reading corresponding to the surface resistance/flexibility of the bottle. If the feed-back reading is high, it will be an indication that the bottle is made of glass. If the reading is low, it will be an indication that the bottle is made of plastic. This sensor unit will operate on DC power inputs, receive the linear actuator signal from the microprocessor, actuate a linear motor to extend to and apply pressure to the recyclable plastic or glass container, then sense the material property (surface tension) of the recyclable container, and output a sorting actuator signal in accordance with **Table 5.3.2**. The proposed piezo-electric pressure sensor for this project is the Tekscan FlexiForce Standard Model A101 whose parameters are

shown in **Table 2.1.2.2**. In order to implement the A101 sensor it will be necessary to build an op-amp circuit (shown in **Figure 2.1.2.1**) to drive the output of the sensor. This op-amp circuit can be adjusted to accommodate different loads on the sensor by adjusting the feedback resistor and the capacitor values.

Table 2.1.2.2: Piezo-electric Pressure Sensor FlexiForce Standard Model A101

Supplier/Manufacturer	Tekscan
Thickness [mm]	0.203 (0.008 in.)
Length [mm]	15.6 (0.62 in.)
Width [mm]	7.6 (0.30 in.)
Sensing Area [mm]	3.8 (0.15 in.) diameter
Connector	2-pin Male Square Pin
Substrate	Polyester
Pin Spacing [mm]	2.54 (0.1 in.)
Linearity (Error)	< ± 3% of full scale
Response Time	< 5μsec
Operating Temperature [°C]	-40 – 60 (-40 - 140°F)
Durability	≥ 3 million actuations
Temperature Sensitivity	0.36%/°C (± 0.2%/°F)
Measurement Range	Up to 44 N (10 lb.)
Standard Force Range	18 N (0-4 lb.)

Figure 2.1.2.1: Pressure Sensor Output Driver Op-amp Circuit (KRS)



Pressure Sensor Output Processing Circuit

Upon further analysis of the feasibility of utilizing the previously described pressure sensor and linear actuator setup, it was discovered that there were too many variables in the equation. The design concept for this project is for the recyclable item to drop into a box, or examination area, where the image detection, metal sensing, and the pressure sensing would be performed. The fact that the recyclable items will vary in both size (height & girth) and shape (cylindrical or square), as well as the fact that the item's location will not be precisely known within the examination area (due to being "dropped" into the examination box), all pose problems for attempting to "poke" the item and measure its feedback resistance accurately. In order to simplify the means by which plastic and glass are discerned from each other it is proposed to utilize a beam style load cell in a scale type setup. The differences in materials densities between plastic and glass bottles is extreme enough to easily differentiate between

the material types by measuring the force exerted upon them by gravity. The load cell will utilize strain gauges mounted and pre-wired in a Wheatstone Bridge configuration to convert the applied force to a measurable output voltage. The output of the load cell will be in the millivolt range and the span utilized in this application will be small, therefore it will be necessary to implement an amplifier circuit to make the signal more useable. A 5kg load cell with a 1mV/V output as shown in **Table 2.1.2.3** has been selected for this application. When utilizing a 5V excitation voltage, this will lead to a full scale (5kg load) range of 5mV, of which the anticipated readings (0-1kg) will be in the range of ≤ 1mV, which is why the amplifier circuit will be necessary. Research has pointed to the Analog Devices AD7780 24-Bit, Pin-Programmable, Ultralow Power Sigma-Delta Analog to Digital Converter IC to accomplish both the signal amplification as well as the conversion from an analog signal to a digital signal for use by the microprocessor. The functional block diagram for the AD7780 can be seen in **Figure 2.1.2.2**, where it can be observed that the device can be operated at a gain of either 1 or 128, and either a 10 Hz or a 16.7 Hz filter can be selected. When utilizing the 16.7 Hz filter at a gain of 128, the device settling time is a low 120 ms. The data output coding for the AD7780 is offset binary and is SPI communication compatible. **Figure 2.1.2.3** shows the typical weight scale setup for the AD7780, however EMI filtering via R-C antialiasing filters as well as decoupling capacitors will be needed for implementation. The design schematic of the AD7780 Load Cell Amplifier can be seen in **Figure 2.1.2.4.**

Table 2.1.2.3: Parallel Beam Load Cell SEN-14729 (KRS)

Supplier/Manufacturer	SparkFun Electronics
Capacity	5 kg
Safe Overload	120 % FS (full scale)
Ultimate Overload	150 % FS (full scale)
Rated Output	1.0 ± 0.1 mV/V
Excitation Voltage	5 VDC
Input Resistance	1000 ± 10 Ω
Output Resistance	1090 ± 10 Ω
Electrical Connection	4 color wire, Ø0.8 x 200 mm
Non-Linearity	± 0.05 % FS (full scale)

Figure 2.1.2.2: AD7780 Functional Block Diagram (KRS)

FUNCTIONAL BLOCK DIAGRAM

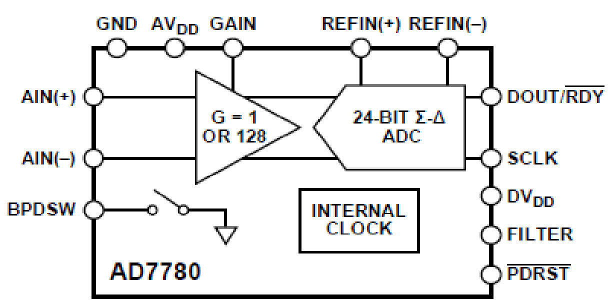
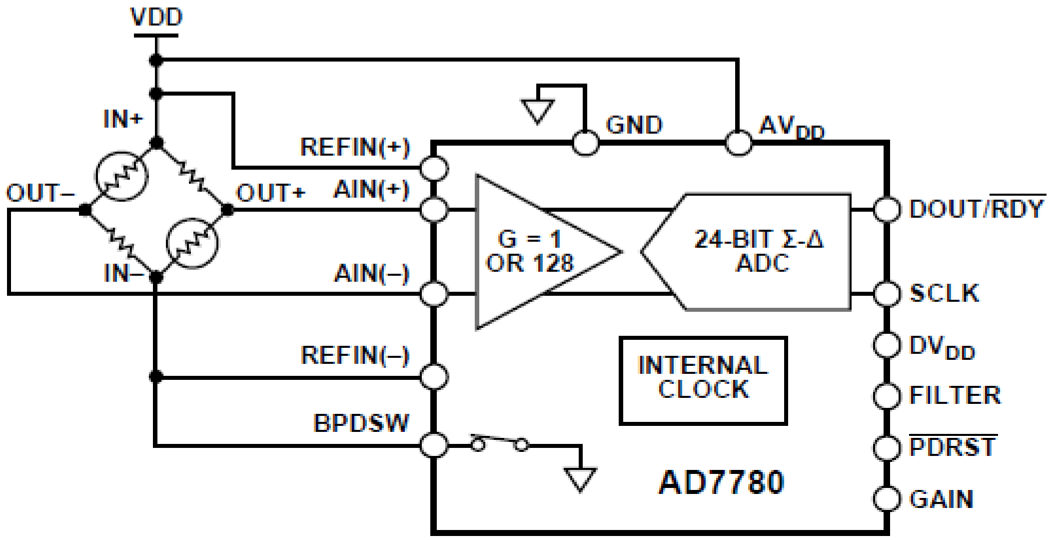


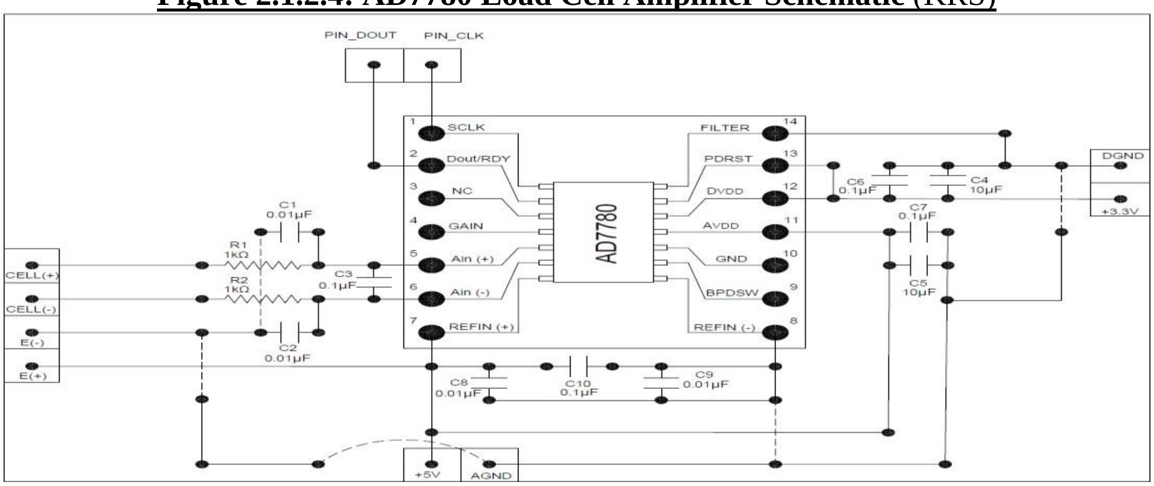
Figure 1.

Parameter	Gain = 128		Gain = 1	
Output Data Rate	10 Hz	16.7 Hz	10 Hz	16.7 Hz
RMS Noise	44 nV	65 nV	2.4 μV	2.7 μV
P-P Resolution	17.6	17.1	18.8	18.7
Settling Time	300 ms	120 ms	300 ms	120 ms

<u>Figure 2.1.2.3: Typical Weight Scale Using the AD7780</u> (KRS)



<u>Figure 2.1.2.4: AD7780 Load Cell Amplifier Schematic</u> (KRS)



2.1.2(a) Sensors Revisions (KRS)

While testing and analyzing the AD7780 Load Cell Amplifier Circuit, it was discovered that establishing SPI communication between the amp and the microcontroller would require “bit-banging” in terms of writing code, in order to read the 32 bit offset binary signal from the load cell amp. This “bit-banging”

would add many lines of code to the program and involve extensive hours of coding and troubleshooting that could be better utilized in the implementation and integration coding for the rest of the systems; therefore the use of an analog amplifier was analyzed. The Burr-Brown (Texas Instruments) INA125P instrumentation amplifier IC was determined to be a great choice for amplifying the load cell output signal. This amplifier has built-in precision voltage reference and can be powered from 2.7 to 36VDC, which means the 12VDC power supply will supply the needed voltage. The precision voltage reference available for this amp is 1.24-, 2.5-, 5-, or 10VDC; in order to supply 5VDC excitation voltage to the load cell a supply voltage of at least 6.25V (1.25V above the reference output) must be supplied to the amplifier, therefore 12VDC will be supplied. This analog amp will provide an amplified voltage as the output which will be sent to the microcontroller's AD converter for processing the voltage signal into a weight. It was also determined that an offset voltage would be inserted into the amplifier in order to set a peak output of 3.3VDC at full load for the load cell amplifier in order to satisfy the peak input voltage of the microprocessor's AD converter.

2.2 Embedded Systems

2.2.1 Microprocessor (BTB, SOQ)

The Microprocessor will handle all outputs of the detection module, including readings from both the inductive sensor, the load cell, and the Visual detection microcontroller. The inductive sensor's output is a voltage level that can be stepped down with a relay which then can output a digital logic level of 3.3V

and 0V. The load cell uses the SPI protocol to output a 32-bit buffer which contains the level of the load cell in hexadecimal. To simplify things, the decision was made to utilize a USB to UART serial connection as opposed to taking advantage of RS232 functionality. Finally, the stepper motor utilizes 3.3V in order power the driver circuit while the stepper motor itself utilizes a voltage of 12V. A PWM signal is responsible for stepping the actual motor. Utilizing an Interrupt Service Routine as well as a timer (TMR2) from the microcontroller, an interrupt is continuously triggered to check the status of the timer. Upon the timer reaching zero, a signal is sent to a stepper motor pin PIN_STEP resulting in the rotation of the motor.

2.2.1(a) Microprocessor Revision (BTB)

Initially, the SPI communication protocol was going to handle the readings from the load cell. As our group progressed towards the stages of implementation, the decision was made to select an alternative load cell amplifier in order to avoid using a method in the software referred to as “bit-banging”. Overall, this decision saved us a significant amount of time, allowing us to finish the project on schedule.

Figure 2.2.1.1: Calculation for Maximum PWM Resolution (BTB)

EQUATION 15-2: CALCULATION FOR MAXIMUM PWM RESOLUTION[1]

$$\text{Maximum PWM Resolution (bits)} = \frac{\log_{10}\left(\frac{F_{CY}}{F_{PWM} \cdot (\text{Timer Prescale Value})}\right)}{\log_{10}(2)} \text{ bits}$$

Note 1: Based on $F_{CY} = F_{OSC}/2$; Doze mode and PLL are disabled.

2.2.2 Visual Detection Controller (SOQ)

The Visual Detection algorithm should be able to run in the NVIDIA Jetson Nano, which is an embedded microprocessor with a dedicated GPU. This device should be able to detect whether the item in the system is a bottle or a can. The device will also serve as a status terminal to indicate the state of the system.

To implement this visual detection, a Deep Neural Network (DNN) will be trained to recognize bottles and cans from other items that are inserted into the bin. The model will be built using Tensorflow and the Darknet Framework. To achieve the fastest possible detection, the model chosen will be the YoloV3. This model outperforms similar models in recognition time and accuracy, as can be show in **Figure 2.2.2.1**. It is the perfect balance between fast detection and accurate detection.

The current model is only trained to recognize bottles. However, the design team has acquired over 2000 training and testing images for both the bottle and the can classes. With an 80/20 Training-Validation/Testing split. The model should be able to recognize bottles and cans within the allotted time of 20 seconds per the Engineering Requirements.

2.2.2(a) Visual Detection Controller Revision 1 (SOQ)

The current software running on the Jetson Nano uses Tensorflow models, rather than the YoloV3 models due to the ease of portability across different platforms. Specifically, Tflite models were found to be the fastest performing in the Jetson Nano. The GUI was written using TKinter, and the library used for UART communication was PySerial.

2.3 Signal Processing

2.3.1 Inductive Sensor (KRS)

Because some glass bottles have metal lids, the dwell time, or length of time the metal is sensed must be more than instantaneous. Therefore, it may be necessary to program into the logic of the microprocessor to require a positive signal from the inductive sensor for a period (maybe 500 ms) before determining the material to be metal. This is so that a glass bottle that happens to have a metal cap will still be sorted into the glass bin and not into the metal bin. When glass bottles are recycled, they are crushed into small pieces, which easily allows for removal of metal contamination via electromagnets or by way of sifting through sieves. If glass were to be sorted into the aluminum/metal bin, it would cause a more worrisome contamination issue down the line, since the metals are melted down.

2.3.2 Pressure Sensor (KRS)

The output of the pressure sensor will need to be processed through an amplifier circuit in order to amplify the signal to a usable level. The amplifier circuit will also act as a calibration unit for setting the parameters for glass vs plastic. After the parameters are determined (experimentally), thresholds will need to be programmed into the microcontroller for actuation of the sorting unit.

