Garment Tag Scanning and Sorting:
Final Report and Fabrication Package

The Bees Knees

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Executive Summary

62.5% of used textiles end up in landfills, and only 14.5% recyclable textiles are actually recycled [1] just in the United States. With this issue in mind, Celestial Theory desires to create an assembly line that can take in recycled clothing and remanufacture the fibers in order to use them in new ways. Starting the process, Celestial Theory needs a device that sorts clothes based on the primary material before the recycling process can begin. The device will be used by an operator that scans the garment's tag and puts it into the device for sorting. The device should be user-friendly and at its current stage, only focus on readable tags and not damaged or faded tags. However, a workaround should be created in order to keep up the flow of production.

Engaging challenges for this device are scanning garment tags accurately and sorting the clothes in their corresponding bins. A Raspberry Pi with an attached camera will read in the tags for scanning the garment tags. The camera has a focus range of 4–10mm and will be placed under an acrylic plate for its protection and to guide the scanning of the garment tag. The largest technical challenge is identifying the dominant material. Currently, the software can repeatedly identify the dominant material, and in the event of two materials being equally dominant, the first material analyzed is considered the dominant one. To correctly sort the clothes, the device will use a pipe assembly that is rotated by a motor and gears. The bottom of the pipe assembly will guide the clothes to their corresponding locations. This angle minimizes the effects of friction on the clothes and effectively transfers vertical kinetic energy to horizontal kinetic energy. A stepper motor was selected to rotate the pipe due to its simple open-loop position and speed control. The selected stepper motor provides 56.5 oz-in of torque and requires 4.8W of power. This torque and power meet the Celestial Theory's specifications for the design. Celestial Theory's other specifications include the weight and safety of the device. The current weight projection of the prototype is 16lbs which meets the OSHA requirement of 40 lbs or less for a device that can be carried. Following OSHA requirement 1910.219, the gears will be enclosed to eliminate the possibility of clothes getting jammed or potential injuries.

The end goal is for the machine to be as straightforward and user-friendly as possible while accurately scanning and efficiently sorting. Through testing and adjustments, the team aims to find the optimal motor speeds to match an operator's pace. The device also will store the information of the clothes being fed through and be able to report the information to the operator.

Nomenclature

a. FEA - finite element analysis, a way to create stress and strain models
b. Pinch point - an area where two surfaces meet and move inward as to grab and pinch
c. OCR - Optical Character Recognition, meaning image to text conversion
d. Python - a high-level programming language
e. Tesseract - an OCR library built by Google. Used with a Python wrapper called pytesseract
f. Raspberry Pi - a miniature computer capable of controlling voltage output pins, a screen, a camera, and running Python code
g. Jellyfish - a library in Python used to pair strings with close matches
h. CNN - Convolutional Neural Network, a deep learning algorithm for image classification
i. GUI - Graphical User Interface, a term describing the shell which allows a user to run a program without seeing or editing the underlying code.

1. Introduction and Background

According to SMART (Secondary Materials and Recycled Textiles Association), 95% of textiles are recyclable, but only around 15% of these textiles are recycled. Recycling used textiles is a sought-after solution, as many of these clothes end up in landfills [1]. At present, infrared scanning technology [3] is the main way to sort clothes based on material type, but there are some problems with these systems [4]. To improve the current industry standard, a combination of a tag scanning and sorting system is created to supplement the current industry standard. This new innovation will help to prevent the problems that often occur with current textile recycling methods. This aligns with Celestial Theory LLC's goal of recycling textiles into new clothing. With this new system, Celestial Theory LLC can increase its production even more.

There are many needs Celestial Theory LLC has regarding each subsystem. One major need is that the overall system must effectively collect and store the amounts and types of material obtained from recycled clothing. This device will be used by a single operator to reduce the number of employees needed in order to operate the business. As Celestial Theory LLC continues to grow, it will need a device that is easily transportable, so it can be used in a variety of different settings. Switching between the subsystems, the tag scanner will read a garment's tag through image recognition software called Tesseract and store the data in a CSV file for quick analysis and record keeping. The system will then command the sorter on how to sort the garment. These features will let Celestial Theory LLC effectively sort the types of materials necessary for recycling.

The overall system as explained will face many challenges regarding manufacturing and prototyping. For the scanning system, the main concern is the current reproducibility of the text recognition software. Currently, the software in collaboration with the current hardware is successful at recording the garment's clothing, however, limitations have not been fully tested such as how much orientation of the image will affect the readability of the software or not. Furthermore, another challenge will be honing in the large bevel gears of the sorting mechanism. These gears are necessary to reduce the amount of moving parts in the machine to not only reduce the weight to help with the transportability needs of Celestial Theory LLC but to also reduce the number of parts to maintain. From a safety standpoint, the code OSHA 1910.147 [5] has played a large concern in prototyping the sorting system. OSHA 1910.147 is the standard that ensures the system is safely de-energized before any maintenance is performed to prevent injury to anyone working on the machine.

With the current needs assessed, a few models of the system have been created. From these, a final design has been chosen that accurately and consistently reads garment tags that can be quickly sorted. In the preliminary selection of the sorting system, a few designs were created that use a rotating sorting mechanism to sort the clothes while other designs use conveyors to move and sort the recycled textiles. The final design included the selection of the rotating system. In regards to the scanning technology, two different softwares were considered: Tesseract, an open-source OCR platform for the RaspberryPi, and Google Cloud Vision API, a software that contains pre-trained machine learning algorithms and a monthly payment. After careful consideration of each software, the free open-source Tesseract library was chosen as the final selection. With these selections, the prototype of the total system will successfully sort garments in 20 to 25 seconds which will be enough to prove the system's viability.

2. Existing Products, Prior Art, and Applicable Patents

Many laundry sorting systems exist, and there are several that sort textiles for recycling purposes based on images of the clothing or material composition. However, there were no systems which sorted them specifically based on the information found on tags after scanning the tags.

The closest current product to what the sponsor has asked for is a system from a company in Sweden that sorts textiles for recycling based on their material compositions [3]. However, this company accomplishes that by using infrared to scan the fabric, as opposed to the tag scanning that the sponsor has requested. The system they designed pulls individual items of clothing from a pile and uses a conveyor belt type system to move items. The sorting system shown in this video performs a similar function to the sorting system in the project, but it is much larger in scale than the scope of this project. In the realm of tag scanning, there is a laundry care app available on the Apple Store which recognizes and translates laundry care symbols based on images of the tag [6]. This product performs the same functions as what is being sought after in tag scanning for laundry care symbols, but it does not use text recognition on the tag, only symbol translation. Similarly, there are several apps which explain symbols but do not perform any image-based analysis or tag scanning. However, Laundry Lens and other apps like it serve as proof of concept that laundry symbol translation can and has been done.

Many of the patents seen in **Table A-1** relate to this project but none of them cover the exact space that this system will occupy: using information generated by tag scanning to sort recycled clothing by textile composition and laundry care needs. The closest patent is patent WO2014198608A1, but that patent is incredibly broad and it is believed that the system will provide sufficient innovation to escape any legal issues. Overall, the search for prior art and patents has served as proof of concept that there is a market for this product and that it is feasible. However, no prior art or patents that were found combined tag scanning with textile sorting for a recycling system. The system from the Swedish company was large scale, processing hundreds of textile items at once. Celestial Theory could potentially work up to that scale, but for now, this product will only be dealing with items one at a time with a target throughput is 1-10 items per minute. The Laundry Lens app performs one of the functions of this project, but it does not include text recognition or sorting. Finally, the patents found are either very broad, with room for innovation, or specific to a different purpose, function, or step in laundry processing.

