Waste Sorter: Design Document

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Needs Assessment

Client/Customer Definition

The customer base of our product are a) business owners within the food service industry that are b) of the upper middle class that are c) willing to spend the money to improve their customer satisfaction and eco-friendliness. For our launch, we plan to primarily target local businesses within the Waterloo area while slowly expanding to eventually cover the North Americas and possibly work with franchises/chains to implement our products into their restaurants. The product will aid owners facing the challenges of lazy and/or ignorant customers when it comes to properly sorting their waste into categories such as recycling, organics, and trash which then contaminates sorted waste. For recycling this means that: plastics and metals don't get recycled and are now wasted [2]. For trash this means that: lots of trash can end up in recycling facilities which can cause issues for the machines, and employees can get harmed, among other consequences [3]. For organics this means that: compostable items can get wasted and not composted properly. They can also end up in garbage cans which will amplify the stench.

Consumers are evidently clueless about sorting, for example "Most people CBC Toronto asked on the street weren't aware that the bottom part of the rotisserie chicken container belongs in the garbage and not the blue bin." [1]. This problem is not limited to the customers and even the restaurants themselves are unaware, "Some restaurants and cafes are looking for new suppliers and even rebranding after finding out that the black plastic containers and lids they're using aren't recyclable in Toronto." [1]. In fact, it has been found that some restaurants have given up entirely and even with garbage bins with proper labeled holes, they all lead to the same bag, defeating the entire purpose and making customers question if it's even worth be mindful anymore, "Some are even questioning why they're given the option to recycle if everything is just apparently thrown into the garbage anyway." [7]. When restaurants are ignorant and lazy themselves about being eco-friendly, it actually leaves customers unsatisfied and even angry. Restaurants are aware of everything that is going on, and are making small strides to improve themselves to gain consumer support for their actions with 65% of restaurant operators having recycling programs in place, 60% of consumers preferring restaurants that recycle, and 51% of diners even willing to pay a premium for eco-friendliness according to the National Restaurant Association [8]. With our product manually sorting the waste, customers will be happy and inclined to come to participating restaurants with their significant improvement in eco-friendliness.

Competitive Landscape

Below are three existing systems in society that are meant to address some of the issues that the Waste Sorter addresses. These systems have shortcomings, which the Waste Sorter aims to address.

- Recyclable packaging materials and utensils
  - “A lot of quick service restaurants are using more biodegradable plates and cups, others are opting for refillable containers instead of using plastic water bottles.” [8]
  - More eco-friendly options means that they will either be recycled, will naturally degrade, or can be reused rather than end up in landfills
  - The shortcoming of this is that it still requires them to be sorted still as it won’t matter if everything is recyclable or biodegradable if aren’t going in the proper bins anyways (a problem our product will solve)
- Labeled food packaging
  - Some restaurants “label[their] food packaging into recyclables and non-recyclables so that the restaurant patrons may sort their waste into the proper waste bin according to the labels” [9]
  - Tells the consumers whether or not the packaging can be recycled or not
  - The shortcoming of this is some consumers are simply lazy and simply do not care about properly sorting their own waste and so these labels only work if the consumer takes the effort to read the label and follow instructions (with our product they can do what they want since it will always be sorted regardless)
- Labeled bins [10]
  - Separates trash into its respective categories
  - Increases the awareness about properly disposing of waste
  - The shortcoming here is that it still requires consumers to manually sort and be knowledgeable on what goes where. Also, if something ends up in the wrong bin then the whole section would be contaminated.