2.3.3 Load Cell (KRS)

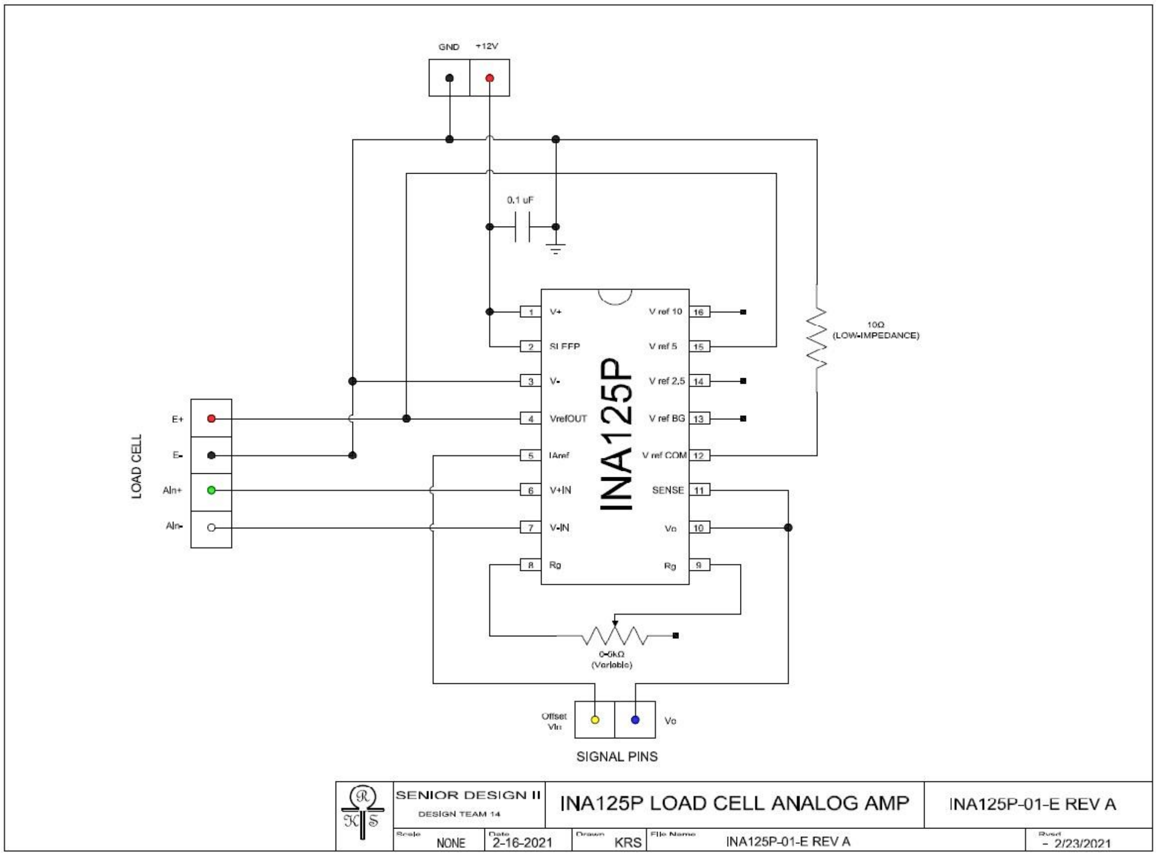
The output of the load cell will be a voltage signal in the millivolt range and will need to be amplified before use. The AD7780 will both amplify the load cell output as well as convert the signal from an analog voltage into a 32-Bit Offset Binary Coded digital signal for use by the microcontroller. The digital signal will be transmitted over Serial Peripheral Interface (SPI) to the microcontroller, and then converted to a weight measurement by the firmware programmed into the microcontroller.

2.3.3(a) Load Cell Revision (KRS)

As previously mentioned, the millivolt range output signal from the load cell will need to be amplified before use and the digital amplifier previously selected created communication issues, therefore the Burr-Brown (Texas Instruments) INA125p analog instrumentation amplifier IC was selected for this purpose. The INA125P amplifier circuit was designed to output an amplified voltage signal to be sent to the microcontroller's AD converter and then processed and converted to a weight measurement by the firmware programmed into the

microcontroller. A schematic of the new INA125P load cell amplifier circuit can be seen in **Figure 2.3.3.1**.

<u>Figure 2.3.3.1: INA125P Load Cell Amplifier Circuit Schematic</u> <u>(KRS)</u>



2.4 Communications

2.4.1 UART Messages

The Microprocessor and Visual Detection Controller (VDC) should be able to communicate with each other through the UART protocol. The VDC should detect the item and communicate its result to the microprocessor using UART. The Microprocessor should then, depending on what the VDC message

said, actuate its sensors, and message the VDC back on its result so that the status terminal is updated.

For the VDC to send the detection message, the following protocol was formulated as shown in Figure 2.4.1.1. A typical detection message for an aluminum can being detected with a confidence of 90% by the VDS could be ‘`a9’.

Table 2.4.1.1.: UART Detection Message Table in ASCII (SOQ)

Character	Hex Value	Meaning
a	0x61	Aluminum Can
p	0x70	Plastic Bottle
g	0x67	Glass Bottle
u	0x75	Unrecognized Bottle/Can
n	0x6E	No Bottle/Can
`	0x60	Detection Message

2.5 Electromechanics

2.5.1 Stepper Motor (SRP)

The sorting system unit for this project is dependent on an angled platform rotating to four different positions as seen in **Figure 6.2**. Each position will be 90° apart and represent a different output bin for the system. The recyclable materials will drop from a trapdoor after the material is determined. The material will hit an angled platform that causes them to slide in the correct bin.

A stepper motor will be used in the sorting unit to send the recyclables to their correct bin instead of a servo. Servo motors have more torque compared to stepper motors. The only downside to this torque is that there is no way to determine the location of the servo after initiated. Also, servo motors usually can only rotate 180° which in this case does not fit the application. Stepper motors on the other hand are very uniform and rotate in steps for a full rotation of 360°. There are multiple types of stepper motors from only 50 steps to 400 steps. In this case a stepper motor would be more useful because it can accurately rotate 360 °. This can be as precise as only a couple of degrees per step and the accuracy can be ± 11% or less depending on the quality of the stepper motor. One downside to the stepper motor is that at high speeds the stepper motor's torque output decreases. This should not affect the sorting system for the recycling bin since only a small, angled platform will be needed to rotate for the system.

The stepper motor determined to be used in this project was the ROB-09238. This was determined because it has a very accurate step angle of 1.8° which equates to 200 steps/rotation. The required voltage to driver the ROB-09238 is 12 V, since the expected power supply for this project was a 12 V DC this is a good match. Also, the current rating for this motor is 330mA. This is good because it is a lower current then most of the stepper motors looked at which were generally 1 A or more. This stepper motor has a solid build which is needed so that it can withstand bottles and cans being dropped on it and not being damaged.

An earlier design was thought of to use a conveyor belt instead of a chute. The conveyor belt would push the recyclable materials down the line and actuators would push them into the bin. This design has a lot of room for error. Bottles or cans could easily get tipped over and possible stuck in this mechanism. For this reason, a simpler sorting unit was designed. Since the current design is dependent on gravity the materials should not get stuck as they fall down the chute. There are also only two moving parts as opposed to numerous actuators and motors. Because the chute design is simpler and has fewer moving parts it was the method used for the sorting unit.

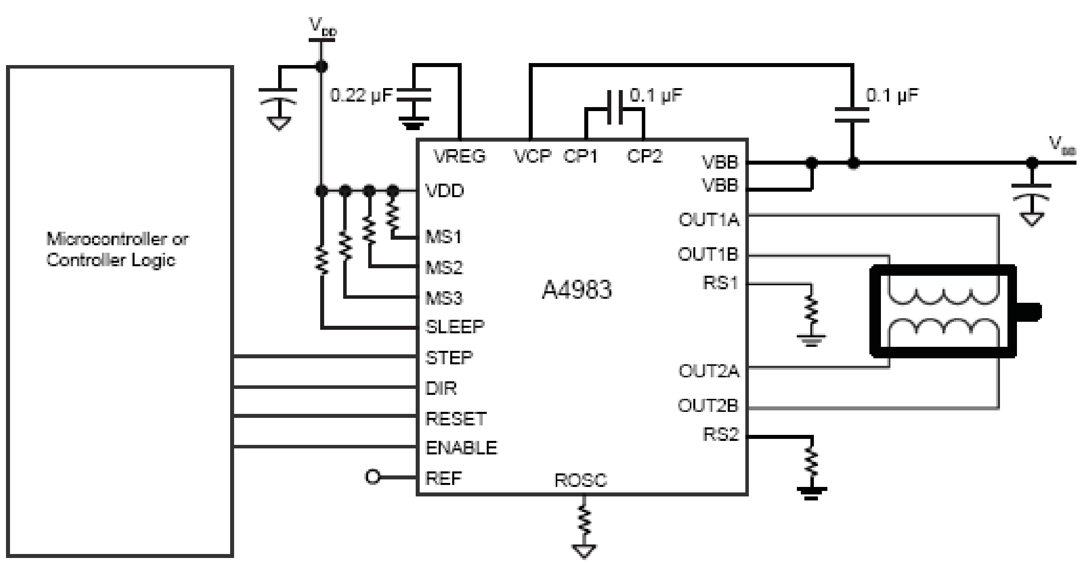
2.5.2 Stepper Motor Driver (SRP)

The stepper motor will be driven by the A4983 stepper motor chip. This IC was chosen because it is able to power bipolar stepper motors easily, the datasheet is documented well, and that it has a lot of customizability. The A4983 is a micro stepping controller that can help make the stepper motor more accurate. By setting the chip in the right configuration it can do full-, half-, quarter-, eighth-, and sixteenth-step modes. This can be useful in turning a lower resolution stepper motor into a higher resolution one. Another benefit to micro-stepping is that it helps reduce the amount of noise coming from the stepper motor. The circuit to apply the chip is seen in Figure 2.5.2.1. The MS1, MS2, and MS3 pins determine which micro-stepping configuration is selected. One thing that needs to be calculated is the reference voltage VREF applied to the REF pin. This can be calculated from the datasheet by ITripMAX = VREF / (8 × RS). The rated current of the stepper motor used is 330 mA. The RS would be 0.05 Ω. From this

the VREF can be calculated to be 0.132 V. This voltage can be attained by using a voltage divider at the input of the REF pin.

The stepper motor driver needs to have a 3.3-5.5 V DC input to operate. In order for it to drive the stepper motor the driver needs to receive a low to high voltage input from the microcontroller at the STEP input. The stepper motor can rotate by implementing a pulse width modulator for the correct length of time. A full rotation would be achieved after 200 pulses were applied to the STEP input. The last input for the A4983 driver is the VBB which is the rated voltage for the stepper motor.

Figure 2.5.2.1: Typical Application Diagram for the A4983 Driver (SRP)



2.5.3 Servo Motor (SRP)

A servo will be used for the trap door module in the project as seen in **Figure 5.1.4**. Servo motors are faster than stepper motors and can be used to simulate a trap door. The input to the trapdoor will be the recyclable materials as seen in **Table 5.1.8.** The servo will be horizontal with the ground holding up the recyclable materials so that the material can be determined **Figure 6.2**. Once the material is determined and the sorting actuator is in place the servo will rotate 90° down so that the material can fall down the chute. Since servo motors have higher torque than stepper motors, they will be better suited to hold up the material during the sensing period.

The trap door module section of this project is still being determined and is subject to change. One idea would be using a stepper motor instead of a servo but that would depend on how strong the holding torque is of the stepper. Another idea would be to use an actuator to push the recyclable materials down a chute after the material is determined.

2.5.3(a) Servo Motor Revision (SRP)

The final build for the recycling bin had a servo that would hold up the material while it was sensed. The servo would then act like a door and allow the material to fall from gravity into the chute. This was the simplest and most effective way to introduce the servo while still having a clear image from the camera and while it still can be sensed by all of the sensors.

3. Engineering Requirements Specification

Table 3.1.1: Engineering Specifications

Marketing Requirements	**Engineering Requirement**	**Justification**
1, 2, 4	1. The system shall have a sorting accuracy of 85% or better	Based on the average contamination rates of modern recycling centers, our system shall differentiate between common materials with an accuracy of at least 85%. By sorting materials before they reach the recycling plant, we can reduce overall average contamination rates resulting in increased profitability for the recycling industry.
1, 2, 4	2. The system shall detect Ferrous/non-ferrous metals with a detection accuracy of 95%	Metal detection accuracy is based on the baseline specifications of the sensors that will be used. Given the rate at which items will be input, the accuracy shall be above 95%.
1, 2, 4	3. The system shall discriminate between Plastic and Glass with a detection accuracy of 75%	Plastic and class detection accuracy is based on the baseline specifications of the sensors that will be used. Given the rate at which items will be input, the accuracy shall be above 75%.
1, 3, 4, 5	4. The system shall Visually Detect the item within 20 seconds	In order maintain an efficient system, the device shall collect relevant image data and process algorithm, giving at least 20 seconds for metal, glass and plastic sensing.
1, 2, 4	5. The system shall sense and sort the item within 20 seconds	In order maintain an efficient system, the device shall collect relevant data, adjust the angle of the stepper motor, and activate the trap door, all within 20 seconds of object detection.
3, 4, 5	6. The system will be able to accept at least 1.33 items per minute	Based on our estimation that the system will be able to process at least 1 item per minute.

5	7. The system will be able to track bin capacity based on experimental data	The system will have a counter to keep track and approximate how full the bins will be.
3	8. The system will limit the size of bottle accepted to have a radius of 100 mm	Based on the average size of a 1-liter container, the system will only accept bottles of this size
3, 5	9. The system shall show visually to the user, the capacity of each bin in real time	To provide visual feedback to the user on the status of the system
3, 5	10. The system shall show visually the result of the detection	To provide visual feedback to the user on the computed result of the detection
1. The system shall be able to accurately detect materials 2. The system shall be able to accurately sort bottles and cans from mixed recycling 3. The system shall be intuitive for the user 4. The system shall detect and sort in a timely manner 5. The system shall provide feedback of the detected material to the user		

4. Engineering Standards Specification

4.1 Safety	NEC 310.16
4.2 Communications	UART, SPI
4.3 Data Formats	Offset Binary, ASCII
4.4 Design Methods	Simulation,
4.5 Programming Languages	Python, C/C++
4.6 Connection Standards	RS-232, IP 67

5. Accepted Technical Design

5.1. Hardware Design:

The following figures and tables show the project block diagrams and their functional requirements as well as hardware circuit schematics.

Figure 5.1.1: Block Diagram Level 0

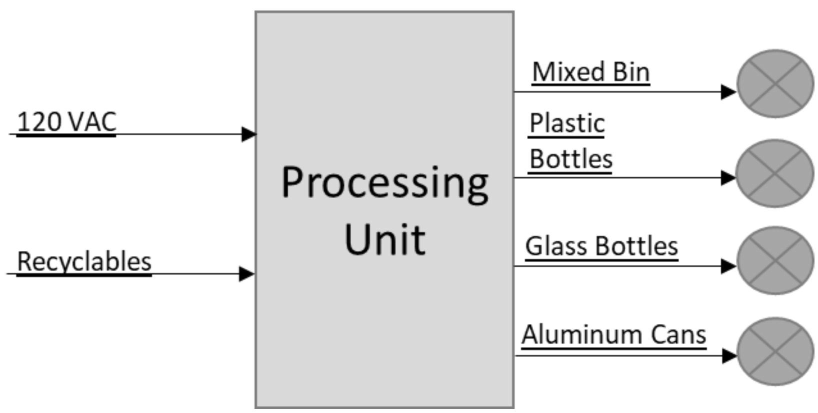


Table 5.1.1: Level 0 Functional Requirement

Module	Smart Recycling Bin
Designers	Brandon Bannavong, Sergio Orozco-Quintanar, Stephen Pirosko, Keith Small
Inputs	Power: 120 VAC, unsorted trash containing recyclable bottles
Outputs	Sorted input material to the correct bin including aluminum cans, plastic bottles, glass bottles, and trash for anything unrecognizable
Description	The system shall detect and sort plastic, glass, and aluminum bottles and cans, from mixed recycling and provide feedback to the user.

Figure 5.1.2: Block Diagram Level 1:

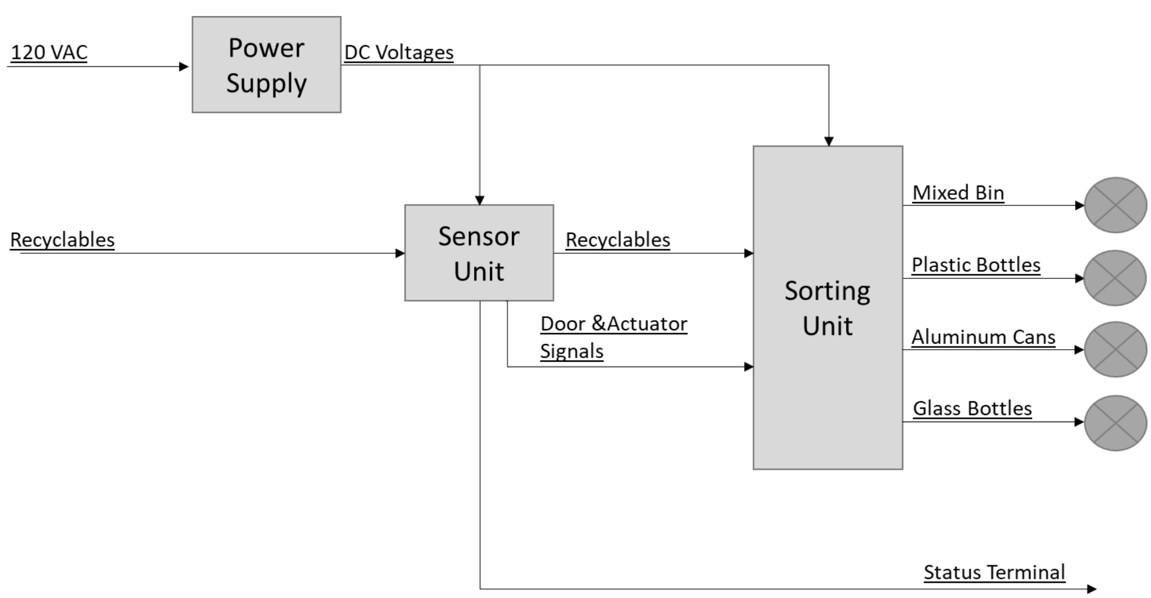


Table 5.1.2: Level 1 Sensor Module Functional Requirements

Module	Sensor Unit
Designer(s)	SO, BB, KS, SP
Input	Recyclables, DC Power
Outputs	Actuator signals
Description	Collects data in order to clearly differentiate between materials that pass through the device.