3. Codes and Standards

Each system has several codes that may apply. The garment tag scanner and the sorting system both are affected by OSHA 1910.147 [5]. This code ensures that if either machine must be opened, the electrical system will be safely shut off to keep those maintaining the device safe from potential shock. Because the parts in the sorter in motion are controlled electrically by PLC's, an electronic safety switch will prevent the motors from running while someone is maintaining the sorter system as well. The code that is only applicable to the sorting subsystem is OSHA 1910 Subpart O which regards safety guarding machines[13]. This code relates to guarding pinch points of the machine as there are gears that can rotate and easily catch and jam a limb. These gears will therefore be guarded in an enclosure to prevent this from occurring.

4. Customer Requirements and Engineering Design Specifications

Celestial Theory provided expectations and additional guidance to the design team. These requirements are outlined and analyzed in the first section of **Appendix B**, along with a discussion of their impacts on the project.

5. Market Research

With this system, the best applicable general market is the textile recycling industry. According to Allied Market Research, the textile recycling industry was valued at $5.6 billion in 2019 and is expected to grow to $7.6 billion in 2027[2]. This shows that there is a viable global market for a garment tag scanner. However, most companies in this industry use fiber scanning devices. A research paper published in 2021 [4] explores the feasibility of sorting textiles based on fiber content. The findings in this paper support the need for tag scanning when possible to make up for shortfalls in textile scanning which is the direction Celestial Theory is taking. Therefore, the design has not changed much as the main purpose is to tailor the design to fit the needs of Celestial Theory. The end-user will be employees of Celestial Theory, so current client and user reviews would not add anything to the user needs that were discussed with the sponsor. Due to this, there are no client or user reviews applicable at this time.

6. Design Concept Ideation

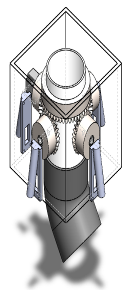
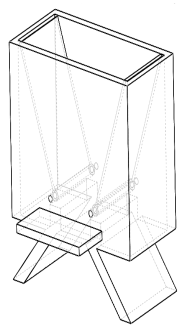
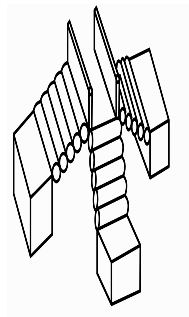
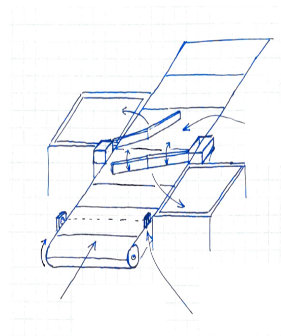
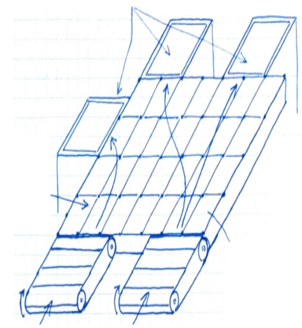
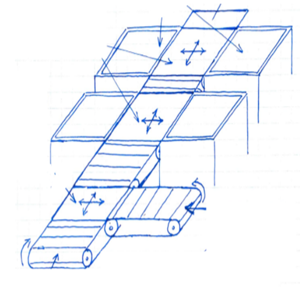
The design team developed several concepts for each subsystem based on the customer requirements and prior art research. These concepts and explanations of the design process involved are included in **Appendix B**.

7. Concept Selection and Justification

The team decided to select the chute method of feeding clothes. While the conveyor belt did allow for a long-term assembly line, it is out of the budget and adds complications the chute does not. To sort the clothes, the team chose the rotating funnel (**Figure C-1**) over the box sorter system, the roller system, and the conveyor systems using the concept selection process below (**Table 1)**. The rotating funnel design is beneficial over the flaps as only one motor is needed and the motor can move in only one direction. The flaps require two motors that both would move back and forth creating more wear and lower longevity as well as increasing the cost. Flexibility and speed were two of the most important design considerations. Because of the support structure built into the sorting mechanism, there are only very few select positions for the bins and sorter to be placed. On the other hand, the funnel sorter with its detachable and interchangeable tripod supports can be placed on any surface or height and in any orientation while still accomplishing its desired task. The rotating funnel sorter also has a much shorter time interval between each piece of clothing which means significantly more clothes can be sorted per minute than the box sorter. Finally, the rotating funnel sorter is lightweight. Initial weight analysis of the box sorter set its weight at around 100 lbs while the funnel sorter in its disassembled state (legs removed) was only around 25 lbs. With all of these factors in mind, it was clear to the team that the best option for a small-scale, efficient clothes sorter was the rotating funnel design.

The chosen rotating funnel sorter is better than the other competing designs and also fulfills the design requirements set out by the sponsor. The first and most important requirement is the ability to sort the clothes into 3 separate bins. The tripod support system allows for the easy placement of three bins around the sorter between each set of legs and the 360 degrees of motion for the rotating chute allows it to direct the clothes into different bins. The next design requirement that the rotating funnel fulfills is the weight and size requirements. The sponsor needs a design that can be carried by a single person and fits into the back of a small car. In coming up with design solutions to deal with these problems, the team came to the ultimate conclusion a full sorter with its supports attached could not be feasibly and safely made under the 40lb weight limit and small enough to fit in a car. To solve this issue the funnel sorter has been designed to have a detachable support system made up of 3 legs and a central joint. When the device needs to be moved, the legs can be removed and carried separately which will allow a single person to transport the entire machine since this action will drop the sorter to around 25lbs which is below the 40lb weight limit. This will also allow the sorter to fit in the back seat of a car since the legs can be removed and stored more compactly. At the moment, the biggest risk for this design is clothes not properly feeding through the sorter and getting stuck as they move through it. This would primarily happen due to friction forces but could also result from improper manufacturing that leads to sharp or jutting edges. The team is currently heavily researching ways to reduce and correct this issue if it comes up by either increasing the angle (towards vertical) of the chute/funnel or applying a chemical coating to the inner surfaces to reduce friction. This design has already been changed based on this concern and cut open the top of the chute exit to allow for easy clearing of clothing jams.

Table 1 Rating Selection Matrix (clearer images in Appendix B-4)

1 - poor 3 - average 5 - excellent Categories	 Rotating Funnel Sorter	 Box Sorter	 Roller	 Backbone and Conveyor Rake	 Omnidirectional Conveyor	 Bidirectional Line Diverging and Merging
Lightweight	5	3	1	1	3	1
Efficient Design	3	3	3	3	3	5
Minimal Moving Parts	5	3	1	1	1	1
Adjustability	5	3	3	5	5	5
Portability	5	3	1	1	1	1
Total	23	15	9	11	13	13

For the tag scanner, the team selected a Raspberry Pi 4 microprocessor with a compatible Raspberry Pi camera for capturing visual input. Compared to an Arduino microcontroller, the Raspberry Pi offers more complex processing features, including Wi-Fi communication for transferring and storing garment data. In addition, the Pi is easier to program using Python, making it easier for the team to work with due to its program language familiarity, and it has a wider support network than the Arudino. For the OCR functionality, the Tesseract Python library will be used. While Google Cloud Vision API offers pre-trained machine learning models that can perform OCR and object detection, the usage of the software requires a monthly fee and initial testing with the Tesseract library showed promising results, deeming the Google software to be unnecessary. **Figure C-3** depicts a flowchart of the text detection algorithm. For the laundry symbol interpretation, the team planned on creating an object detection software capable of drawing bounding boxes around specific objects of interest (i.e. laundry symbols) within an image and evaluating it. The initial plan consisted of using a convolutional neural network (CNN), a machine learning algorithm commonly used in computer vision that takes an image and detects edges/defining features to classify the image. However, due to limitation of the Raspberry Pi's computational capabilities, the team deemed for the laundry symbol interpretation program to be infeasible. Having a text detection algorithm and object detection software running concurrently will require too much power that the Pi cannot provide, so the essential function of OCR was prioritized.