Requirement Specification

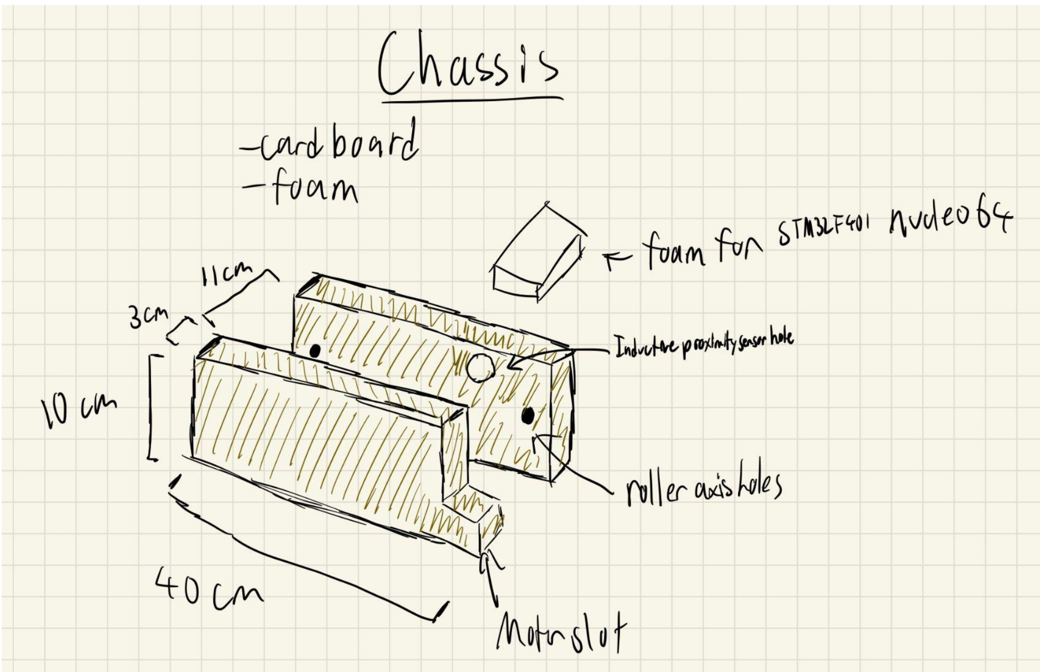
1. Rotating Dish Requirement
   - Rotating dish should be able to quickly rotate the correct collection section into place after the machine classifies inputted trash so that it lands safely and correctly off the conveyor belt. To pass this requirement, the dish must rotate to the correct position and stop in under 2 **seconds**.
2. Metal detection requirement

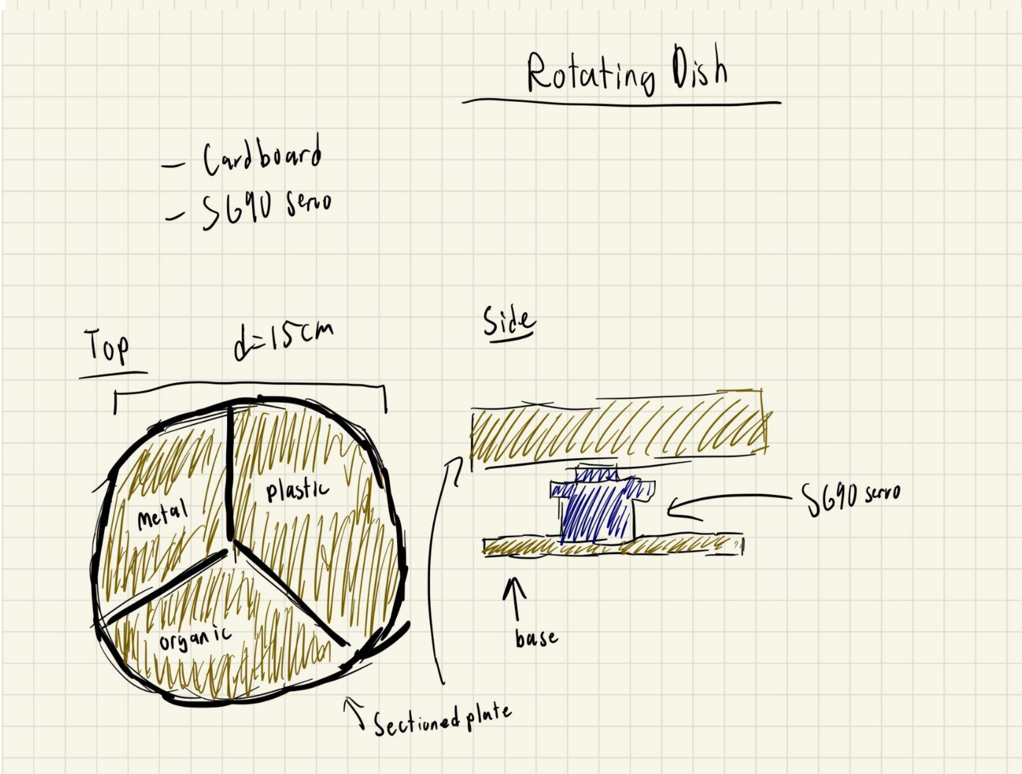
- Inductive proximity sensors should identify whether or not trash is metal. In order to meet requirement, sensor should successfully identify metal from non-metal at minimum 75 **percent** of the time