Table 5.1.3: Level 1 Sorting Module Functional Requirements

Module	Sorting Unit
Designer	SP, KRS
Input	Actuator signals, Recyclables
Outputs	Sorted Recyclables
Description	This module transports the detected recyclables to the bins determined by the sensing module

Table 5.1.4: Level 1 Power Supply Module Functional Requirements (KRS)

Module	Power Supply Unit
Designer	KRS
Input	120 VAC
Output	12 VDC
Description	This module converts 120 VAC into 12 VDC that will power the rest of the system. The 5 V and 3.3 V power rails will be outputs of the microcontroller, which will be powered by the 12 V power

Figure 5.1.3: Sensor Unit Level 2 Block Diagram

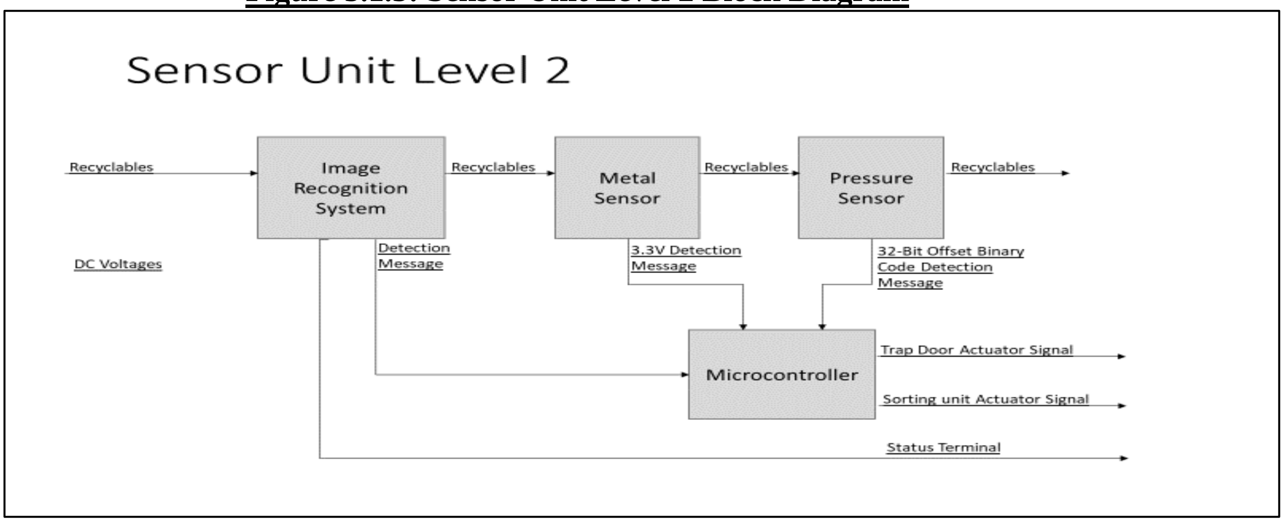


Figure 5.1.3(a): Revised Sensor Unit Level 2 Block Diagram (KRS)

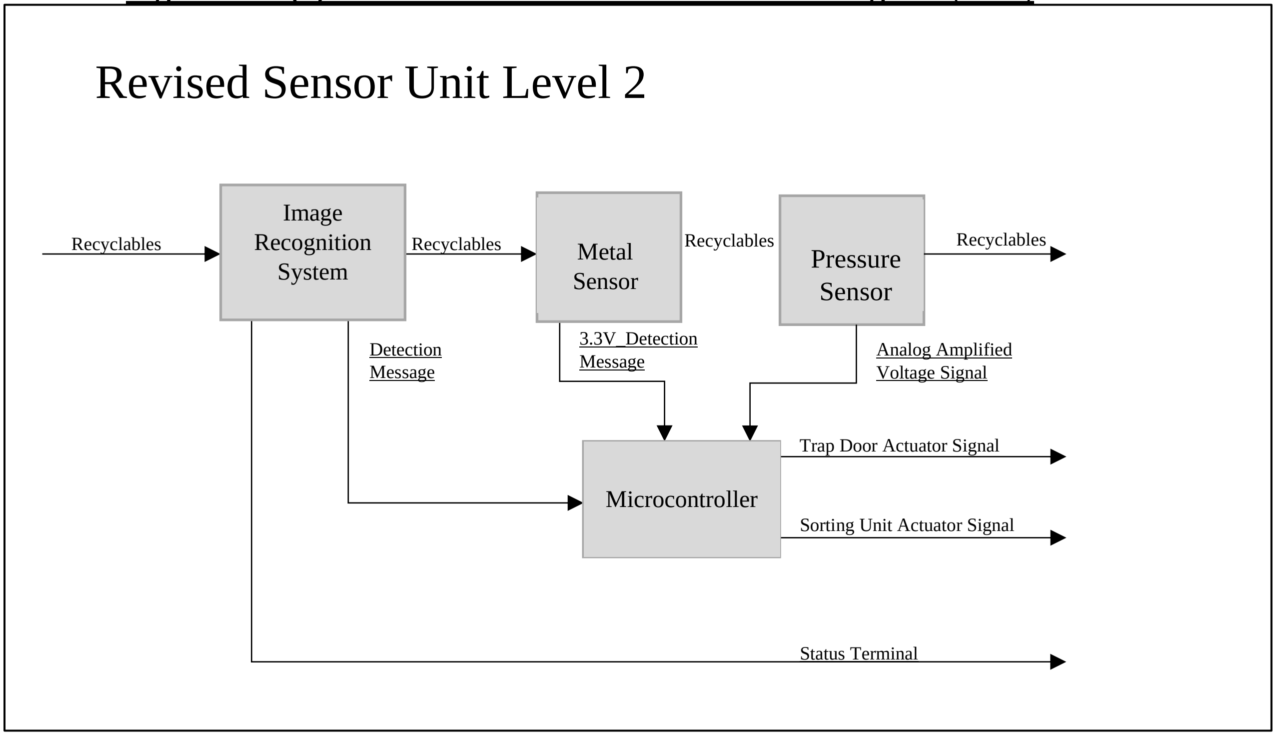


Table 5.1.5: Level 2 Metal Detection Module Functional Requirements

Module	Metal Detection Unit
Designer	KRS
Input	12 VDC and 3.3 VDC Power, Recyclables
Outputs	3.3 VDC Detection Message
Description	This module utilizes the electrical properties of the recyclable material to sense metal

Table 5.1.6: Level 2 Pressure Sensor Module Functional Requirements

Module	Pressure Sensor Unit
Designer	KRS
Input	5 VDC and 3.3 VDC Power, Recyclables
Outputs	32-Bit Offset Binary Code Detection Message
Description	This module utilizes the density properties and the force of gravity exerted on the recyclable material to differentiate between plastic and glass

Table 5.1.6(a): Revised Level 2 Pressure Sensor Module Functional Requirements

Module	Pressure Sensor Unit
Designer	KRS
Input	12 VDC and 3.3 VDC Power, 1.85 mV to 3.25 V Offset Voltage, Recyclables
Outputs	989 mV to 3.3 V detection signal connected to microprocessor ADC
Description	This module utilizes the density properties and the force of gravity exerted on the recyclable material to differentiate between plastic and glass

Table 5.1.7: Level 2 Visual Detection Module Functional Requirements

Module	Visual Detection Unit
Designer	SOQ
Input	DC Power, Recyclables
Outputs	Detection Signal, ...
Description	This module utilizes the Yolo V3 Visual Detection Algorithm to determine whether the item in the system is a bottle or a can.

Figure 5.1.4: Sorting Unit Level 2

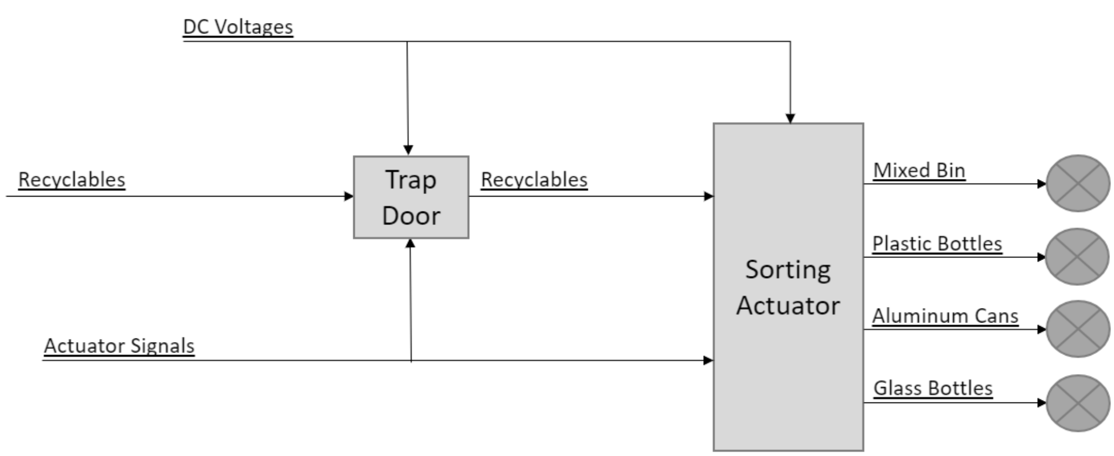


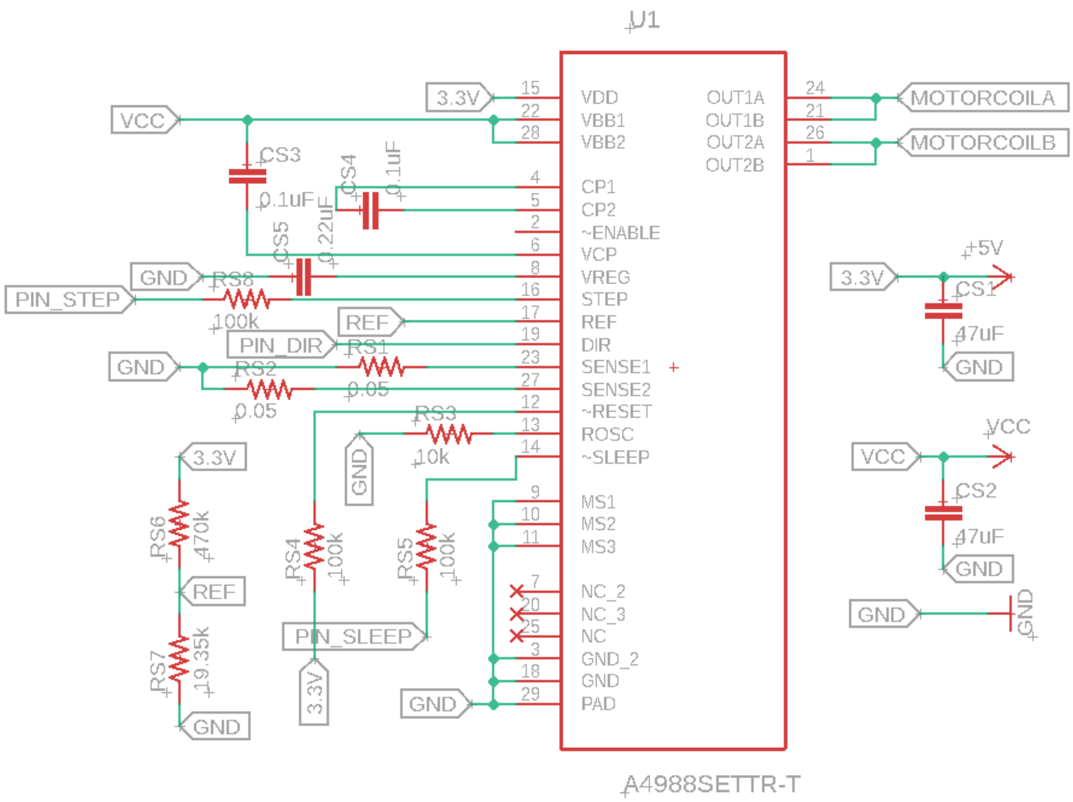
Table 5.1.8: Level 2 Trap Door Module Functional Requirements

Module	Trap Door
Designer	SRP
Input	5 V DC, Recyclables, Actuator signal from microcontroller
Outputs	Recyclables
Description	This module holds the recyclables in place until the material is determined. Then it sends the recyclables into the sorting unit.

Table 5.1.9: Level 2 Sorting Actuator Module Functional Requirements

Module	Sorting Actuator Unit
Designer	SRP
Input	3.3 V DC, 12 V DC, Recyclables, PWM from Microcontroller
Outputs	Sorted Recyclables
Description	This module sends the recyclables to their correct bin based on what the sorting unit determined, using the A4983 stepper motor driver.

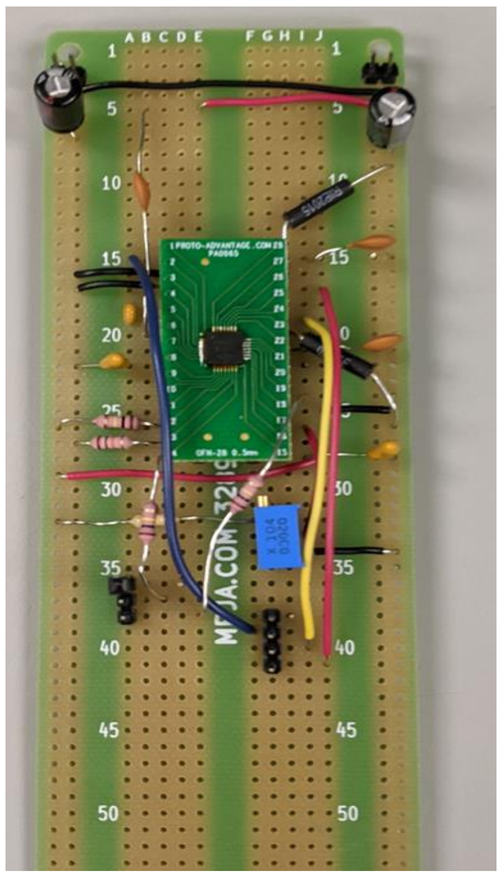
Figure 5.1.5: Schematic of the Stepper Motor Driver Circuit (SRP)



In **Figure 5.1.5** the input voltage for the IC is 3.3 V. It will be receiving this from the explorer board. The VCC is the motor voltage which is 12 V. PIN_STEP, PIN_SLEEP, and PIN_DIR will be connected to the microcontroller. PIN_STEP will be the step input, which is a voltage from low to high, this will increment the stepper motor one step. PIN_SLEEP will be either a high or low voltage depending on if the system is active or not. Putting the A4983 stepper motor driver to sleep will stop the voltage from going into the stepper motor when not in use preventing the motor from getting overheated. PIN_DIR will controller the direction the stepper motor rotates. When applying a low the stepper motor will rotate clockwise while a high voltage will cause it to rotate counterclockwise. The output of the A4983 stepper motor driver would be

OUT1A, OUT1B, OUT2A, and OUT2B. These correspond to the two stepper motor coils needed to drive the bipolar stepper motor. A voltage divider is used to get a reference voltage of 0.132 V. This voltage was attained by using a 470k Ω resistor along with a 100k Ω potentiometer tuned to 19.35k Ω

<u>Figure 5.1.6: Completed Protoboard of the Stepper Motor Driver Circuit</u> <u>(SRP)</u>



In **Figure 5.1.6** the stepper motor driver circuit was transferred from a breadboard to the protoboard shown above. The stepper motor driver chip needed to be soldered onto a 28-pin adapter. This adapter was then breadboarded to make sure the chip was working correctly. After this the components were transferred to a protoboard. The rail voltages were provided at the top left and right for 3.3 V and 12 V respectively. The input from

the microcontroller was at the bottom left connector. The output for the bipolar stepper motor is the 4-pin connector at the bottom right.