8. Industrial Design

Due to this device being run by an operator, ease of use is a mandatory requirement. To make the scanning as accurate as possible, a design will be etched into the acrylic plate to indicate where to put the garment tag, and live feedback will be shown on a screen. Additionally, the on-screen user interface will offer clear instructions and large, accessible buttons. The opening of the pipe will be in a convenient location that should allow the machine to be intuitive to new operators. This opening will also be above the concealed gears to minimize the possibility of injury. These features will reduce training time and increase safety, which are two of Celestial Theory's main specifications.

9. Engineering Analyses and Experiments

Gearing Loads and Design

The gear train need only be designed for low-load, low-speed conditions. In addition, impacts are not expected in nominal operation. However, the gear train is designed to be resistant to expected loads, and the robustness to impacts should also be known. The maximum expected load is 12.4 N or 2.79 lbf as the motor is rated at 1.26 Nm, and the diameter of the pinion it is attached to is 4 inches. With this in mind, the material selected does not have to have high yield stress due to the size of the gears.

<u>Gear Material Selection</u>

Considering customer requirements, the most important material indexes for the gears are, in order:

1. Minimize rotating mass: power consumption, system weight
2. Maximize lubricity: power consumption, reliability
3. Minimize cost
4. Maximize strength and toughness: reliability

Consulting material bubble charts showing yield strength per density (**Figure 2**) and fracture toughness per density (**Figure 3**), it is noted that polymers underperform metals, alloys, many composites, and some natural materials along both indexes.