3. Organic/moisture detection requirement
    - Soil moisture sensors should identify whether or not trash contains moisture and is therefore organic. In order to meet requirement, sensor should successfully identify organics from non-organics at minimum 75 **percent** of the time
4. Object identification requirement
    - Ultrasonic sensor should be able to identify whether or not trash has been inputted into the machine and has passed by the sensor. In order to meet requirements, sensors should successfully recognize that an item has passed by 75 **percent** of the time.
5. Speed/efficiency requirement
    - Design is able to intake and properly sort at minimum 5 **pieces of trash per minute** in order to meet speed and efficiency requirement

Analysis

Design

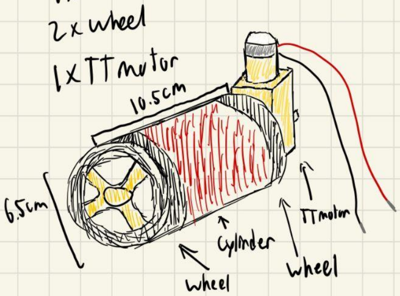




Conveyor Belt

① Conveyor Roller x2

1x metal cylinder
2x wheel
1x TT motor

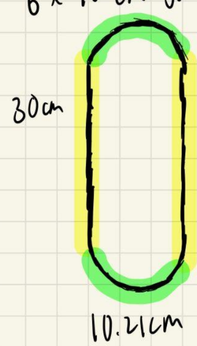


description:

Conveyor rollers constructed by connecting 2 wheels with soda cans, and powered by TT motor

② Belt

6 x 90 cm gorilla tape

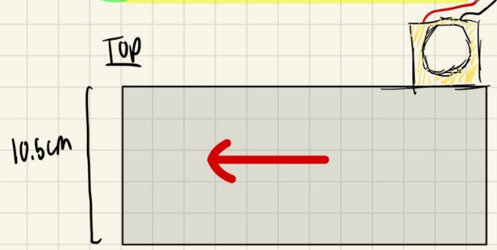


description:
yellow is length between rollers
green is wrap around rollers

③ Combine

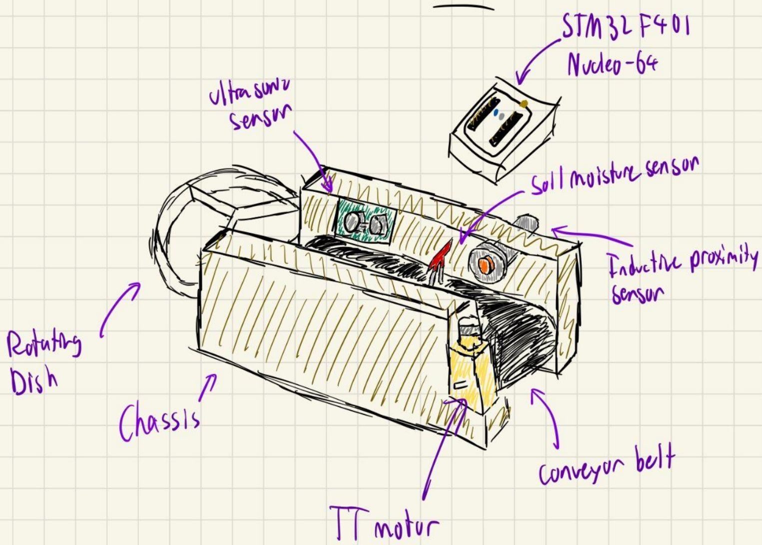
Side:

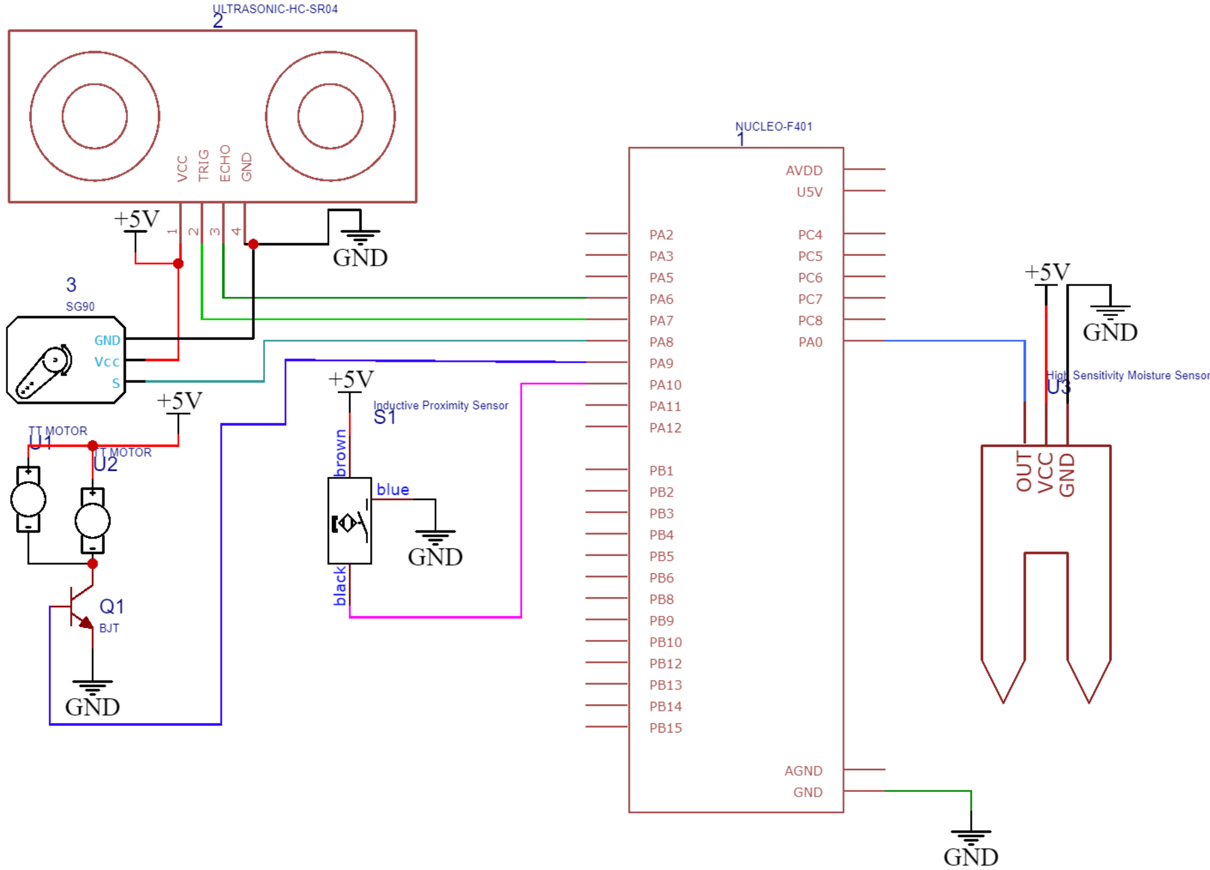
Top



description:
Belt should wrap tightly around rollers, rollers should be mounted to chassis.

Final





Schematic Diagram Depicting Wiring Scheme
For the non-technical reader, this is aimed to depict how many elements(or how much clutter) they should expect to see in the completed build design.