Figure 5.1.7: 3D Stepper Motor Angled Platform Model (SRP)

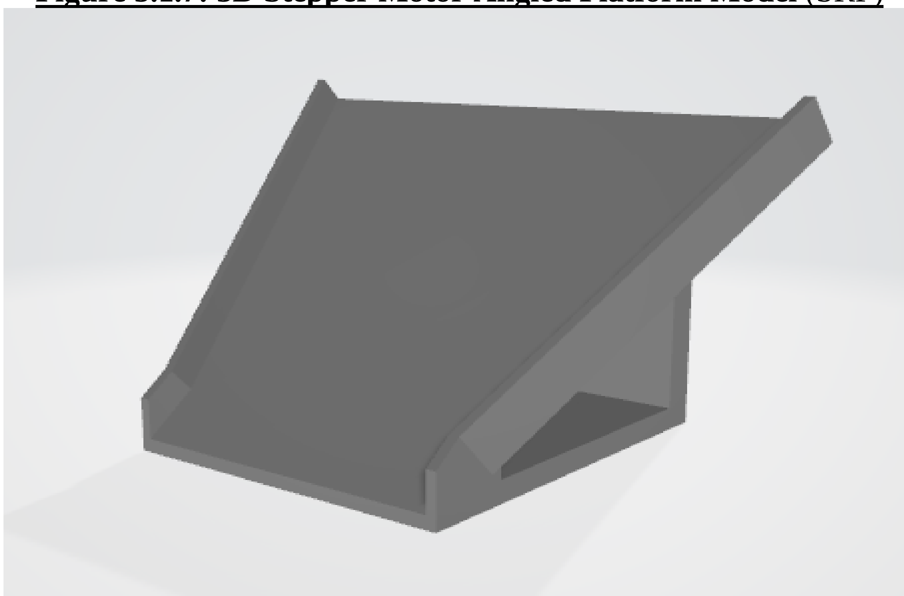


Figure 5.1.8: 3D Printed Stepper Motor Angled Platform (SRP)

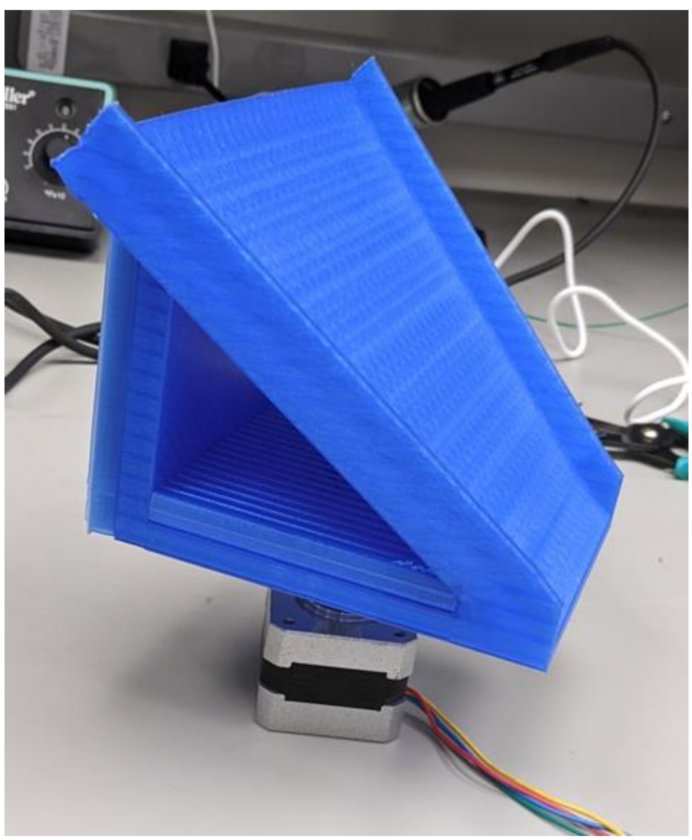


Figure 5.1.8 shows the 3d printed angled platform used in the project. This was 3d modeled using Autodesk Inventor. The model can be seen in **Figure 5.1.7**. The platform needed to be big enough to catch a falling bottle and angled enough so that they would be redirected into the correct bins. The model needed to be able to be attached to the stepper motor through a universal mounting hub. The model was printed in one piece and then the holes for the mounting hub were drilled in. This worked effectively since the stepper motor was able to rotate the angled platform without it disconnecting. Extra fins were added the sides of the platform to better catch and direct the recyclable materials.

Figure 5.1.9: Inductive Sensor Relay Circuit and Connector Pin-out (KRS)

Inductive Sensor Relay Circuit and Connector Layout

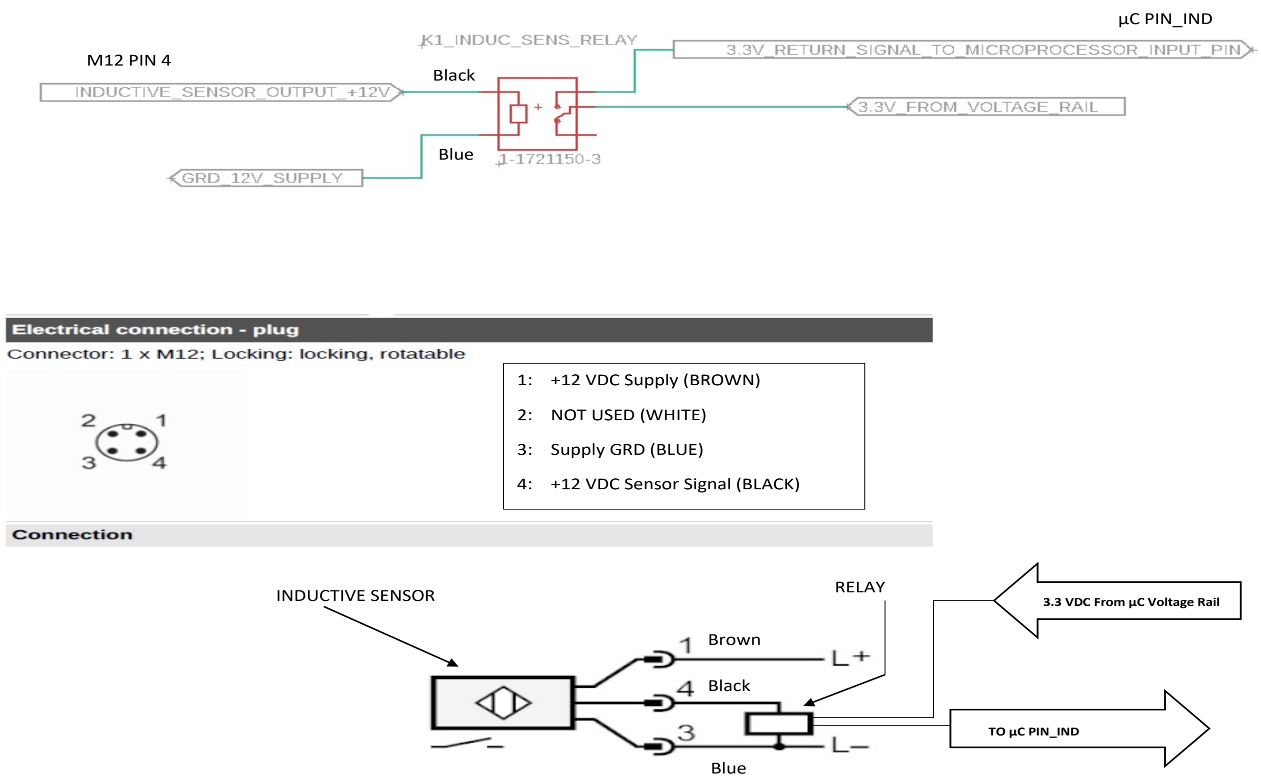


Figure 5.1.9 shows a simple relay circuit being utilized to avoid dropping the 12 VDC output of the inductive sensor across the microcontroller (which would overload the microcontroller circuitry). A 3.3 VDC voltage is fed from the DV_{DD} rail to the relay and is returned to the microcontroller via PIN_IND as a 3.3 VDC signal when the inductive sensor’s output activates the relay. A general purpose 12V, 10A, SPDT relay was selected for this task.

Figure 5.1.10: AD7780 Amplifier/ADC Circuit Schematic (KRS)

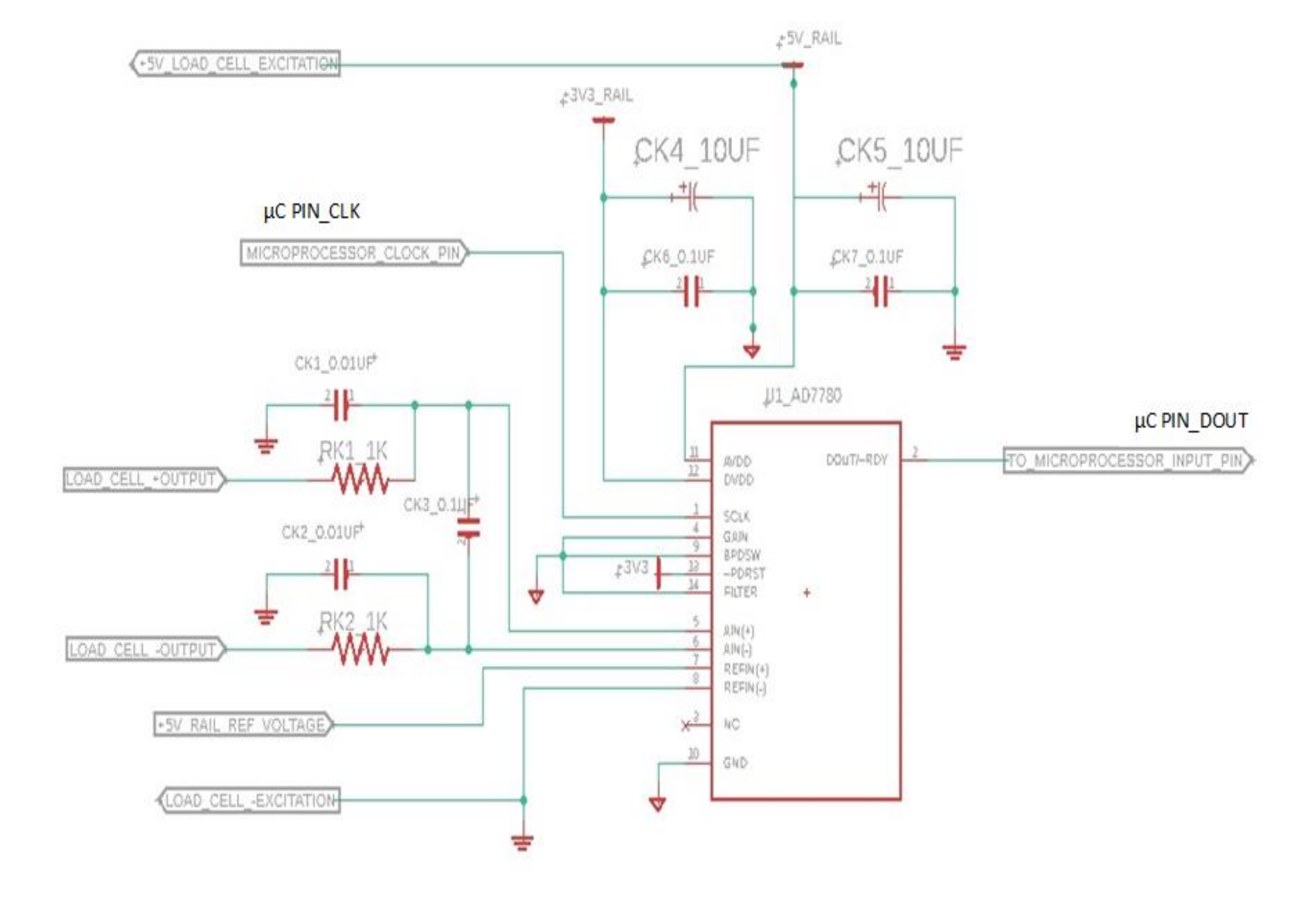


Figure 5.1.10 shows the Load Cell Amplifier/ADC circuit including the necessary anti-aliasing filters, decoupling filters, as well as the microprocessor clock output pin (PIN_CLK) and the microprocessor pin (PIN_DOUT) designated for the input of the 32-Bit Offset Binary Code Detection Message from the AD7780. The coded detection message will be decoded by the microprocessor and converted to a weight corresponding to the sensed recyclable material to determine whether it is made of plastic or of glass.

<u>Figure 5.1.11: Prototyped AD7780 Load Cell Amplifier Circuit</u> <u>(KRS)</u>

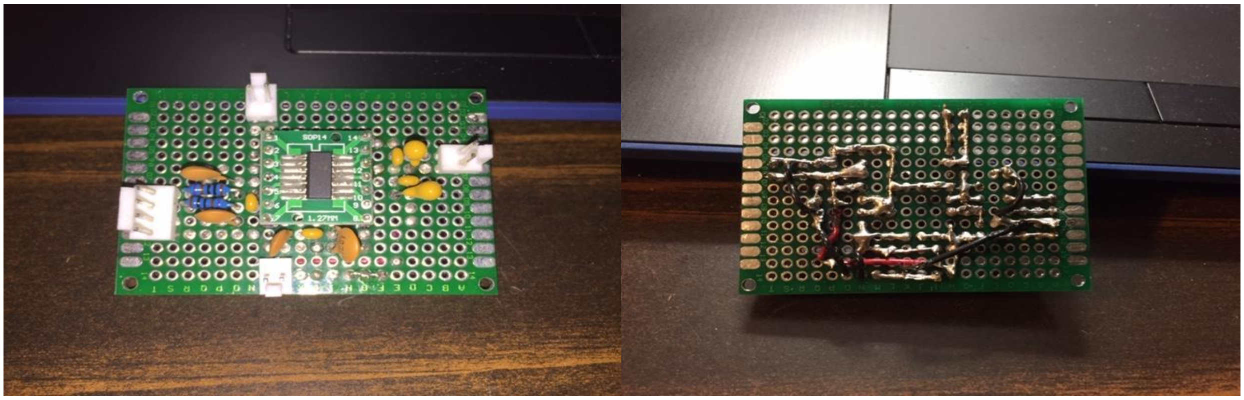


Figure 5.1.11 shows top and bottom images of the prototyped AD7780 Load Cell Amplifier Circuit. Due to communication issues with the microcontroller, this digital amp circuit was abandoned and replaced with an analog instrumentation amplifier shown in **Figure 5.1.12**.

<u>Figure 5.1.12: Prototyped INA125P Load Cell Amplifier Circuit</u> <u>(KRS)</u>

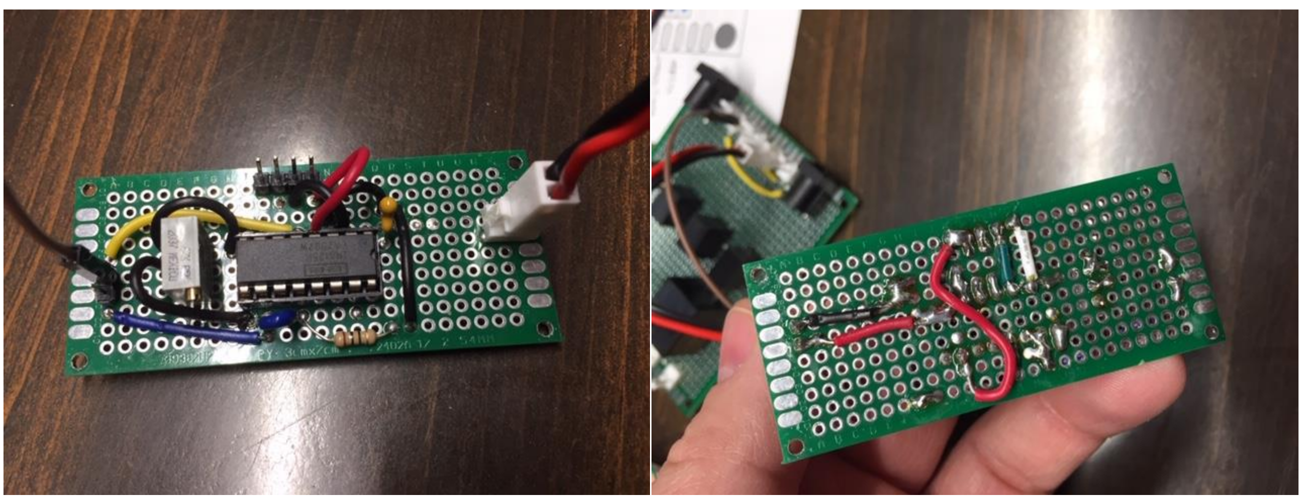


Figure 5.1.12 shows top and bottom images of the prototyped INA125P Load Cell Amplifier Circuit. The schematic for this circuit can be seen in **Figure 2.1.2.4**.