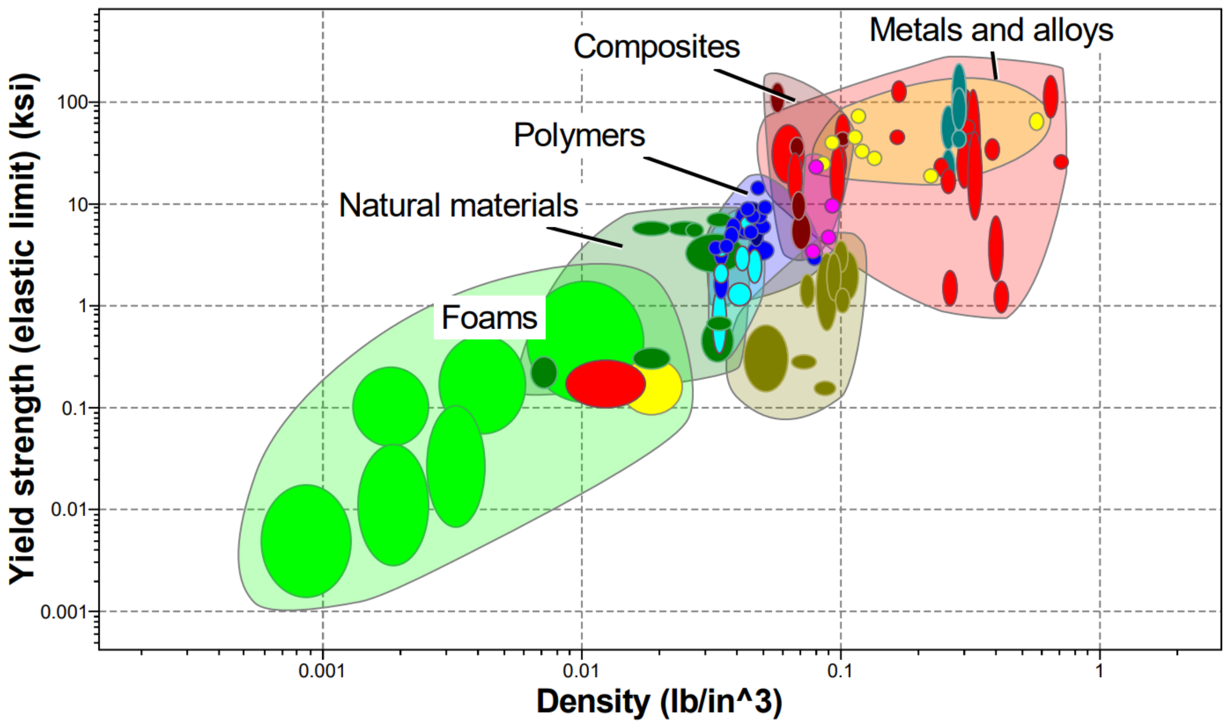


Figure 2. Maximizing Yield Strength per unit Density

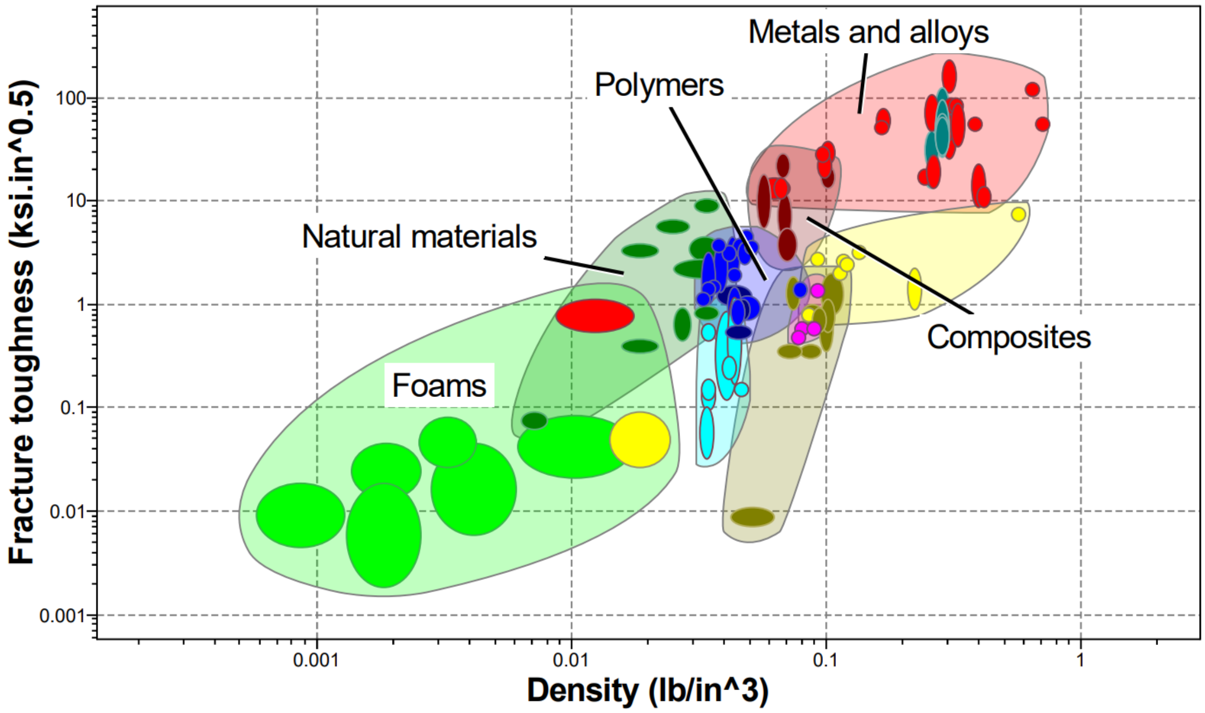


Figure 3. Maximizing Fracture Toughness per Density

However, any material from the entire class of polymers provides a sufficient margin of 2 to be suitable for the expected loads and impacts of this system. The priority of properties related to mechanical strength is therefore reduced so that the material selection better performs against customer requirements and specifications. Most significantly, the rotating mass of the gears affects both system weight and power consumption. Higher inertia in the gear train requires greater torque and more energy to drive. The bubble chart of density versus price shows that, besides non-machinable or non-rigid materials like wood and foams, the polymer class provides the lowest density materials at the lowest cost. Within the polymer class, many materials have similar strength and machinability characteristics. Many polymers are also more commonly available as self-lubricated products, including some specifically designed to be machined into gears. Therefore, some practical considerations can be made to differentiate polymer candidates. Self-lubricated formulations of Polyoxymethylene (POM) such as Dupont Delrin and other polymers such as Igus Drylin are lighter than metals and require no external, manual lubrication to maintain smooth operation. Out of this category of available materials, Polyplastics Duracon M90-44 is selected for its lower cost, good machinability, and availability. As a check, the maximum bending stress of the pinion from the motor can be found via this equation:

$$\sigma = \frac{P*W^T}{y*F}$$

where the maximum bending stress is 38.5 psi, P is the pitch of 6 in, W^T is the force of 2.79 lbf, y is the Lewis form factor of 0.58, and F is the face width of 0.75 in. The maximum allowable bending stress is found using the equation below:

$$\sigma_{allowed} = \sigma' \frac{K_v * K_T * K_L * K_m}{C_s * S_f}$$

where σ' is the maximum bending stress of 5,333.74 psi for 10^8 cycles, K_v is the velocity factor of 1.35, K_T is the temperature factor of 1, K_L is the lubrication factor of 1, K_m is the material factor of 0.75, C_s is the working factor of 1.25, and S_f is the safety factor of 2 [14]. With this, the maximum bending stress allowed is 2160 psi for 10^8 cycles which is well above the maximum bending stress that the motor can provide.

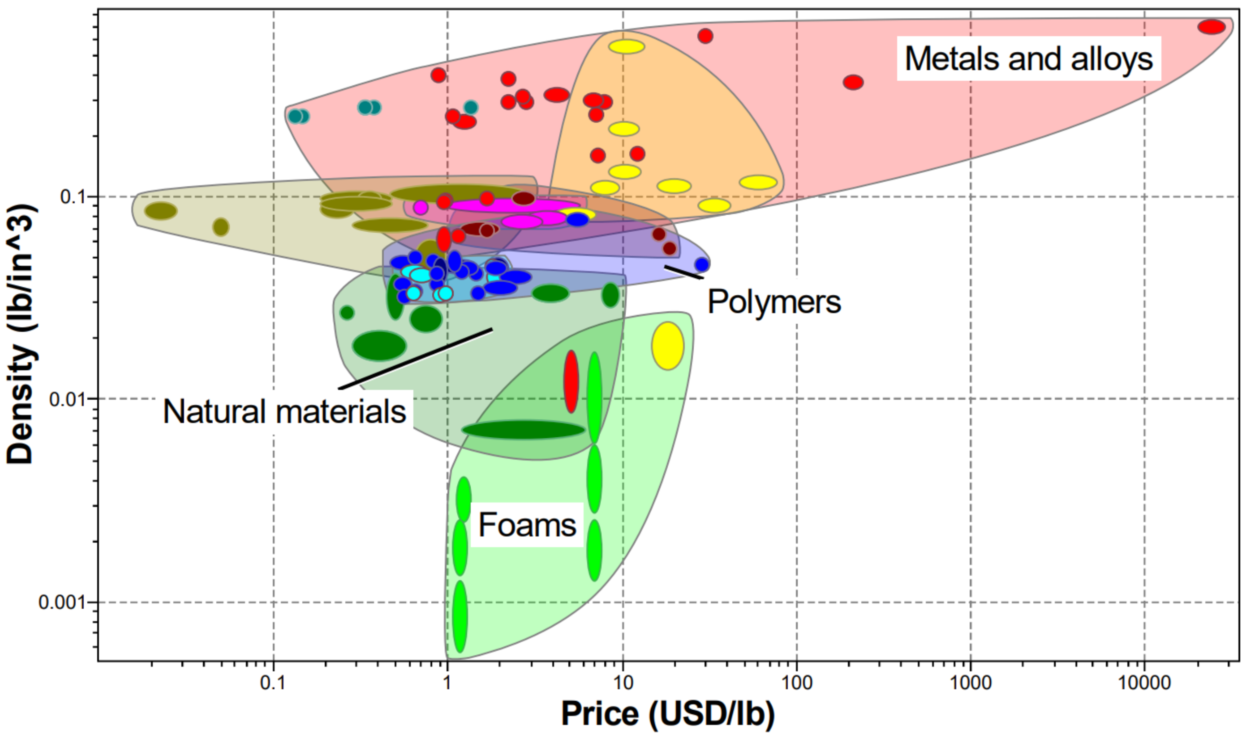


Figure 4. Minimizing Density per unit Price

<u>Throughput Study</u>

Celestial Theory specified that the system should be a base for future expansion. To make this possible, the mechatronic system should not keep human operators waiting. This way, as the human-performed tasks are eventually automated, the entire system will be more likely to operate at higher throughput and without delays. To understand the allowable time limit of a mechatronic system cycle, the team recorded the time it took for humans to locate, flatten, and scan a garment tag (Sample data viewable in **Table A-2**). These steps on average took a human 12.45 seconds. However, the design must be faster than the time it takes for an operator to scan a very simple garment. This lower limit is approximately 8 seconds.

Actuator Sizing

The design requires a rotational actuator that works with the initial system sizing requirements. There must be enough torque to accelerate the rotating mass such that moves are made within a specified reasonable time limit, defined by the above throughput study. In the worst case, the scanning system can take up to 5 seconds to categorize a garment tag. Therefore, only 3 seconds out of the 8 defined by the study are left for the actuator to move. Assuming a conservative case, the motor must be able to traverse at least a full rotation in the 3-second time period. The total driveline inertia was estimated by summing the approximated moments of inertia of the rotating components:

$$\mathrm{I} = \mathrm{I}_1 + \mathrm{I}_2 + \cdots + \mathrm{I}_\mathrm{m}$$

Equivalent inertias of rotating masses separated from the actuator by a gear ratio were calculated by reducing the inertia by a factor of the square of the gear ratio:

$$\mathrm{I}_{\mathrm{eq}} = \frac{\mathrm{I}}{\mathrm{R}^2}$$

Where I_{eq} is the equivalent moment of inertia, I is the moment of inertia without the gearing effect, and R is the gear ratio. Here, $R = 2$. Rearranging the rotational form of Euler's second law shows that the angular acceleration possible with a given actuator is given by the expression

$$\alpha = \frac{\tau_m}{I}$$

Where α is the angular acceleration of the rotating mass, τ_m is the motor torque, and I is the total driveline inertia. For simplicity of control, a conservative, energy-inefficient bang-bang control law is assumed:

$$\ddot{\theta} = \begin{cases} A, & \mathrm{t} \leq \frac{3}{2\mathrm{n}} \\ -A, & \mathrm{t} > \frac{3}{\mathrm{n}} \end{cases}$$