Scientific or Mathematical Principles

Mathematical Principle: Statistics

Moisture sensor will be first calibrated through multiple tests using completely dry material and with pure water. These will return values that will calculate the averages (mean) of [12] to mark 0% (minimum) and 100% (maximum) moisture respectively [15]. In the final implementation, objects will make contact with the moisture sensor for a brief moment where numerous moisture readings will be read and recorded, the returned values of which will be inputted into the following formulas:

$\mathbf{x_{avg} = (x_1+x_2\ldots +x_n)/n}$,

where x_i **for** $i = [1,n]$ is the moisture reading and **n** is the number of readings made during the brief contact period with the sensor. [12]
With this we can calculate the how much moisture there is as a decimal value

$$y = (x_{avg} - min) / (max-min)$$,

where **y** is the percentage of moisture as a decimal [14]. **min** is the average previously calculated when calibrating for air or "zero percent" moisture (this can be recalibrated depending on the environment, but it will likely not actually be zero unless in a very dry environment). **max** is the average previously calculated when calibrating for 100% moisture using pure water. [15]

Using the percentage moisture returned, it will then be determined if the moisture of the object is above a certain threshold to warrant classifying it as an "organic", which items that fall under such a category often contain at least some degree of moisture.

Scientific Principle: Watt's Law (P=IV)

Watt's Law states that the product of voltage and current is power, and the formula to calculate such is **P=IV**, where **P** is the power in watts, **V** is the voltage in volts, and **I** is the current in amps [11]. One of the most crucial requirements of this project as stated on the Learn is that "the design must not consume, transfer, discharge, or otherwise expend more than 30W of power at any point in time and within any component of the design during its operation." In order to ensure our project meets this requirement, we will be taking the total voltage rating of our system and the total current draw to calculate whether or not we are under the limit.

Scientific Principle: Energy Stored in an Inductor

Given that we will be using an induction-based proximity sensor(which contains an inductor), we are required to know how much energy it has the potential to store as a part of our energy analysis to ensure that more than 500mJ of energy is not stored in the system at any given time. According to the datasheet of our proximity sensor[13], the relevant pieces of information regarding the component are as follows:

Length: 68mm = 0.068m
Diameter: 18mm = 0.018m → Radius = 0.009m(since r = d/2)
Maximum output current: 400mA = 0.4A
Material: Nickel → Permeability of Nickel Relative to Permeability of Vacuum = 600 [16]

With the following pieces of information, we can first find the inductance with the formula:

$$L_{coil} = \frac{\mu_r \mu_0 N^2 \pi r^2}{l} \text{ [17]}$$

Where L_{coil} = Inductance of coil in henries (H)
μ_r = relative permeability of the material = 600
μ_0 = permeability of free space = $4\pi \times 10^{-7}$ (H/m)
N = number of turns in coil = 40 (counted)
r = coil radius(m) = 0.009m
l = coil length(m) = 0.068m

Therefore for our coil, L = 4.51×10^{-3} H

With this, we can find the total possible maximum energy stored in the inductor, by using the law:

$$E = \frac{1}{2}LI^2 \text{ [18]}$$

Where E is the energy stored in the inductor in joules(J)
L = inductance of the coil (H)
I = Current

We can find that while the inductor is at its maximum possible current output (0.4A),

E = 3.61×10^{-4} J = 0.361mJ

This calculation tells us that the inductor can store a maximum energy far less than the project's limit of 500mJ

Costs

Manufacturing Costs

1x SG90 Servo
Manufacturer: MMOBIEL
Manufacturer Location: Oldenzaal Overijssel, NL
Vendor: Amazon.ca
Vendor Location: Canada
2x TT Motor + 4x Wheels
Manufacturer: Stemedu
Manufacturer Location: Guangdong, CN
Vendor: Amazon.ca
Vendor Location: Canada
1x Soil Moisture Sensor
Manufacturer: Qianxin
Manufacturer Location: China
Vendor: Amazon.ca
Vendor Location: Canada
1x Inductive Proximity Sensor
Manufacturer: URBEST
Manufacturer Location: Xiamen, Fujian, CN
Vendor: Amazon.ca
Vendor Location: Canada
1x Ultrasonic Sensor
Manufacturer: Smraza
Manufacturer Location: Shenzhen, Guangdong, CN
Vendor: Amazon.ca
Vendor Location: Canada
Black Gorilla Tape Roll
Manufacturer: Gorilla Glue
Manufacturer Location: United States of America
Vendor: Home Depot
Vendor Location: Canada
STM32F401 Nucleo-64
Manufacturer: STMicroelectronics
Manufacturer Location: Switzerland
Vendor: W Store
Vendor Location: Canada
Wires
Breadboard

Frame material (currently cardboard)
2x Hollow Metal Cylinder
1x NPN BJT Transistor

Implementation Costs

User Manual

This portion of the Design Document is a user guide for how to install the Waste Sorter.