Figure 5.1.13: Power Distribution Circuit Top (left) and Bottom Traces (right) –KRS)

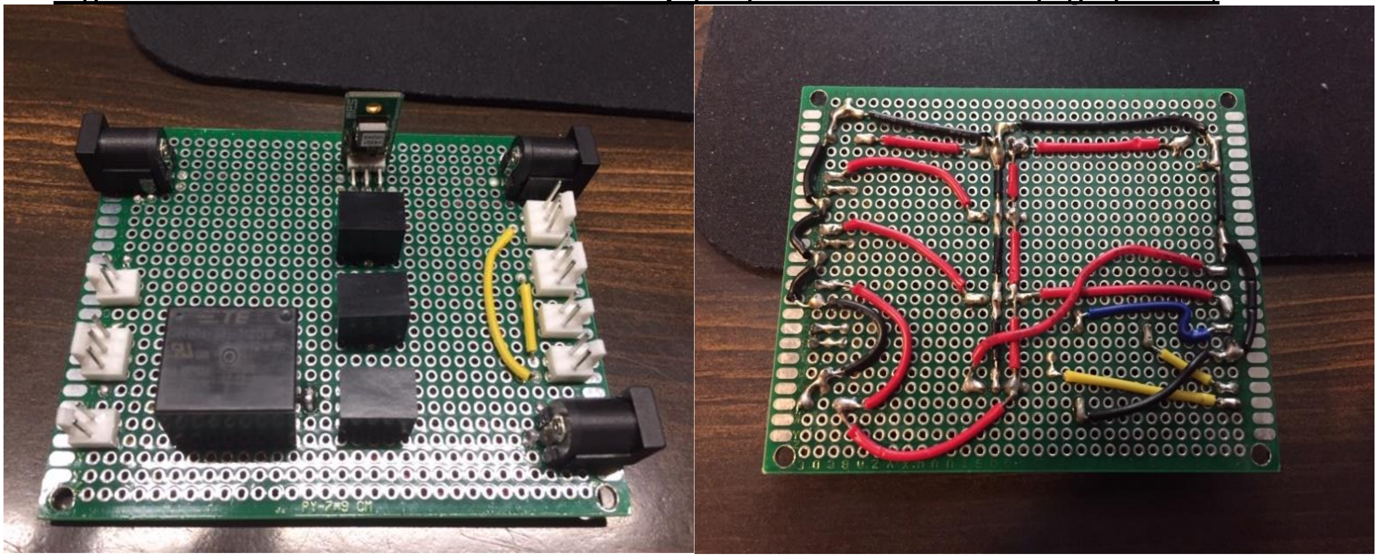


Figure 5.1.13 shows top and bottom images of the prototyped Power Distribution Circuit. The schematic for this circuit is shown in **Figure 2.1.1.2**.

Figure 5.1.14: Revised Power Distribution Circuit (KRS)

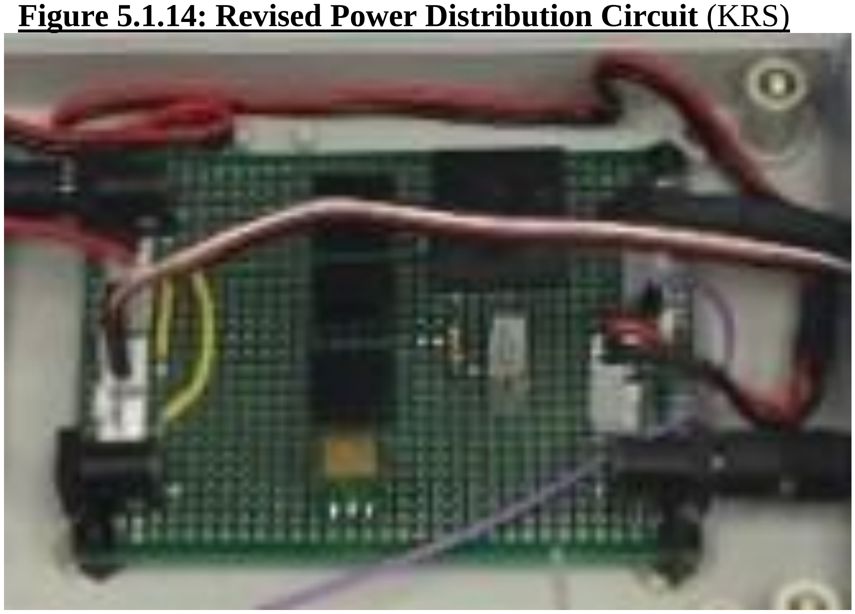
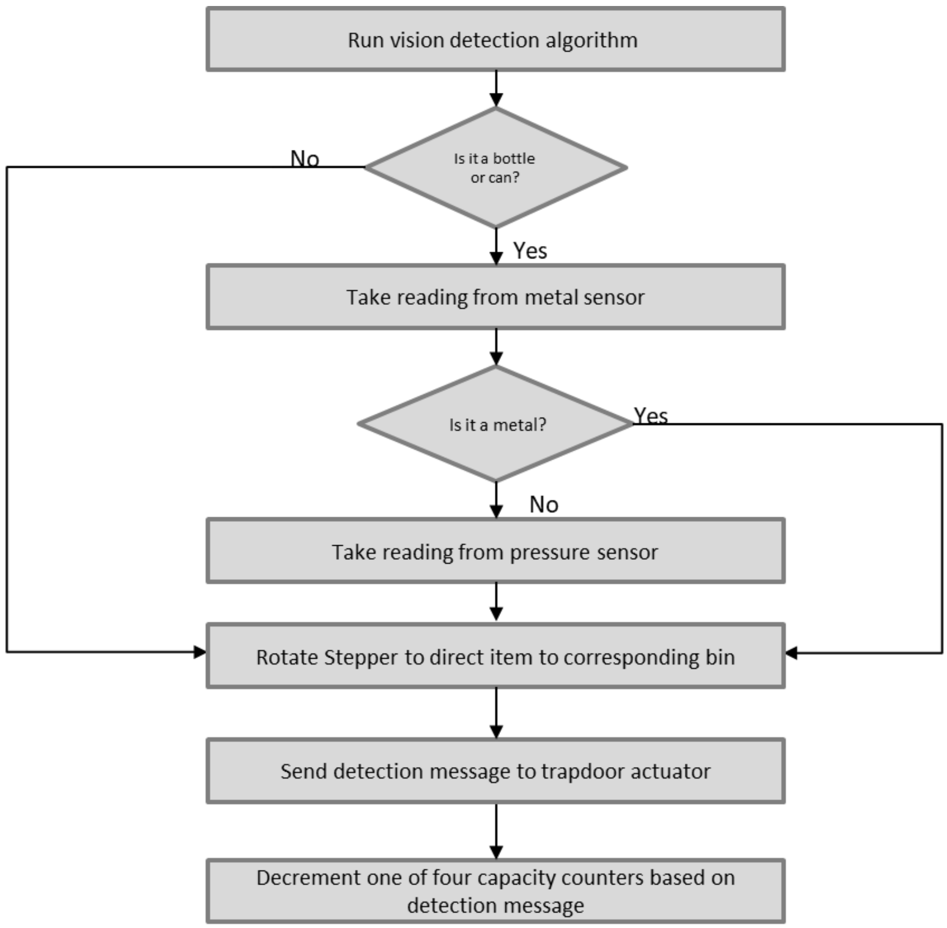


Figure 5.1.14 shows the Power Distribution Circuit in its final form including the 12VDC output pins for powering the INA125P Load Cell Amplifier Circuit, and the regulated 5VDC rerouted through the variable voltage divider and then to an output pin for supplying the offset voltage to the load cell amp. The schematic for this circuit is shown in **Figure 2.1.1.3**.

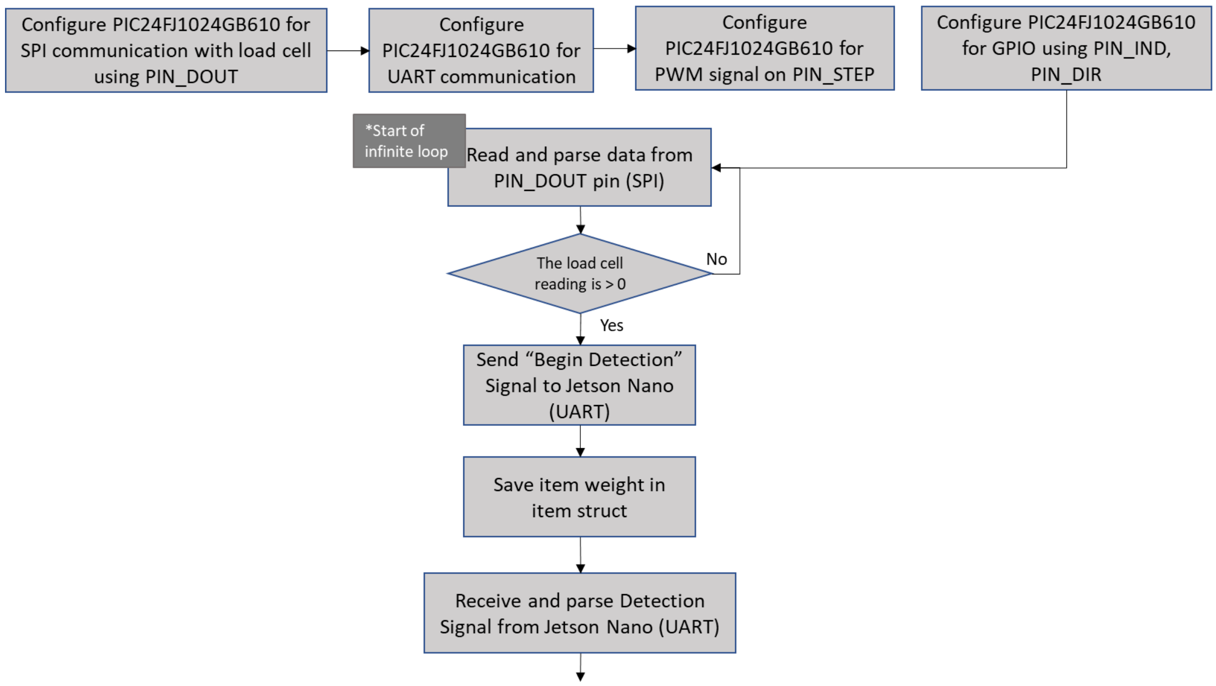
5.2 Software Design

Figure 5.2.1: Software Design Level 0 (BTB)



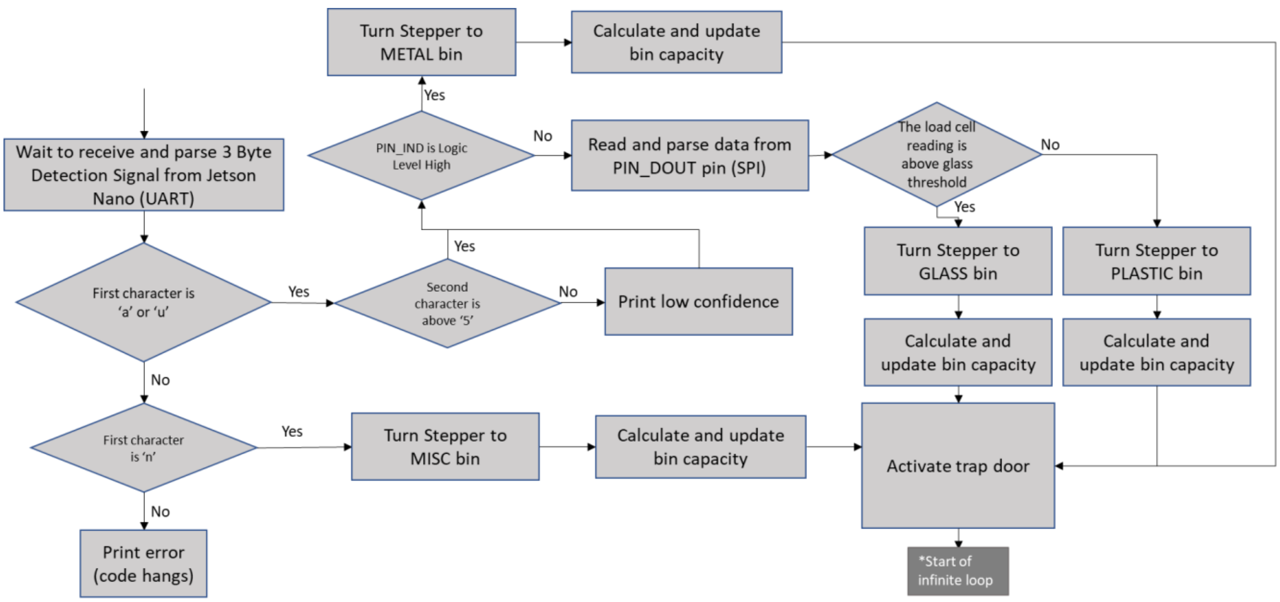
The code running in the PIC24 microcontroller will be tasked with the low level subroutines that are required for this project. This includes communication with inductive sensors, load cells, stepper motors, and servos. It will also communicate through UART with the Jetson Nano running the Visual Detection algorithm

Figure 5.2.2: Software Design Level 1 - Phase 1 (BTB, SOQ)



Phase 1 of the software design is centered around reading and parsing data given by an SPI output signal from the load cell. To accomplish this, the PIC24FJ1024GB610 microcontroller will first be configured to handle both UART and SPI communication protocols as well as generate a PWM signal. If the load cell receives a signal, a signal is sent to the Jetson Nano to initialize visual detection and the load cell reading is recorded. Finally, the Jetson Nano parses through the detection signal in order to classify the detected object.

Figure 5.2.3: Software Design Level 1 - Phase 2(BTB, SOQ)



The second phase of the software design focuses on using the data collected in phase one to successfully sort materials inserted into the system. If the data the microcontroller receives indicates neither a bottle nor can have been inserted into the system, a signal is sent to the stepper motor to turn towards the MISC bin. If the data indicates the object in the system is indeed a bottle or a can, the second character of the 3-byte signal is checked to determine the confidence level of the visual detection result. Next, if the inductive sensor reads logic level high, we send a signal to the stepper motor to face the metal bin and activate the trap door. Finally, if the inductive sensor reads logic level low, we read and parse the data given from the load cell. If the reading is above the threshold for the weight of glass, the stepper motor is rotated towards the glass bin and the trap door is activated. Additionally, if the load cell reading is below this threshold, the stepper motor is rotated towards the plastic bin and the trap door is activated. After every successful sort, the remaining bin capacity is calculated and updated.

<u>Figure 5.2.4: Initiate UART Protocol</u> <u>(BTB, SOQ)</u>

```
//Initialize UART communication protocol
void InitU2(void) {
    U2BRG = 34;             // PIC24FJ128GA010 data sheet, 17.1 for calculation, Fcy = 16MHz.
    U2MODE = 0x8008;        // See data sheet, pg148. Enable UART2, BRGH = 1,
                            // Idle state = 1, 8 data, No parity, 1 Stop bit
    U2STA = 0x0400;         // See data sheet, pg. 150, Transmit Enable
                            // Following lines pertain Hardware handshaking
    TRISFbits.TRISF13 = 1;  // enable RTS , output
    RTS = 1;                // default status , not ready to send
}//InitU2

/* Transmit a string using UART
 * Parameters: Character string, integer length of string
 * Returns: Nothing
 */
void PutU2String(char* str, int len)
{
    int c;
    for(c = 0; c<len;c++)
    {
        PutU2(str[c]);
    }
}//PutU2String

/*Transmit a character using UART
 *Parameters: Input character
 *Returns: Input character
 */
char PutU2(char c) {
    while (CTS); //wait for !CTS (active low)
    while (U2STAbits.UTXBF); // Wait if transmit buffer full.
    U2TXREG = c; // Write value to transmit FIFO
    return c;
}//PutU2

/*Receive a character using UART
 *Parameters: None
 *Returns: UART receive buffer
 */
char GetU2(void) {
    RTS = 0; // telling the other side !RTS
    while (!U2STAbits.URXDA); // wait
    RTS = 1; // telling the other side RTS
    return U2RXREG; // from receiving buffer
} //GetU2
```

The figures above depict the code used to configure the PIC24FJ1024GA610 for the UART serial communication protocol. Also depicted are multiple functions that allow us to send and receive data between the microcontroller, load cell and visual detection system.