Where theta is angular displacement. The control input is acceleration. The acceleration changes magnitude halfway through the desired period, and the desired period is reduced by a factor n that describes by what margin the design will exceed the minimum performance. The switching is time-dependent, so the assumed control approach is entirely open-loop. Considering the first case, it is desired to have

$$\theta\left(\frac{3}{2\mathrm{n}}\right) = \pi$$

That is, the angular displacement should complete one half of one rotation by the time half of the time period is elapsed. By integrating angular acceleration and solving for the constant A, the following result is obtained:

$$\mathrm{A} = 2.79\mathrm{n}\ \ \mathrm{rad/s^2}$$

Substituting into the Euler equation, we can obtain a requirement for the motor torque:

$$\tau_{\mathrm{m}} = 0.149697\mathrm{n}\ \ \text{N-m}$$

The team decided to select a stepper motor versus other kinds of actuators because of the advantages in motion control applications. Stepper motors allow simple open-loop speed and position control, require simple and widely available driving circuitry, offer high torque for cost, and often include standardized mounting interfaces. Motor candidates were considered based on their pull-out torque. This means that even if a motor candidate achieved the above criterion by some margin, it may operate in the slewing range, potentially requiring acceleration control methods to be more carefully determined via experimentation. In the interest of avoiding these types of time-consuming problems, the team has chosen to select a motor that satisfies the criterion with a high margin. The 23HS22-2804S stepper motor (**Figure A-1**) has a holding torque of 1.26 N-m and a pull-out torque of approximately 0.7 N-m at 450 RPM which is a speed faster than the expected operation of this system. This leads to the following calculation of design margin:

$$\mathrm{n} = \frac{\tau_{\mathrm{m}}}{0.14967} = \frac{0.7}{0.14967} = 4.68$$

This motor is, therefore, a safe choice for preventing loss of control, and it should easily satisfy the timing requirement to ensure the system is human-limited in terms of throughput.

It should be noted that if a stepper motor encounters a torque overload condition, the motor will lose steps, hindering movement. This presents a safety advantage in that, if excessive resistance is encountered, the motor will not demand a higher current draw from the motor driver. The selected motor driver is physically incapable of providing more than 2.8 A per phase, which is the rating of the selected stepper motor.

Mechatronic System Design

4 GB RAM is the standard requirement for most OCR libraries as well as neural networks. The 4 GB Raspberry Pi was also the highest RAM computing board available for a lead time of less than a month, so it was selected for the computing board.

The camera needed to be able to produce an image of over 300 DPI quality from a few inches away. This meant that the camera needed to have either a focal distance of a few inches or adjustable focus to that range. Additionally, the camera must be compatible with Raspberry Pi. Lighting conditions and durability were not a concern since we believe they can be controlled by isolating the camera inside a scanning box. The team selected the least expensive and shortest lead time camera which met these requirements, the Arducam OV5647. This camera is 5 megapixels or 1920p, which will produce well above the required 300 DPI quality with a true-to-size image output. The focus on the camera is manually adjustable down to an inch away from the camera and uses a ring locking mechanism to prevent the focus from changing. The team decided against autofocusing cameras to avoid control bugs that could result in changing focus and prevent accurate tag scanning.

The team selected a screen to use as a feedback device. The screen needed to provide visual feedback and messages to the user, preferably high enough quality to allow live image feedback to help the user troubleshoot easily if tags are not scanning properly. Live image feedback will allow the user to easily identify issues such as scratches or cloudiness on the lens, lights out in the scanner box, and other issues which might be difficult to pinpoint using only electronic feedback. Additionally, the size of the screen needed to be large enough to fit a reasonably sized image of the tag as well as user interfaces such as buttons and text feedback. Finally, the screen had to be Raspberry Pi compatible. These requirements, as well as a package discount when purchasing the Pi, led the team to select the 7” Raspberry Pi touchscreen. Not only did the screen fulfill all of the design requirements, but it also allowed for out-of-the-box setup and had the added benefit of removing the need for a computer mouse and keyboard to control the machine once the algorithm was finalized.

The last electronic component in the scanning system was lighting. Using an initial prototype, the team discovered that soft white light produced the best results with the tag scanning algorithm. The lights also needed to surround the camera to provide universal illumination, but with space to block them out from the camera. Thus, the team selected Sparkfun Lumenati 90L lights which could easily be made into a ring with space in the center for the camera. These lights require a 5V input, so they were combined with a logic level converter to step up the 3.3V output from the Raspberry Pi.

A diagram of the complete mechatronic system is shown in **Figure 5**. The system is divided into three subsystem divisions: power, sensing and processing, and actuation. To simplify the design, a single power supply is used. A screw terminal adapter was chosen and purchased to provide power to the Raspberry Pi, and a buck converter was selected to step down the voltage for use by the LED array. Peak power consumption is shown in red above each major component, reflecting the highest transient values each component is expected to experience. The total peak power consumption of the system is 36.2 W. This figure assumes no efficiency losses at the buck converter, motor driver, and adapters and wiring.

Losses that are not designed for are compensated by the selection of a larger power supply than necessary: a 12 V, 5 A (60W) power supply provides a design margin of 1.66 times the required transient power while staying well below the customer requirement of 70 W maximum power consumption. Therefore, it is not even possible for the system to experience power overruns beyond the customer demand.