Step 1. Make sure you're in a food service environment in order to use the Waste Sorter. This will ensure that waste gets sorted correctly, as all the waste you will find in a food-service environment is much more likely to be able to be sorted by this iteration of the Waste Sorter than in other environments.

Step 2. Make sure that you have your three waste chutes for each of the three types of waste installed(Metal, Organics, Other) that all converge under the rotating dish. The production version of the Waste Sorter will have trap doors that slide out from under the rotating dish to empty each piece of waste into its respective waste chute. Now make sure that the three sorting compartments of the rotating dish line up with the three waste chutes below.

Step 3. Make sure that there is sufficient indoor space around where the Waste Sorter will be installed such that when the chutes are lined up with the sorting plate, the Waste Sorter fits within the given space without causing a safety hazard.

Step 4. Move the industrial Waste Sorter into its final location, and drill it into the Floor or Counter it is resting on.

Step 5. Plug in the 100-240VAC to DC Adapter to a 110VAC Wall Socket. The Waste Sorter should now be operational.

Risks

Energy Analysis

Power Supply

Every single Component will be powered by a 5V 4A switching power supply Power supply. The reasoning behind this is because our group already has access to one without spending any extra money, and as it turns out, every single component we are using is able to operate on 5V. Adding up the total current of all devices used allows us to operate well within the limit of 4A that the power supply can provide. This power supply can output up to a total of 5V*4A = 20W at any given time, which is within the specified 30W power limit. This gives us an extra 10W to work with for power produced by kinetic or other forms of energy.

Picture of reference standards that the AC Power Adapter meets (Valid according to UW Safety Office[24] and it's verified list of approved markings[25])

Nucleo 64 Board

Table 20. Typical and maximum current consumption, code with data processing (ART accelerator disabled) running from SRAM - V_{DD} = 1.7 V

Symbol	Parameter	Conditions	f_{HCLK} (MHz)	Typ	Max(1)			Unit
				T_A= 25 °C	T_A= 25 °C	T_A=85 °C	T_A=105 °C	
I_{DD}	Supply current in **Run mode**	External clock, all peripherals enabled(2)(3)	84	21.8	23.1	24.1	25.3(4)	mA
			60	15.8	16.5	17.5	18.7	
			40	11.4	11.9	12.9	13.9	
			20	6.0	6.3	7.3	8.3	
		External clock, all peripherals disabled(3)	84	12.7	13.5	14.5	16.3(4)	
			60	9.2	10.5	11.5	12.8	
			40	6.7	7.1	8.1	9.1	
			20	3.6	3.8	4.8	5.8	

1. Guaranteed by characterization, not tested in production unless otherwise specified
2. When analog peripheral blocks such as ADC, HSE, LSE, HSI, or LSI are ON, an additional power consumption has to be considered.
3. When the ADC is ON (ADON bit set in the ADC_CR2 register), add an additional power consumption of 1.6 mA for the analog part.
4. Tested in production.

As we can see from the above table taken from the STM32F401RE datasheet[19], the maximum current draw the Nucleo 64 Board should ever draw is 25.3mA. The Nucleo Board should not have the capacity to store a significant amount of energy. If it were, then this course would be impossible to complete. Generally, the only types of stored energy in a circuit with no batteries will be in inductors and capacitors(as there will be no potential chemical energy without batteries).

Induction-Based Proximity Sensor

The next component we used is an induction-based proximity detector. As calculated above in the scientific principles section, the maximum possible energy stored in our sensor at one given time is 0.361mJ which is far below our maximum of 500mJ. Also, according to its data sheet [13], the maximum current consumption is 13mA.

TT Motors

The Garbage Sorter will use two TT Motors to rotate the conveyer belt. These motors operate at ~150mA±10% at a default rate[20]. Also according to the data sheet, if the motors were to stall due to too much load, the current draw increases to 1.5A when powered by 6VDC.

The motors should never stall, nor require 6VDC, but for the sake of argument, we are assuming that every component is drawing the absolute maximum current.