Figure 5.2.5: UART Communication Logic

- All Messages use 115200 as baud rate with 8 Data bits 1 Stop bits and No Parity bits
- The detection message will always start with the tilde character ‘ ` ‘ or 0x60
- The next character will determine which of the 4 categories the Visual Detection module has detected:
  1. ‘a’ for aluminum cans and bottles or 0x61
  2. ‘p’ for plastic bottle or 0x70
  3. ‘g’ for glass bottles or 0x67
  4. ‘u’ for unrecognized bottle and/or can or 0x75
  5. ‘n’ for no bottle and/or can has been recognized or 0x6E
- The last character will be a number out of 10 which is the confidence level of the detection message 0x30 – 0x39
- Example “`a9” would mean a detection message of an aluminum bottle with a confidence level of above 90%

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Figure 5.2.6: Stepper Motor and Servo Motor PWM Generation (BTB)

```
//Generate PWM signal for stepper motor
void InitStepper()
{
    T2CON = 0x8030;     //Enable TMR3, 1:256, 16 bit Timer, intclock
    PR2 = 625 - 1;      //100 Hz
    _T2IF = 0;          //Clear interrupt flag
    _T2IE = 1;          //Enable TMR2 interrupt
    OC2R = OC2RS = 0;   //Initialize at 0% duty cycle
                        //OC2R also loaded since first time.
    OC2CON = 0x0006;    //OCTSEL = 0 for Timer2, OCM<2:0> =110 for PWM mode

}//InitStepper


//Generate PWM for servo
void InitServo(void) {
    T3CON = 0x8030;     //Enable TMR3, 1:256, 16 bit Timer, Initialize clock
    PR3 = 1250 - 1;     //50 Hz
    _T3IF = 0;          //Clear interrupt flag
    _T3IE = 1;          //Enable TMR3 interrupt
    OC1R = OC1RS = 625; //Initialize at 50% duty cycle
                        //OC1R also loaded since first time.
    OC1CON = 0x000E;    //OCTSEL = 1 for Timer3, OCM<2:0> =110 for PWM mode
} // InitServo
```

The figures above depict the code that generates the PWM signals driving both the stepper motor and servo motor respectively. Both functions utilize separate 16 bit timers

at a 1:256 pre-scale. The stepper utilizes a 100 Hz PWM while the servo is given a 50 Hz signal.

Figure 5.2.7: Initialize Analog to Digital Converter (BTB)

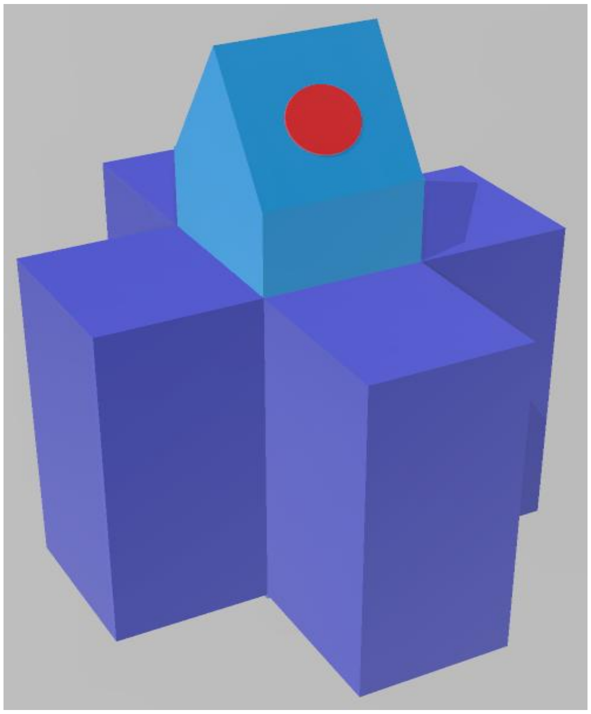
```
//Initialize analog to digital converter
void InitADC(void)
{
    AD1CON1 = 0x00E0;      //Select auto-convert mode
    AD1CON2 = 0;           //Using MUXA, AVss and AVdd as Vref
    AD1CON3 = 0x1F01;      //Tad = 2 * Tcy = 125ns
    AD1CSSL = 0;           //No scanning
    AD1CON1bits.ADON = 1;  //Activate ADC
}//InitADC

/*Read ADC value
 *Parameters: Channel select (integer)
 *Returns: ADC buffer (integer)
 */
int ReadADC(int ch)
{
    AD1CHS = ch;                 //Select analog input channel
    AD1CON1bits.SAMP = 1;        //Start sampling.
    while( !AD1CON1bits.DONE);   //Wait for conversion to complete
    AD1CON1bits.DONE = 0;        //Clear flag
    return ADC1BUF0;             //Return the ADC buffer
} // ReadADC
```

The first function depicted in the figure above is responsible for initializing the registers that are essential for operating the ADC. Additionally, the ReadADC function allows for channel selection, begins sampling, converts the result then finally stores it in a buffer and returns an integer.

In the Visual Detection Software side, the detector waits for the UART signal to begin detection, and then after detection is completed, the VDS will communicate back the result of the detection. At this point the microcontroller will weigh the item, run the metal detector, which determines where the item will go in the bin. Finally the VDS will wait for the microcontroller to report back the sensor readings.

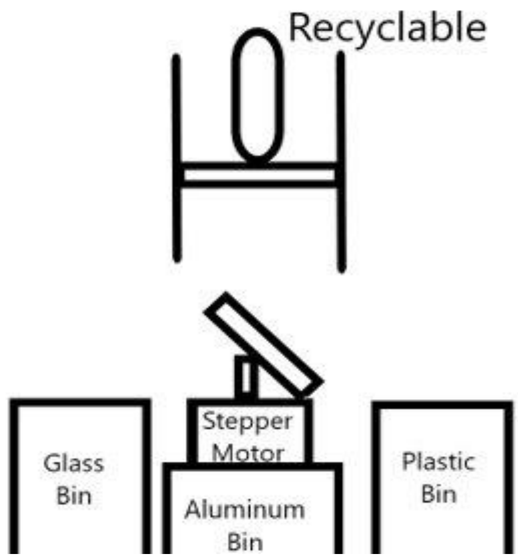
6. Mechanical Structure

<u>Figure 6.1: Mechanical Sketch (SRP)</u>



This is a rough model of what the final smart recycling bin could look like. The material would be input in the red circle. The sensing would be done in the light blue area. After being sensed, the material would be dropped into one of the four dark blue bins.

Figure 6.2: Internal Diagram (SRP)



This is the internal diagram of the mechanism inside the smart recycling bin. The recyclable will land onto a platform and the material will be determined. Then it will fall through the trapdoor and on the stepper motor that is angled toward the correct bin.

6.3 Detection Area/Load Cell Top (KRS)

Upon analysis it was determined that an angled platform or "chute" would be ideal for use as a detection area. This would allow gravity to assist in getting the recyclable materials into an ideal placement for the sensors and visual detection unit. It was decided that a half cylinder shaped chute would work best for this. Taking the load cell into consideration, this detection area was designed to be isolated from the rest of the structure, and consisting of a platform acting as the top of the load cell (or scale top), the inspection chute (and its supports), the trap door and its servo actuator, as well as the inductive sensor. The conceptual sketch of the detection area can be seen in **Figure 6.3.1**, and a mock-up of the concept is shown in **Figure 6.3.2**. The platform was constructed from a 12" X 18" piece of 16-gauge weldable sheet steel that was cut to be a 7" X 14"

with a little “L” at the front corner on witch to mount the servo motor (measuring 2” X 2”). The chute was constructed out of two 8” long. Plastic half cylinders of approximately 4” dia., connected together to form the chute. The rear (entry side) of the chute was supported by another 8” section of plastic half cylinder, making the angle of the chute to be an approximately 30° downward slope. The weight of the entire detection area apparatus will be calibrated out of the weight sensing of the load cell (i.e. tare weight). **Figure 6.3.3** and **Figure 6.3.4** show images of the completed version of the detection area/load cell top as implemented in the project.

Figure 6.3.1: Detection Area/Load Cell Top Conceptual Design (KRS)

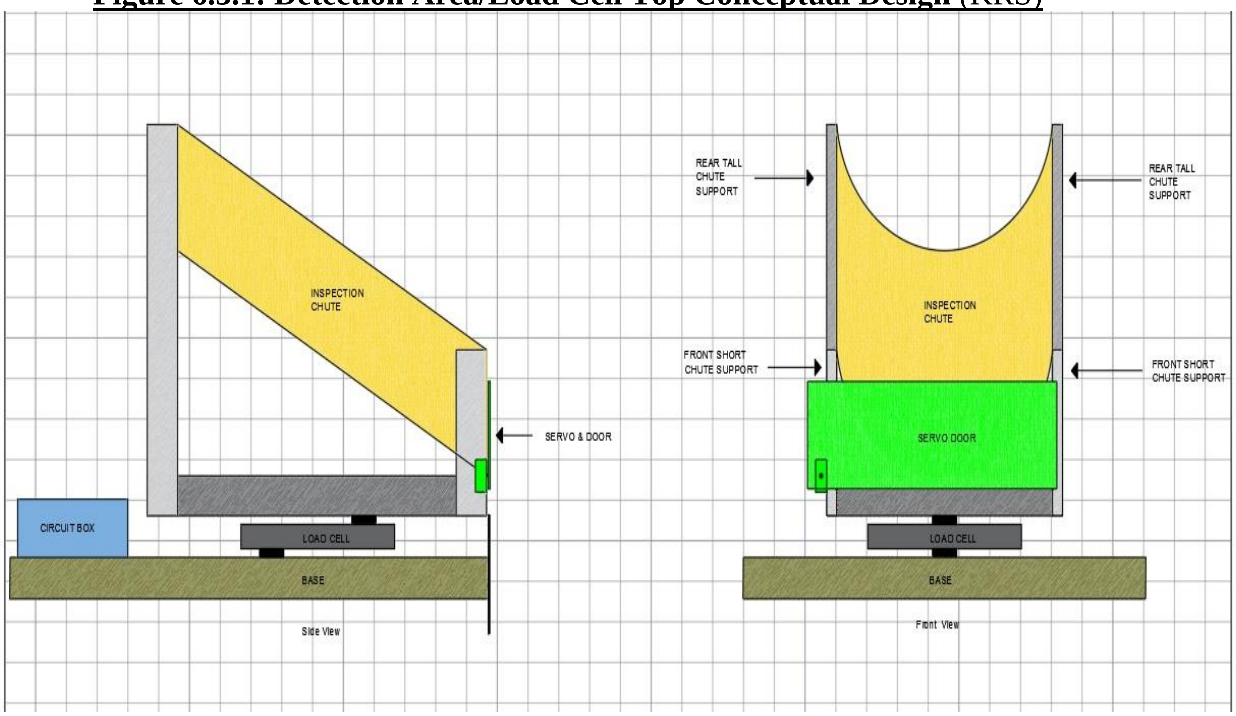


Figure 6.3.2: Detection Area/Load Cell Top Mock-up (KRS)

Figure 6.3.3: Detection Area Completed 1 (KRS)

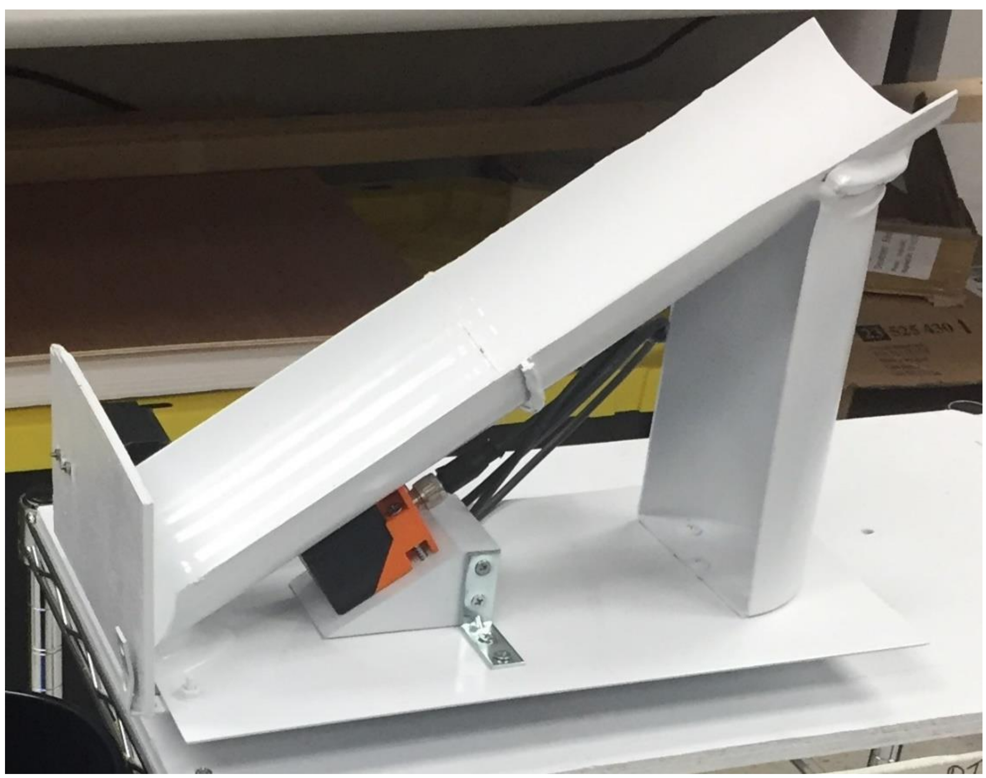


Figure 6.3.4: Detection Area Completed 2 (KRS)

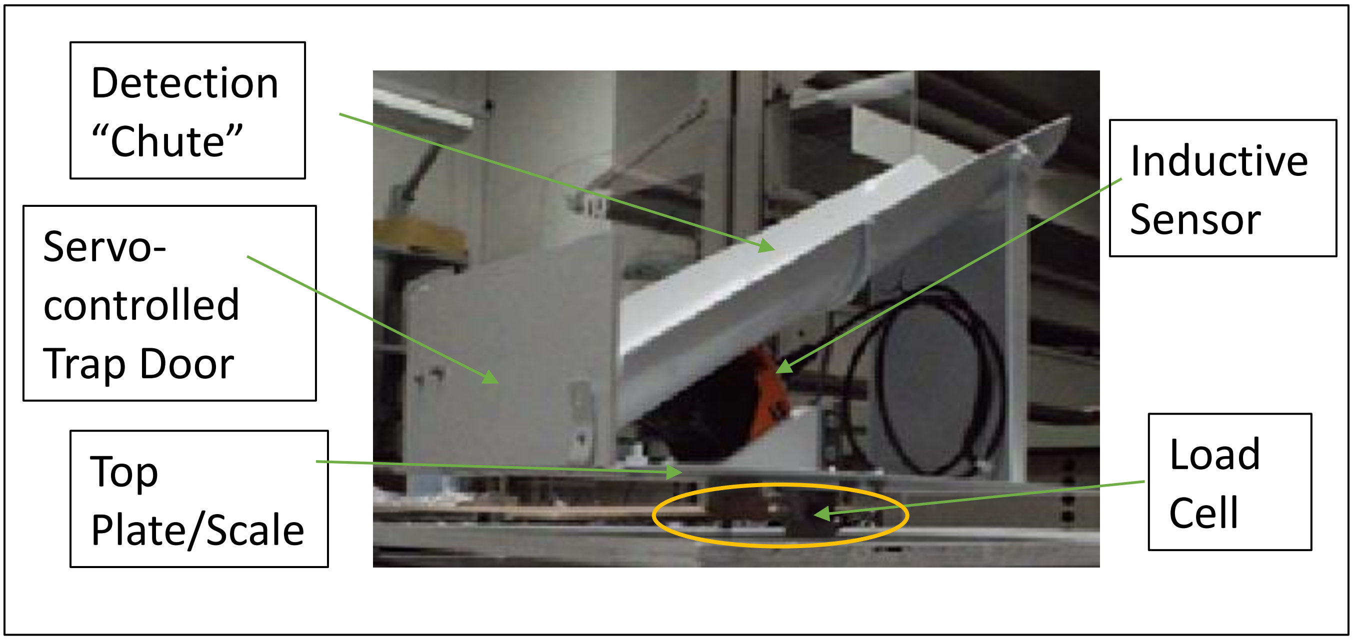


Figure 6.3.4 is an image of the implemented detection area/scale top with call-outs for the detection chute, the load cell location, the placement of the inductive sensor, the servo controlled trap door, and the top plate.