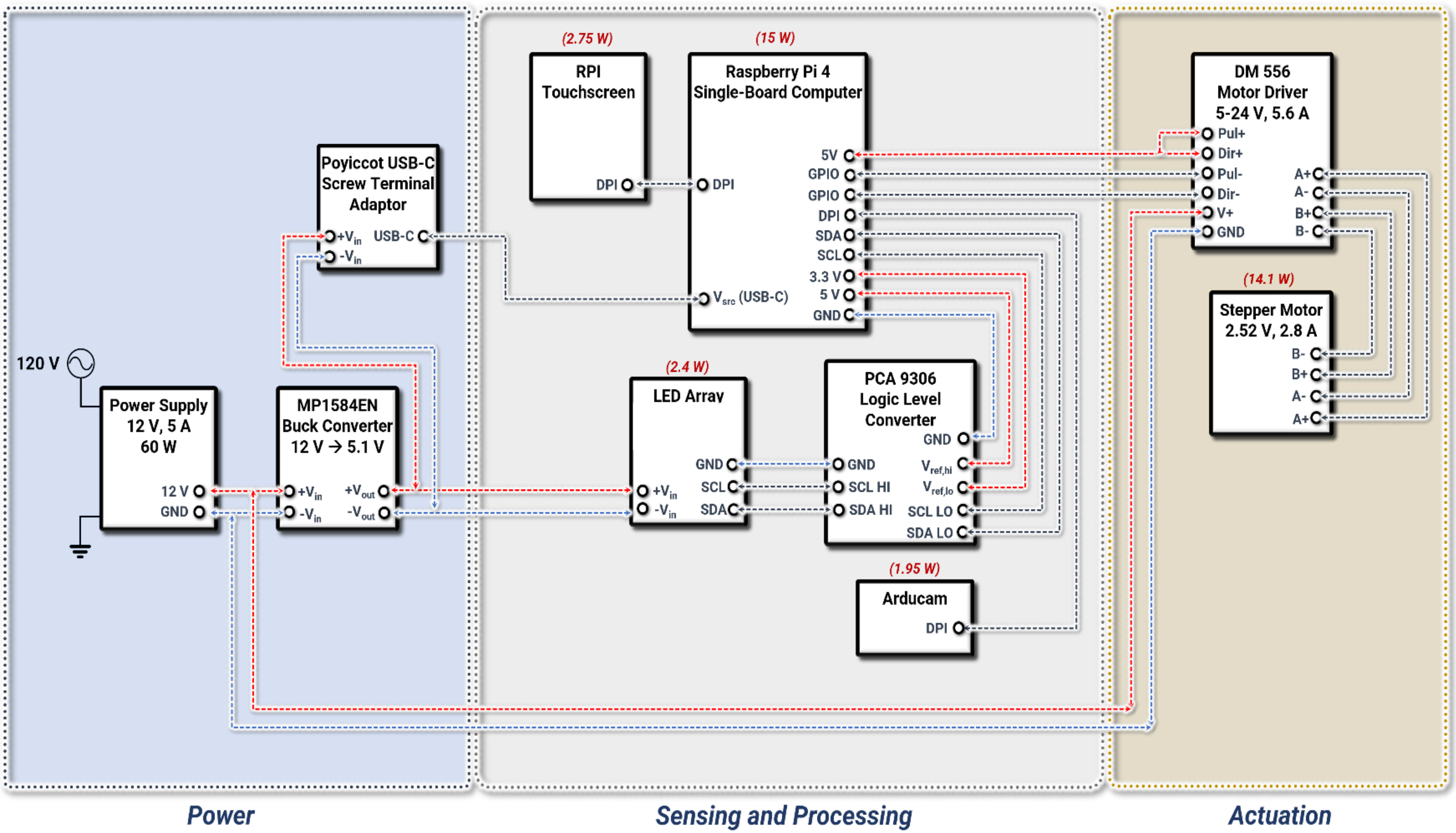


Figure 5. Mechatronic System Diagram

OCR Algorithm Tuning

The algorithm for tag scanning has been developed and a more detailed flowchart is shown in Figure C-4. The algorithm is built around the OCR library Tesseract [15]. The first tuning parameter explored was within the Tesseract call itself. Tesseract has different modes called page segmentation modes which determine the pre-processing and parameters Tesseract will apply to the image. The options are shown in the following figure:

```
0    Orientation and script detection (OSD) only.
1    Automatic page segmentation with OSD.
2    Automatic page segmentation, but no OSD, or OCR.
3    Fully automatic page segmentation, but no OSD. (Default)
4    Assume a single column of text of variable sizes.
5    Assume a single uniform block of vertically aligned text.
6    Assume a single uniform block of text.
7    Treat the image as a single text line.
8    Treat the image as a single word.
9    Treat the image as a single word in a circle.
10   Treat the image as a single character.
11   Sparse text. Find as much text as possible in no particular order.
12   Sparse text with OSD.
13   Raw line. Treat the image as a single text line,
                         bypassing hacks that are Tesseract-specific.
```

Figure 6: Tesseract page segmentation modes

On sample tags, mode 6 performed well. When iterating through live scanned images, it can also be beneficial to test mode 4, in case different text or text sizes are used, and mode 11, in case the tag is damaged and words are difficult to find.

The algorithm is also capable of pre-processing images on its own using functions such as increasing contrast, thresholding, and edge detection. While these functions could improve readability for humans, however, they had little effect on the OCR output, so they are not currently being implemented. Additionally, the current algorithm takes three images spaced 0.05 seconds apart and iterates through them, stopping once the material composition has been identified. Then, if no material composition has been identified, it prompts the user to 'rescan' and performs the same process again. This process minimizes the impact of user error or potential blurry images from slight movement.

Finally, in order to match the words output from OCR to expected materials, 'fuzzy string matching' is performed using the jellyfish library in Python [16]. Several string distance algorithms were tested including Levenshtein distance, Jaro distance, Damerau-Levenshtein distance and Jaro-Winkler distance. Essentially, all of these algorithms measure the number of edits it would require to change one string into the other. Selecting between the algorithms was a trade-off between time and accuracy, but eventually normalized Jaro distance was selected for all of the material categories due to its speed. Each string that follows a percent sign is compared to the words ‘cotton’, ‘polyester’ and ‘spandex’. A future version of this algorithm could also search for related words such as ‘elastane’, ‘nylon’, and the original three words in different languages.

<u>User Interface</u>

The team also designed a graphical user interface (GUI) seen in Figure 6 in order to make the system user-friendly and meet the requirement that a user should be trained on the machine in under 5 minutes. The interface displays a live image from the camera so the user can see if the tag is aligned properly, alongside a large scan button and status display. At the bottom of the display, there is a button for the user to press if a tag is damaged or missing, which will immediately send the garment to the ‘Unknown’ category, as well as a settings button to adjust the motor settings and an exit button. Finally, next to the camera display there is a running tally of the types of clothes which have been sorted, and options to clear the tally or export it as a .csv file.

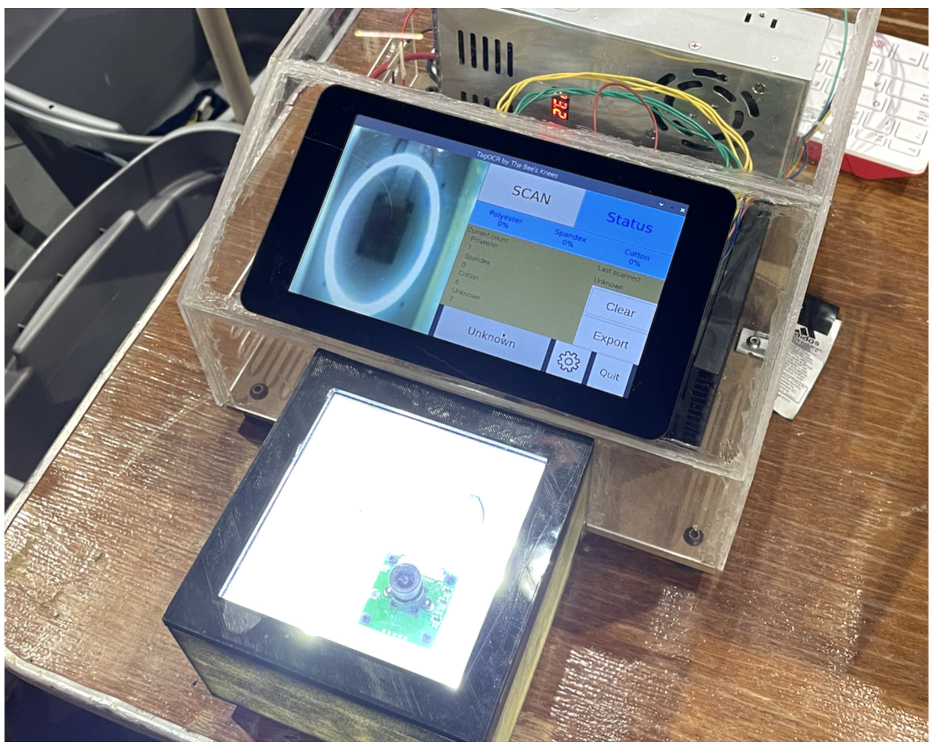


Figure 6. User interface shown on the interactive touch-screen with the scanner assembly