Moisture Sensor

Our project will also use a moisture sensor to detect if an object is made of organic matter, as the assumption is that the organic matter found in the given applications of this product will have some type of moisture in it. According to the user manual of the moisture sensor[21], It will not use more than 20mA of current

SG90 Servo

The design will make use of an SG90 servo to rotate the collection bin that will collect waste into different compartments depending on where they belong. According to some tests run by a third party[22], the servo should operate at a maximum of 360mA when it is stalled.

Ultrasonic Proximity Sensor

The operating current of the ultrasonic proximity sensor is 15mA according to its datasheet[23].

Final Calculations

Since all the components will be run in series, we can find the absolute maximum current draw by simply funding the sum of the worst-case current draws which are found above.

$$A_{max} = 25.3mA + 13mA + 1500mA + 1500mA + 20mA + 360mA + 15mA = 3433.3mA$$

As demonstrated, even in the worst possible case, the design will draw only 3433.3mA which is less than the maximum current output of the AC adapter which is 4000mA @ 5V. This means, in the very worst possible case, the design will use 3.43A * 5V = 17.15W of power at any given moment. This meets the maximum power draw requirements for the project of 30W.

As for the maximum energy stored, we concluded that the only non-negligible source of energy storage would be the inductor in the induction-proximity sensor. Any other places where energy could be stored (ex. capacitors, which the current design has none of, but might expand to include) have a negligible amount of energy stored and we can therefore conclude that the max energy stored in the system will be ~0.136mJ which is far below the limit of 500mJ.

Risk Analysis

One negative consequence on the environment that may result from using the design as intended is the electricity usage in comparison to traditional unpowered garbage bins. While our design helps to prevent environmental damage, it does come at the cost of being electronically powered which slightly drags down the positives of our design.

There is also the possible safety risk of injury from the moving components of our design, if our design is used incorrectly. This could occur if someone sticks their hand into the conveyor belt or rotating sorting dish portions of the design while it is still on, which could result in physical injury. A scenario in which someone may make this mistake is if they reach in to retrieve a piece of trash or to clean it without turning the machine off. This can be prevented by making sure that the moving components are properly covered and inaccessible to normal people, and that the machine should only be worked on by certified professionals.

Safety and environmental consequences arise especially when the design is used for an unintended purpose. The most likely is that it may be used outside of the food service settings it was intended to operate in. The reason this is risky is that the items thrown out within a restaurant for example are easily predictable, and our design was created with these trash items in mind. If placed outside a food service setting, the design will likely be exposed to a much wider variety of trash items that it may be incapable of sorting or that do not belong within the three sectioned bins of the design (organics, metals, plastics), resulting in environmental damages.

Some ways that the design may malfunction include improper sorting and failure of moving components. Our design utilizes a variety of sensors to sort inputted trash, and while this should theoretically work, it will occasionally be faced with difficult trash pieces that could trigger unintended sensors or none at all. With moving components, there is always the possibility of failure due to the constant strain and wear as a result of motion and friction. This should not be an issue however if the machine undergoes constant and proper maintenance.

Testing and Validation

Test Plan

Test #1 (Rotating Dish Requirement):

Test Setup:
1. Set project down
2. Plug in and turn on project

Environmental Parameters:
- Ambient temperature at approximately room temperature
- Indoors (low/no humidity)
- Level ground
- No obstructions to sensors
- Normal lighting

Test Inputs:
- Apple core
- Tinfoil
- Candy bar wrapper

Quantifiable Measurement Standard:
Seconds

Pass Criteria:
Rotates the correct section of the dish into ready position to collect trash as it falls off the conveyor belt within 2 seconds of identifying the trash.

Test Plan:
Each input will trigger one out of three of the sensors; apple core to soil moisture sensor; tinfoil to inductive proximity; candy bar wrapper to ultrasonic. The testing process will involve holding up each input to their respective sensor so that the material will be detected and the servo will react by rotating the dish's correct sections into place. The dish is separated into 3 sections of metals, organics, and plastic. Once the trash has been detected, we will time how long it takes for the servo to react and properly rotate into the correct position, which in order for the design to pass must do so within 2 seconds.