6.4 Machine Structure

The detection area structure (described in **section 6.3**) was mounted onto a sheet of plywood approximately 13" wide by 23" long acting as the bottom or base of the load cell. This sheet of plywood was in-turn mounted to the top shelf of a 24" W x 14" D x 30" H, 3-tier steel wire shelving unit. The middle shelf was cut in-half and one section was utilized to mount the sorting unit and the other to mount the stepper driver unit, the microcontroller, and the Jetson Nano processor. The framing of the unit was constructed out of 1" X 2" wood as can be seen in **Figure 6.4.1**. Luan plywood was utilized for mounting the recyclables entry opening, the start button, and to make a shelf for the GUI display monitor. Once all of the internal units and

components were installed, the framing was covered with white foam poster board to enclose the machine, which was attached to the framing utilizing Velcro in order to facilitate easy access for demonstration and maintenance. The completed and enclosed Smart Recycling Bin can be seen in **Figure 6.4.4**, and a close-up image of the GUI is shown in **Figure 6.4.5**.

Figure 6.4.1: Open Framing of Smart Recycling Bin During Build (KRS)

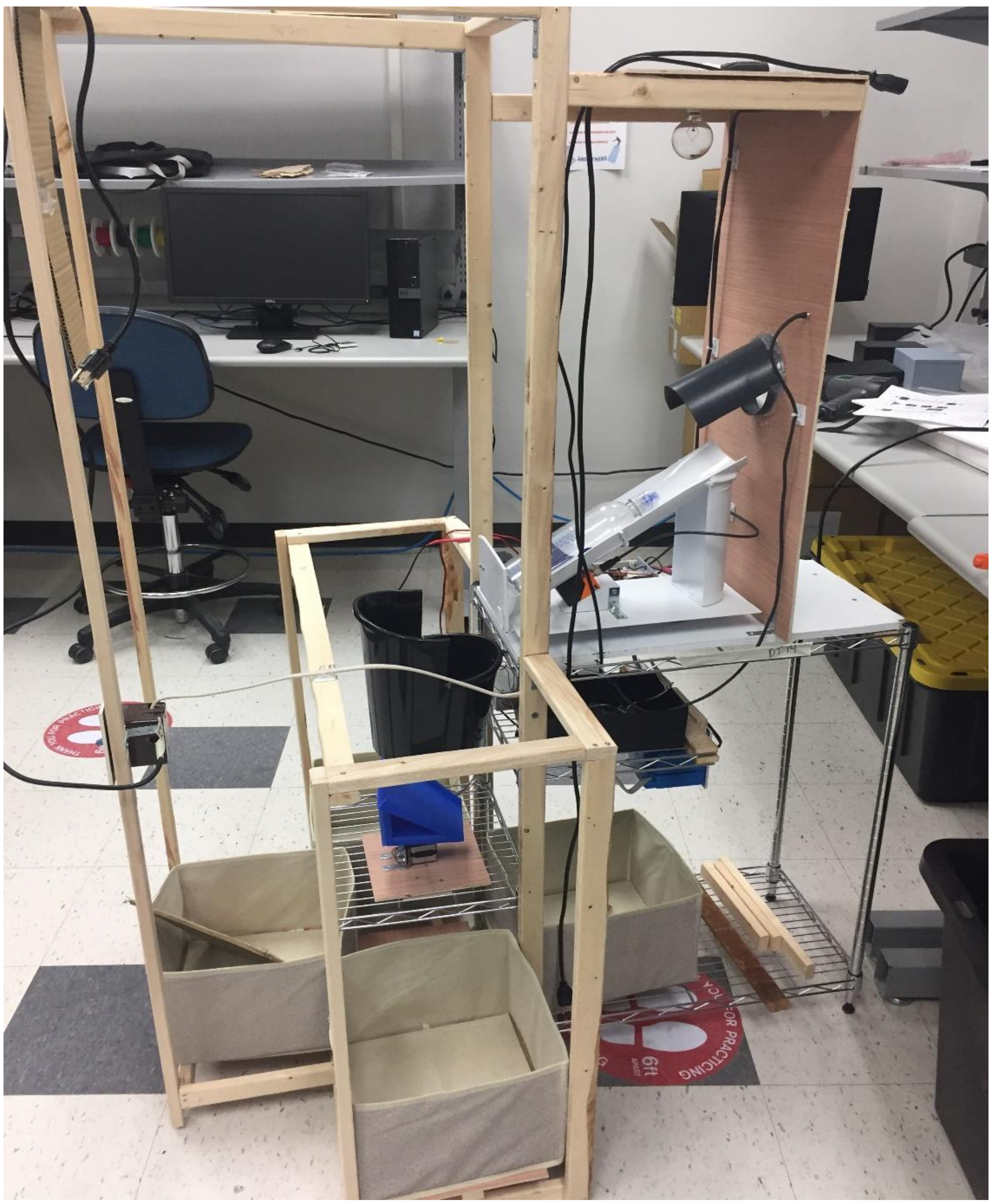


Figure 6.4.2: External Picture of the Structure

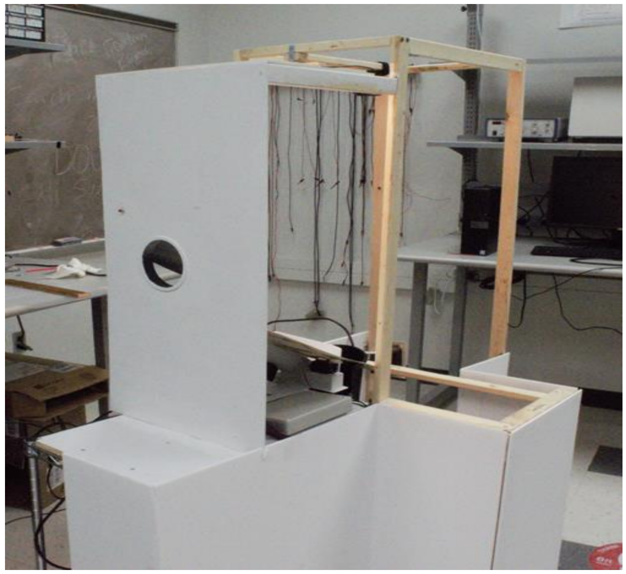


Figure 6.4.3: Internal Sorting and Sensing Unit (SRP)

The structure for the recycling bin was made up of wood for support and foam poster board pieces as the wall. The recyclable material enters through the hole in the front. This causes the material to land onto the sensing unit and then the user would have to click the

red button to start as seen in **Figure 6.4.2.** The sensing unit is a half tube that the bottle would sit in as seen to the right in **Figure 6.4.3**. Once the material is sensed the stepper motor rotates the angled platform to the correct bin and the servo would actuate. This would cause the material to slide down the tube onto the angled platform to then bounce into the correct bin. Then the servo and stepper would reset allowing for another material to be able to be determined.

Figure 6.4.4: Completed and Enclosed Smart Recycling Bin (KRS)

Figure 6.4.5: Close-up of GUI Displaying Captured Image & Bin Fill Percentages (KRS)

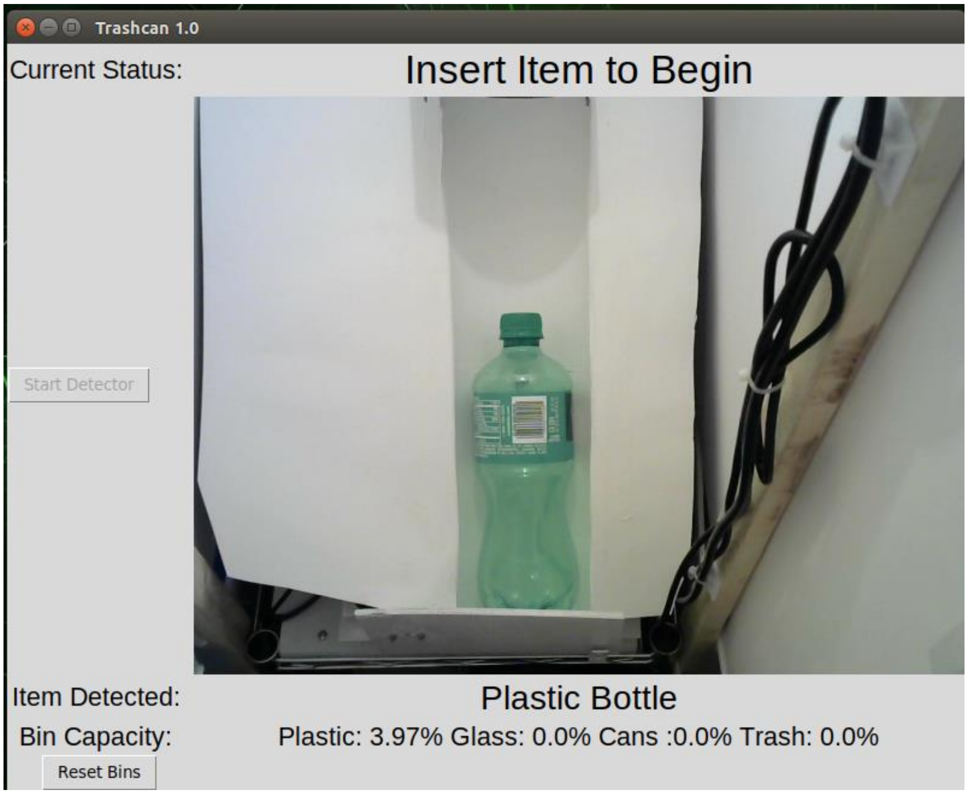
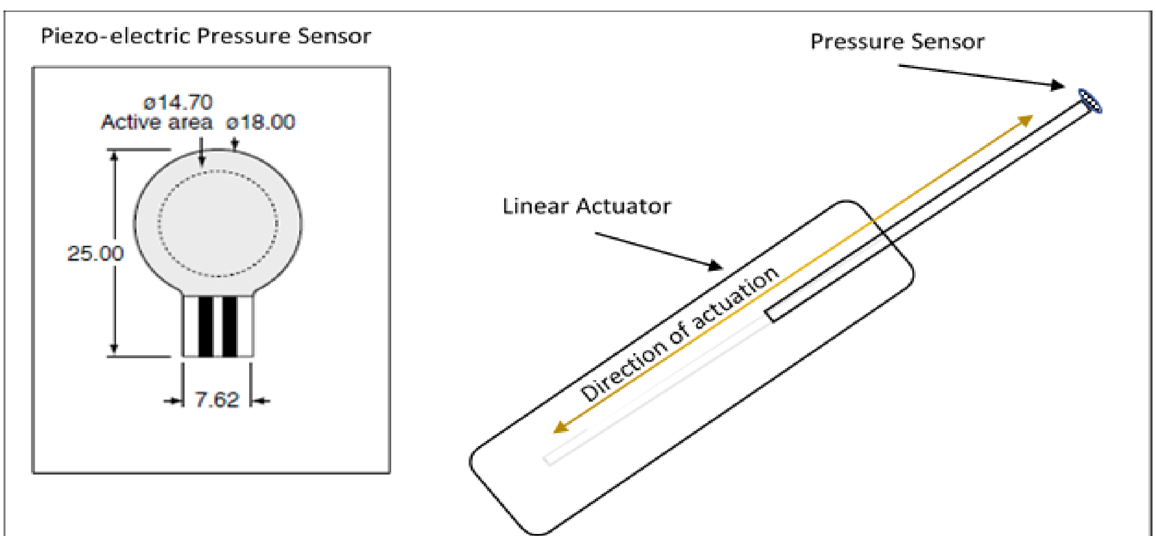


Figure 6.5: Pressure Sensing Unit (KRS)



Linear Actuator and Piezo-electric Pressure Sensor

Figure 6.5 is a conceptual drawing of how a piezo-electric pressure sensor might be implemented utilizing a linear actuator. This concept was ultimately abandoned due to the number of variables involved in locating the recyclable item to be tested within the test area.

7. Team Information

Brandon Bannavong, Major: Computer Engineering, Software Manger

Sergio Orozco-Quintanar, Major: Computer Engineering, Project Lead

Stephen Pirosko, Major: Electrical Engineering, Hardware Manager

Keith Small, Major: Electrical Engineering, Archivist

8. Parts List

8.1 Material List

Table 8.1.1: Material List

Qty.	**Refdes**	**Part Num.**	**Description**
1			NVIDIA developer board for visual detection
1		ROB-09238	Stepper motor
1	LC1	SEN-14729	5Kg Load Cell
1	IS1	IM5116	Inductive Sensor
1	U1_AD7780	AD7780BRZ	24Bit sigma-delta IC - Load Cell AMP IC
1	N/A	MCP6004-E/SL	4 circuit IC Op Amp
1	U1	A4983SETTR-T	Motor Driver Chip
1		28-653000-10	Chip Socket

2	RK1, RK2	MFP-25BRD	Anti-aliasing Filter Resistors 1k
5	CK3, CK6, CK7, CS3, CS4,	C320C104K3R5TA	Decoupling and anti-aliasing Capacitors (.1µF)
2	CK1, CK2	S103M47Z5UN63J7R	Anti-aliasing Filter Capacitors (0.01µF) (10000pF)
2	CK4, CK5	TAP106K010CCS	Decoupling Capacitors (10µF)
1	CS5	TAP224M050SCS	Decoupling Capacitors (0.22µF)
2	RS1, RS2	MT1A-0R05F2	0.05 OHM Resistor
1	RS7	3299X-1-104LF	100k Potentiometer
3	RS4, RS5, RS8	FMP100JR-52-100K	100k resistor
1	RS3	FMP100JR-52-10K	10k resistor
1	CBL_K1	21348500390010	CBL FMALE TO WIRE LEAD 4P 3.28' (M12 Cable for Inductive Sensor)
1	K1_INDUC_SENS_RELAY	ORWH-SH-112D1F,000	RELAY GEN PURPOSE SPDT 10A 12V
2	CS1, CS2	Stock	Decoupling Capacitor (47µF)
1	RS6	Stock	470k Resistor
1	12V_Supply 1	Amazon	12V 5A 60W AC DC Power Supply Adapter
1	U2_INA125P	INA125P	Instrumentation Amplifier IC – Analog Load Cell Amp
2	RK3, RK4	67XR5KLFTB	Trimmer 5k Ohm 0.5W, 20-turn, side adjust, through hole potentiometer
Var.	Various fasteners, brackets, screws, Velcro, Wire Shelving unit, Foam boards, wire connectors, AC service sockets, Romex cable, wire ties, junction boxes, light socket & bulb, wood framing, collapsible bins, Luan sheet, and other cabling, connectors, and glues as needed.		