10. Final Design, Mockup and Prototype

With the final design specifications created, the full final design was established, and all aspects of the final design can be seen in the fabrication package attached. The final design consists of the scanning subsystem and the sorting subsystem that work together. The scanning subsystem uses a camera to capture the garment's tag which will be put through an OCR library called Tesseract. With the text of the tag recognized, the string is searched for the materials desired to be sorted (polyester, cotton, and spandex). If none of these are found, the clothing is labeled as consisting of an unknown material. From this, the information is transferred to the sorting system. The sorting system will take what material the clothing is made out of, and it will rotate the pipe assembly using a stepper motor to direct the clothing to the correct material bin as seen in the fabrication package. Initially, a wooden prototype was created. This was to ensure that the initial spacing and concepts were going to be successful. Once it was seen that the design was successful, a final prototype of extrusion was made to create a more visually appealing and consistent final prototype. Some improvements were seen in this new prototype such as better and more consistent output as the wooden prototype sometimes would expand due to humidity which caused the necessary torque to increase due to the friction from the bearings. The upgraded steel shafts fixed this problem. With the final prototype created and tested, the design specifications were easily met with its performance. The stepper motor could handle the torque required from the system, and the OCR was more successful than was initially anticipated. Regardless, other options were created to work around issues observed in the OCR. In the end, the OCR was 82.5% successful at recognizing what the clothing was made out of.

11. Manufacturing

Because this machine is a one of a kind specifically built for the sponsor, there are no future plans in regards to mass production. With that in mind, the machine was built as simply as possible with the fewest parts and maintenance necessary. For ease of manufacturing, pre-made, common parts were outsourced such as aluminum extrusion that was cut to length and bearings. If the sponsor so desires to have this machine be mass produced, there are a few options for manufacturability. The best way to make the plastic bevel gears would be through injection molding. With everything else already pre-made, there are two ways the machines could be assembled. Assuming low volume needs, the machine could be assembled by a group of laborers, and they would only need simple tools to assemble the machine. If mass production is desired, fully automated lines could be created to build the machines using motion controlled robots such as SCARA robotic arms. The machines could then be easily packaged in boxes where they are prebuilt, or they could come as a disassembled kit as well. The estimated cost of manufacturing the device would be $650 as the parts cost about $500 depending on fluctuating prices of goods and the 6 hours of labor at $25 per hour would result in the remaining $150.

12. Societal, environmental and sustainability considerations

We chose to analyze the sustainability and societal and environmental impacts of the electronics in our project because we expect those components to be the most detrimental towards sustainability. Given that the sourcing for those components will change significantly if the project is scaled up, we chose to focus only on the product use and end of use phases, when the product will be in the hands of Celestial Theory. The results and analysis of this social impact study are in Appendix D.

13. Risk Assessment

A risk assessment for the overall product was performed to ensure that the most costly potential errors are guarded against. This risk assessment can be found in **Table A-3**. The highest priority risk was determined to be a mechanical failure of the camera. This will be guarded against by keeping the camera in an enclosure to protect it from scratches, smudges, and accidental focus/position changes. The next highest priority risks are mechanical failures of the structure and sorting mechanism. These risks are mitigated by including factors of safety in design calculations and covering the gears. Finally, the risk of algorithm failure will be reduced by testing on a large dataset with a variety of tag qualities and material compositions.

14. Team Member Contributions

To begin prototyping, Austin Solomon worked on the CAD models for the bevel gears, while Caleb Harris and Britt McCord 3D printed these gears for prototyping. Caleb Harris began the construction of the prototype. Ryan Murphey worked with the stepper motor and its analysis and design of the mechatronic system. Katherine Beuchel and Jeongwoo Cho worked on the software elements and created code that can scan garment tags. Katherine and Ryan also designed a scanner box to house the electronics and created a prototype of it. Finally, Jeongwoo worked on creating the user interface and connecting the mechatronics system with the scanning software.

15. Conclusions, Future Work, and Project Deliverables

With the Expo completed along with the final prototype and design, the last deliverable is to deliver the final design and prototype to the sponsor. The sponsor must also be taught on how to assemble and use the prototype. While this solution works well and is viable for the challenge at hand, there were more unforeseen issues that came up while manufacturing the prototype. Assuming this project will be further improved by another group, the next steps for improvements would be to quicken the processing time the OCR takes. Currently, the OCR is the limiting factor due to the computing power. A mini-PC could probably work better for the OCR that can be used in conjunction with an Arduino to drive the motor. Also, a better quality camera could be used along with more techniques to recognize text using the OCR. There was not enough time to further delve into other filters and possibilities to eliminate all variabilities seen while scanning tags. Also, the pipe could be made larger, and a larger and more powerful stepper motor could be bought. The only issue with all of these suggestions is that they will increase the cost of the device. The motor chosen was the most cost effective due to the budget along with the raspberry pi. A simple mini-PC and touchscreen easily costs more than raspberry pi and touchscreen used in the final prototype. Furthermore, the next strongest reliable stepper motor is an order of magnitude more expensive.

References

[1] “SMART,” Frequently Asked Questions. [Online] Available: https://www.smartasn.org/resources/frequently-asked-questions/ [Accessed: 07-Mar-2022].

[2] “Allied Market Research,” Global Recycled Textiles Market. [Online] Available: https://www.alliedmarketresearch.com/recycle-textile-market#:~:text=The%20global%20recycled%20textiles%20market,3.6%25%20from%202020%20to%202027 [Accessed: 07-Mar-2022].

[3] IVL Svenska Miljöinstitutet. "IVL Svenska Miljöinstitutet," YouTube, 10 Nov., 2022. [Video file]. Available: https://www.youtube.com/watch?v=nTPWrtwBQaE&ab_channel=IVLSvenskaMilj%C3%B6institutet. [Accessed:07-Mar-2022].

[4] K. Cura, N. Rintala, T. Kamppuri, E. Saarimäki, en P. Heikkilä, “Textile Recognition and Sorting for Recycling at an Automated Line Using Near Infrared Spectroscopy”, Recycling, vol 6, no 1, 2021.

[5] “UNITED STATES DEPARTMENT OF LABOR,” Occupational Safety and Health Administration. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.147. [Accessed: 07-Mar-2022].

[6] Pegoli, A. (2020). Laundry Lens (Version 1) [Laundry symbols reader]. App Store. https://apps.apple.com/us/app/laundry-lens/id1513767864#?platform=iphone

[7] Geyer, J., & Hoffman, J. (2019). Scanner, scanning system containing this scanner and method for sorting items to be treated (DE102018203938A1). Deutsche Patent- und Markenamt. https://patents.google.com/patent/DE102018203938A1/en

[8] Birke, H., Philipp, S., & Schmietendorf, W. (2019). Method of organizing items of laundry to be treated and system for organizing these items of laundry (DE102018200702A1). Deutsche Patent- und Markenamt. https://patents.google.com/patent/DE102018200702A1/en

[9] Darwiche, S., Hanau, A., Heyer-Wevers, M., & Rosenbauer, M. G. (2014). Analysis of items of laundry (WO2014198608A1). World Intellectual Property Organization. https://patents.google.com/patent/WO2014198608A1/en

[10] Clothes sorting method and device and clothes washing method and device (CN104730930A). (2017a). China National Intellectual Property Administration. https://patents.google.com/patent/CN104730930A/en

[11] Clothes sorting method and device and clothes washing method and device (CN105665299A). (2017b). China National Intellectual Property Administration. https://patents.google.com/patent/CN105665299A/en

[12] Cassady, T., & Epperson, W. (2009). Automated dry cleaning assembly conveyor system (US20070261997A1). U.S. Patent and Trademark Office. https://patents.google.com/patent/US20070261997A1/en

[13] "UNITED STATES DEPARTMENT OF LABOR," Occupational Safety and Health Administration. [Online]. Available: https://www.osha.gov/machine-guarding. [Accessed: 07-Mar-2022].