Test #2 (Metal Detection Requirement):

Test Setup:
1. Set project down
2. Plug in and turn on project

Environmental Parameters:

- Ambient temperature at approximately room temperature
- Indoors (low/no humidity)
- Level ground
- No obstructions to sensors
- Normal lighting

Test Inputs:

- Apple core
- Banana peel
- Dirty napkin
- Tinfoil
- Soda can
- Candy bar wrapper
- Chip bag
- Plastic fork

Quantifiable Measurement Standard:

Percentage (Success Rate)

Pass Criteria:

Successfully identifies whether or not input is metal or not with a 75% success rate.

Test Plan:

The 9 inputs fall into 3 categories. Apple cores, banana peels, and dirty napkins are considered organics. Tinfoil and soda cans are considered metal. Candy bar wrappers, chip bags, and plastic forks are considered plastic. For this test we will be testing the inductive proximity sensor. To do so, we will be holding up all 9 inputs, 2 times each, to the sensor and basing success off of whether or not the rotating dish correctly rotates the metal section for the metal inputs, and not for the non-metal inputs. To pass, the design must do this with a 75% success rate.

Test #3 (Organic/Moisture Detection Requirement):

Test Setup:

1. Set project down
2. Plug in and turn on project

Environmental Parameters:

- Ambient temperature at approximately room temperature
- Indoors (low/no humidity)
- Level ground
- No obstructions to sensors
- Normal lighting

Test Inputs:

- Apple core
- Banana peel
- Dirty napkin
- Tinfoil

- Soda can
- Candy bar wrapper
- Chip bag
- Plastic fork

Quantifiable Measurement Standard:
Percentage (Success Rate)
Pass Criteria:
Successfully identifies whether or not input is organic or not with a 75% success rate.

Test Plan:
The 9 inputs fall into 3 categories. Apple cores, banana peels, and dirty napkins are considered organics. Tinfoil and soda cans are considered metal. Candy bar wrappers, chip bags, and plastic forks are considered plastic. For this test we will be testing the soil moisture sensor. To do so, we will be holding up all 9 inputs, 2 times each, to the sensor and basing success off of whether or not the rotating dish correctly rotates the organics section for the organic inputs, and not for the non-organic inputs. To pass, the design must do this with a 75% success rate.

Test #4 (Object Pass By Detection Requirement):

Test Setup:
1. Set project down
2. Plug in and turn on project

Environmental Parameters:
- Ambient temperature at approximately room temperature
- Indoors (low/no humidity)
- Level ground
- No obstructions to sensors
- Normal lighting

Test Inputs:
- Candy bar wrapper
- Chip bag
- Plastic fork

Quantifiable Measurement Standard:
Percentage (Success Rate)
Pass Criteria:
Successfully identifies if input has passed by the sensor with a 75% success rate.

Test Plan:
If the inductive proximity and soil moisture sensors are not detecting any inputs, it is either that the input does not meet the qualifications to set off the sensors or that there isn't any input in the first place. In order to allow our design to distinguish from the two possibilities so that it can rotate the collection dish, we have added an ultrasonic sensor at the end which detects passing by inputs. For this test, we will run the machine using the 3 inputs, which classify as plastic and

not organic or metal, 3 times each. The inputs should remain undetected by the first 2 sensors, and upon aligning with the ultrasonic sensor would trigger it and the rotating dish will rotate the plastics section into place. In order to pass the test, the design must do so with a 75% success rate.

Test #5 (Speed/Efficiency Requirement):

Test Setup:
1. Set project down
2. Plug in and turn on project

Environmental Parameters:
- Ambient temperature at approximately room temperature
- Indoors (low/no humidity)
- Level ground
- No obstructions to sensors
- Normal lighting

Test Inputs:
- Apple core
- Banana peel
- Dirty napkin
- Tinfoil
- Soda can
- Candy bar wrapper
- Chip bag
- Plastic fork

Quantifiable Measurement Standard:
Inputs per minute
Pass Criteria:
Successfully takes 5 inputs without interference with one another or their tests per minute.

Test Plan:
All inputs will be randomly picked and placed onto the conveyor belt one at a time (only one input on the conveyor belt at once) as fast as possible without failure/interference for 2 minutes. The number of successful inputs is then counted, and the inputs per minute is calculated, which to pass must be above 5/min.

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