8.2 Material Budget List

Table 8.2.1: Material Budget List

Qty.	Part Num.	Description	Unit Cost	Total Cost
1	n/a	NVIDIA developer board for visual detection	$100.00	$100.00
1	ROB-09238	Stepper motor	$16.85	$16.85
1	SEN-14729	5Kg Load Cell	$11.88	$11.88
1	IM5116	Inductive Sensor	$53.00	$53.00
2	AD7780BRZ	24Bit sigma-delta IC - Load Cell AMP IC	$9.92	$19.84
1	MCP6004-E/SL	4 circuit IC Op Amp	$0.48	$0.48
2	A4983SETTR-T	Motor Driver Chip	$3.76	$7.52
1	28-653000-10	Chip Socket	$31.36	$31.36
4	MFP-25BRD	Anti-aliasing Filter Resistors 1k	$0.58	$2.32
10	C320C104K3R5TA	Decoupling and anti-aliasing Capacitors (.1µF)	$0.22	$2.24
4	S103M47Z5UN63J7R	Anti-aliasing Filter Capacitors (0.01µF) (10000pF)	$0.33	$1.32
4	TAP106K010CCS	Decoupling Capacitors (10µF)	$0.62	$2.48
4	TAP224M050SCS	Decoupling Capacitors (0.22µF)	$0.42	$1.68
2	MT1A-0R05F2	0.05 OHM Resistor	$1.11	$2.22
2	3299X-1-104LF	100k Potentiometer	$3.39	$6.78
5	FMP100JR-52-100K	100k resistor	$0.20	$1.00
5	FMP100JR-52-10K	10k resistor	$0.20	$1.00
2	TAP475M010SCS	Decoupling and anti-aliasing Capacitors (4.7µF)	$0.42	$0.84
1	A4983SETTR-T	Motor Driver Chip	$3.76	$3.76
1	AD7780BRZ	24Bit sigma-delta IC - Load Cell AMP IC	$9.92	$9.92
1	2.13485E+13	CBL FMALE TO WIRE LEAD 4P 3.28' (M12 Cable for Inductive Sensor)	10.24	10.24
4	FIT0193	BREADBOARD GENERAL PURPOSE PTH	3.15	12.60
2	ORWH-SH-112D1F,000	RELAY GEN PURPOSE SPDT 10A 12V	1.32	2.64
1	0	12V 5A 60W AC DC Power Supply Adapter	14.99	14.99
4	VR05S05	DC DC Converter 1 Output 5V 500mA 6.5V - 36V Input	2.40	9.60
2	MEZD71202A-G	DC DC Converter 1 Output 5V 2A 6.5V - 24V Input	5.22	10.44
2	507302B00000G	HEATSINK TO-220 2.5W LOW PROFILE	0.27	0.54
2	4880SG	Mounting Kit For TO-220 Heat Sinks	2.42	4.84
1	2.13485E+13	CBL FMALE TO WIRE LEAD 4P 3.28' (M12 Cable for Inductive Sensor)	10.24	10.24
4	FIT0193	BREADBOARD GENERAL PURPOSE PTH	3.15	12.60
2	ORWH-SH-112D1F,000	RELAY GEN PURPOSE SPDT 10A 12V	1.32	2.64

2	0	Decoupling Capacitor (47µF)	0.00	0.00
1	0	470k Resistor	0.00	0.00
1	0	12V 5A 60W AC DC Power Supply Adapter	14.99	14.99
1	1998	Universal Hub Mount 5mm M3	7.49	7.49
1	1069	M3 Hex Nut (25 pack)	0.99	0.99
1	2695	M3, 10mm screw (25 pack)	1.29	1.29
2	3424	FEETECH Standard Servo FS5103B	8.95	17.90
10	54-00166	CONN JACK R/A PCB 5.5X2.1MM	0.46	4.60
1	2266	NEMA 17 L-Bracket	3.95	3.95
2	3435	Mounting Bracket for Standard-Size Servos	2.49	4.98
1	n/a	Plastic Servo Arms 25T (a set of 8)	9.99	9.99
1	n/a	Logitech c270 Webcam 720p	40.00	40.00
1		1080p 10-inch Monitor	80.00	80.00
			Total	$535.12

9. Project Schedules

9.1 Fall Semester Gantt Chart

Task Name	Duration	Start	Finish
Project Design	**98 days**	**Wed 8/26/20**	**Wed 12/2/20**
Midterm Report	40 days	Wed 8/26/20	Mon 10/5/20
Cover page	40 days	Wed 8/26/20	Mon 10/5/20
T of C, L of T, L of F	40 days	Wed 8/26/20	Mon 10/5/20
Problem Statement	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**
Need	40 days	Wed 8/26/20	Mon 10/5/20
Objective	40 days	Wed 8/26/20	Mon 10/5/20
Background	40 days	Wed 8/26/20	Mon 10/5/20
Marketing Requirements	40 days	Wed 8/26/20	Mon 10/5/20
Engineering Requirements Specification	40 days	Wed 8/26/20	Mon 10/5/20
Engineering Analysis	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**
Circuits (DC, AC, Power, …)	40 days	Wed 8/26/20	Mon 10/5/20
Electronics (analog and digital)	40 days	Wed 8/26/20	Mon 10/5/20
Signal Processing	40 days	Wed 8/26/20	Mon 10/5/20
Communications (analog and digital)	40 days	Wed 8/26/20	Mon 10/5/20
Electromechanics	40 days	Wed 8/26/20	Mon 10/5/20
Computer Networks	40 days	Wed 8/26/20	Mon 10/5/20
Embedded Systems	40 days	Wed 8/26/20	Mon 10/5/20
Accepted Technical Design	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**
Hardware Design: Phase 1	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**

Hardware Block Diagrams Levels 0 thru N (w/ FR	40 days	Wed 8/26/20	Mon 10/5/20
Software Design: Phase 1	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**
Software Behavior Models Levels 0 thru N (w/FR	40 days	Wed 8/26/20	Mon 10/5/20
Mechanical Sketch	40 days	Wed 8/26/20	Mon 10/5/20
Team information	40 days	Wed 8/26/20	Mon 10/5/20
Project Schedules	**40 days**	**Wed 8/26/20**	**Mon 10/5/20**
Midterm Design Gantt Chart	40 days	Wed 8/26/20	Mon 10/5/20
References	40 days	Wed 8/26/20	Mon 10/5/20
Midterm Parts Request Form	47 days	Wed 8/26/20	Mon 10/12/20
Midterm Design Presentations Day 1	0 days	Wed 9/30/20	Wed 9/30/20
Midterm Design Presentations Day 2	0 days	Wed 10/7/20	Wed 10/7/20
Project Poster	14 days	Wed 11/18/20	Wed 12/2/20
Final Design Report	50 days	Tue 10/6/20	Wed 11/25/20
Abstract	48 days	Tue 10/6/20	Mon 11/23/20
Hardware Design: Phase 2	**48 days**	**Tue 10/6/20**	**Mon 11/23/20**
Modules 1…n	**48 days**	**Tue 10/6/20**	**Mon 11/23/20**
Simulations	48 days	Tue 10/6/20	Mon 11/23/20
Schematics	48 days	Tue 10/6/20	Mon 11/23/20
Software Design: Phase 2	**48 days**	**Tue 10/6/20**	**Mon 11/23/20**
Modules 1…n	**48 days**	**Tue 10/6/20**	**Mon 11/23/20**
Code (working subsystems)	48 days	Tue 10/6/20	Mon 11/23/20
System integration Behavior Models	48 days	Tue 10/6/20	Mon 11/23/20
Parts Lists	**48 days**	**Tue 10/6/20**	**Mon 11/23/20**
Parts list(s) for Schematics	48 days	Tue 10/6/20	Mon 11/23/20
Materials Budget list	48 days	Tue 10/6/20	Mon 11/23/20
Proposed Implementation Gantt Chart	48 days	Tue 10/6/20	Mon 11/23/20
Conclusions and Recommendations	48 days	Tue 10/6/20	Mon 11/23/20
Final Parts Request Form	13 days	Sun 10/11/20	Sat 10/24/20
Subsystems Demonstrations Day 1	0 days	Tue 11/10/20	Tue 11/10/20
Subsystems Demonstrations Day 2	0 days	Tue 11/17/20	Tue 11/17/20
Parts Request Form for Spring Semester	9 days	Mon 11/23/20	Wed 12/2/20

9.2 Spring Semester Gantt Chart

Task Name	Duration	Start	Finish	Pre	Resource Names
SDP2 Implementation 2020	**103 days**	**Mon 1/11/21**	**Fri 4/23/21**		
Revise Gantt Chart	14 days	**Mon 1/11/21**	Sun 1/24/21		
Implement Project Design	**89 days**	**Mon 1/11/21**	**Fri 4/9/21**		
Hardware Implementation	**47 days**	**Mon 1/11/21**	**Fri 2/26/21**		
Breadboard Components	**14 days**	**Mon 1/11/21**	**Sun 1/24/21**		
Stepper Motor Driver	14 days	Mon 1/11/21	Sun 1/24/21		Stephen
Load Cell Amp	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Induction Sensor Relay Circuit	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Power Distribution Circuit	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Layout and Generate PCB(s)	**30 days**	**Mon 1/11/21**	**Tue 2/9/21**		
Stepper Motor Driver	14 days	Mon 1/11/21	Sun 1/24/21		Stephen
Load Cell Amp	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Induction Sensor Relay Circuit	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Power Distribution Circuit	14 days	Mon 1/11/21	Sun 1/24/21		Keith
Assemble Hardware	**30 days**	**Mon 1/11/21**	**Tue 2/9/21**	**14**	
Visual Detection unit	14 days	Mon 1/25/21	Sun 2/7/21		Sergio
Pressure Unit (Load Cell Unit)	14 days	Mon 1/25/21	Sun 2/7/21		Keith
Power & Relay Unit	14 days	Mon 1/25/21	Sun 2/7/21	14	Keith
Metal Detection Unit	14 days	Mon 1/25/21	Sun 2/7/21	14	Keith
Sorting Unit	14 days	Mon 1/25/21	Sun 2/7/21	14	Stephen
Microcontroller	14 days	Mon 1/25/21	Sun 2/7/21	14	Brandon
Test Hardware	**16 days**	**Mon 2/8/21**	**Tue 2/23/21**	**21**	
Visual Detection unit	7 days	Mon 2/8/21	Sun 2/14/21	21	Sergio
Pressure Unit (Load Cell Unit)	7 days	Mon 2/8/21	Sun 2/14/21	21	Keith
Power & Relay Unit	7 days	Mon 2/8/21	Sun 2/14/21	20	Keith
Metal Detection Unit	7 days	Mon 2/8/21	Sun 2/14/21	21	Keith
Sorting Unit	7 days	Mon 2/8/21	Sun 2/14/21	21	Stephen
Microcontroller	7 days	Mon 2/8/21	Sun 2/14/21	21	Brandon
Revise Hardware	**7 days**	**Mon 2/15/21**	**Sun 2/21/21**	**28**	
Visual Detection unit	7 days	Mon 2/15/21	Sun 2/21/21	28	Sergio

Task Name	Duration	Start	Finish	Pr	Resource Names
Pressure Unit (Load Cell Unit)	7 days	Mon 2/15/21	Sun 2/21/21	30	Keith
Power & Relay Unit	7 days	Mon 2/15/21	Sun 2/21/21	31	Keith
Metal Detection Unit	7 days	Mon 2/15/21	Sun 2/21/21	28	Keith
Sorting Unit	7 days	Mon 2/15/21	Sun 2/21/21	28	Stephen
Microcontroller	7 days	Mon 2/15/21	Sun 2/21/21	28	Brandon
MIDTERM: Demonstrate Hardware Subsyst	5 days	Mon 2/22/21	Fri 2/26/21		
SDC & FA Hardware Approval	0 days	Sat 2/27/21	Sat 2/27/21	36	
Software Implementation	**47 days**	**Mon 1/11/21**	**Sat 2/27/21**		
Develop Software	**28 days**	**Mon 1/11/21**	**Sun 2/7/21**		
Visual Detection Python Script	28 days	Mon 1/11/21	Sun 2/7/21		Sergio
GUI Script	28 days	Mon 1/11/21	Sun 2/7/21		Sergio
Embedded Software	28 days	Mon 1/11/21	Sun 2/7/21		Brandon
Test Software	**28 days**	**Mon 1/11/21**	**Sun 2/7/21**		
Visual Detection Python Script	28 days	Mon 1/11/21	Sun 2/7/21		Sergio
GUI Script	28 days	Mon 1/11/21	Sun 2/7/21		Sergio
Embedded Software	28 days	Mon 1/11/21	Sun 2/7/21		Brandon
Revise Software	**14 days**	**Mon 2/8/21**	**Sun 2/21/21**	**39**	
Visual Detection Python Script	14 days	Mon 2/8/21	Sun 2/21/21	39	Sergio
GUI Script	14 days	Mon 2/8/21	Sun 2/21/21	39	Sergio
Embedded Software	14 days	Mon 2/8/21	Sun 2/21/21	39	Brandon
MIDTERM: Demonstrate Software Subsyste	5 days	Mon 2/22/21	Fri 2/26/21		
SDC & FA Software Approval	0 days	Sat 2/27/21	Sat 2/27/21	51	
System Integration	**42 days**	**Sat 2/27/21**	**Fri 4/9/21**		
Assemble Complete System Integration	**14 days**	**Sat 2/27/21**	**Fri 3/12/21**	**51**	
Visual Detection unit	14 days	Sat 2/27/21	Fri 3/12/21	51	Sergio
Pressure Unit (Load Cell Unit)	14 days	Sat 2/27/21	Fri 3/12/21	51	Keith
Power & Relay Unit	14 days	Sat 2/27/21	Fri 3/12/21	51	Keith
Metal Detection Unit	14 days	Sat 2/27/21	Fri 3/12/21	51	Keith
Sorting Unit	14 days	Sat 2/27/21	Fri 3/12/21	51	Stephen
Microcontroller	14 days	Sat 2/27/21	Fri 3/12/21	51	Brandon
Test Complete System Integration	**7 days**	**Sat 3/13/21**	**Fri 3/19/21**	**54**	
Visual Detection unit	7 days	Sat 3/13/21	Fri 3/19/21	54	Sergio
Pressure Unit (Load Cell Unit)	7 days	Sat 3/13/21	Fri 3/19/21	54	Keith
Power & Relay Unit	7 days	Sat 3/13/21	Fri 3/19/21	54	Keith
Metal Detection Unit	7 days	Sat 3/13/21	Fri 3/19/21	54	Keith
Sorting Unit	7 days	Sat 3/13/21	Fri 3/19/21	54	Stephen
Microcontroller	7 days	Sat 3/13/21	Fri 3/19/21	54	Brandon
Revise Complete System Integration	**16 days**	**Sat 3/20/21**	**Sun 4/4/21**	**61**	
Visual Detection unit	16 days	Sat 3/20/21	Sun 4/4/21	61	Sergio
Pressure Unit (Load Cell Unit)	16 days	Sat 3/20/21	Sun 4/4/21	61	Keith
Power & Relay Unit	16 days	Sat 3/20/21	Sun 4/4/21	61	Keith
Metal Detection Unit	16 days	Sat 3/20/21	Sun 4/4/21	61	Keith
Sorting Unit	16 days	Sat 3/20/21	Sun 4/4/21	61	Stephen
Microcontroller	16 days	Sat 3/20/21	Sun 4/4/21	61	Brandon
Demonstration of Complete System	5 days	Mon 4/5/21	Fri 4/9/21	68	
Develop Final Report	**103 days**	**Mon 1/11/21**	**Fri 4/23/21**		
Write Final Report	103 days	Mon 1/11/21	Fri 4/23/21		
Submit Final Report	0 days	Fri 4/23/21	Fri 4/23/21	77	
Spring Recess	7 days	Mon 4/12/21	Sun 4/18/21		
Project Demonstration and Presentation					

10. Conclusions and Recommendations

The final form of the Smart Recycling Bin is achieving a sorting accuracy of about 97-98%, which exceeds the proposed 85% (or better) design specification. The metal sorting has been demonstrated to be 99% accurate, exceeding the specification of 95% accuracy. It has been demonstrated that the load cell has been able to discriminate between plastic and glass with an accuracy of approximately 97%, exceeding the specified 75% accuracy, and the visual detection unit has been performing with an approximate accuracy of 95%. The Smart Recycling Bin can also process and sort approximately 4 items per minute; much faster than the specified 1 item per minute goal.

Possible improvements for this device could include adding the second servo motor as a sweeper to clear any materials that may otherwise become stuck on the detection area incline due to friction. Larger capacity sorting bins could be a practical upgrade, as long as one could still re-organize the physical layout of the device to make it more compact. One way to enable the machine size to be compacted might be to utilize a camera that can take accurate images at a more close-up range. Integrating a small display screen into the design is another consideration for improving the design.

11. References

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L. M. Kumar, K. Shankar, K. H. Shah, T. Chinnu and V. Venkataraman, "Embedded wireless-enabled low cost plastic sorting system for efficient waste management," *2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS)*, Trivandrum, 2013, pp. 154-158.

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M. Bonaccorsi, G. Rateni, F. Cavallo and P. Dario, "In-line industrial contaminants discrimination for the packaging sorting based on near-infrared reflectance spectroscopy: A proof of concept," *2017 IEEE SENSORS, Glasgow*, 2017, pp. 1-3

Costa, Arthur Z. Da, et al. “Computer Vision Based Detection of External Defects on Tomatoes Using Deep Learning.” *Biosystems Engineering*, vol. 190, 6 Dec. 2019, doi:10.1016/j.biosystemseng.2019.12.003.

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12. Appendices

A. A4983 Stepper Motor Driver IC Datasheet: https://www.digikey.com/htmldatasheets/production/49727/0/0/1/a4983.html

B. AD7780 Sigma-Delta ADC Datasheet: https://www.analog.com/media/en/technical-documentation/data-sheets/AD7780.pdf

C. Explorer 16/32 Development Board User’s Guide: https://microchipdeveloper.com/boards:explorer1632

D. Microchip PIC24FJ1024GB610 Datasheet: https://ww1.microchip.com/downloads/en/DeviceDoc/PIC24FJ1024GA610-GB610-Family-Data-Sheet-DS30010074G.pdf

E. INA125P Instrumentation Amplifier Datasheet: https://www.ti.com/lit/ds/symlink/ina125.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1619160425977

F. MEZD71202A 5VDC, 2A DC/DC Regulator Datasheet: https://www.monolithicpower.com/en/documentview/productdocumen

t/index/version/2/document_type/Datasheet/lang/en/sku/mEZD71202A/document_id/3643

G. VR05S05 5VDC, 500mA DC/DC Regulator Datasheet: https://media.digikey.com/pdf/Data%20Sheets/XP%20Power%20PDFs/DS_VR05.pdf

H. 67XR5KLFTB 5k ohm Trimmer Potentiometer Datasheet: https://www.ttelectronics.com/TTElectronics/media/ProductFiles/Trimmers/Datasheets/67.pdf