[14] "SDPSI," Designing With Plastic Gears and General Considerations of Plastic Gearing. [Online]. Available: https://sdp-si.com/plastic/design-of-plastic-gears.php. [Accessed: 07-Mar-2022].

[15] Tesseract Open Source OCR Engine Main Repository. GitHub. Retrieved January 24, 2022, from https://github.com/tesseract-ocr/tesseract

[16] Turk, J.. Jellyfish Main Repository. GitHub. Retrieved February 1, 2022, from https://github.com/jamesturk/jellyfish

Appendix A

Table A-1 List of All Applicable Patents

Patent	Idea
Patent DE102018203938A1 [7]	scanning system connected to a container for sorting laundry items based on physical properties
Patent DE102018200702A1 [8]	system which scans the physical properties of laundry items and then sorts the laundry items
Patent WO2014198608A1 [9]	process of analyzing laundry items using a camera and “evaluation device” to determine laundry care properties
Patent CN104730930A [10]	sorting dirty laundry based on laundry care needs using “image identification technology”
Patent CN105665299A [11]	sorting clothing based on fiber for the purpose of respinning
Patent US20070261997A1 [12]	concept which involves tag scanning system for use with dry cleaning. This patent also includes detailed drawings of the machine

Table A-2. Times Taken to Locate, Flatten, and Scan Garment Tag

Trial	Time (s)
1	16.03
2	8.30
3	14.02
4	12.06
5	14.56
6	8.96
7	13.25

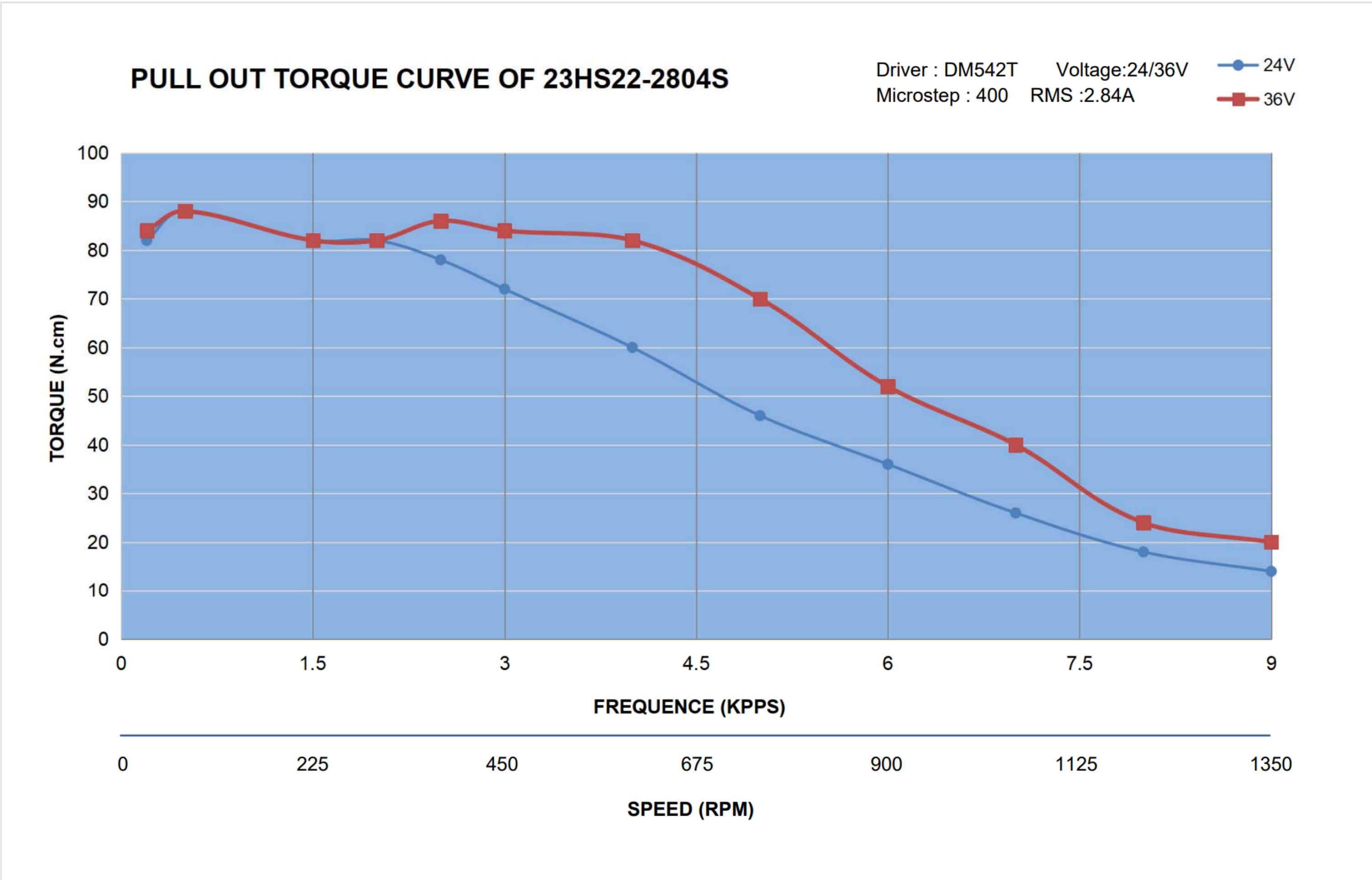


Figure A-1. Pull-out Torque Curve of the Selected Stepper Motor

Table A-3: Risk Assessment

Item/Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Severity Rating	Potential Cause(s)/Mechanism(s) of Failure	Likelihood	Current Design Controls	Detectability	Risk Priority Number	Recommended Action(s)
Gears/Pipe turning system	Jammed, not enough torque to rotate pipe	Gears become altered	9	Garments jamming the gear system	4	Large pipe opening, covering of gear system	1	36	Gear system is covered and secured so no clothes can jam it
Stand Support	Supports break or fall	Machine falls and sustains damage	8	Supports are too weak or not secured	5	Supports are designed in a tripod to maximize stability	1	40	Design supports to withstand portential disturbances and support machines weight with safety factor
Camera	Does not scan clothes properly	Clothes are sorted incorrectly	5	Camera lens is blurry or scratched, or garment tag is indecipherable	5	Camera within shell to minimize potential damage	3	75	Keep the camera within its shell and clean the camera when necessary
Sorting Algorithm	Does not read garment correctly or the bins are mapped incorrectly	Inconsistent or incorrect sorting	5	Non-ideal error bounds on text recognition algorithm implemented	2	Prior model error anlaysis in training and set maximum classification error	2	20	Test sorting mechanism with mulitple tags to insure consistensy

Appendix B: Design Process Documents

Customer Requirements and Engineering Design Specifications

Four parties hold interest and power that must be considered when managing the project and understanding requirements: Celestial Theory, the design team, Georgia Tech, and Dr. Green. These parties are arranged in **Figure B-1** to illustrate relative power over and interest in the project. Celestial Theory is the project sponsor and therefore has ultimate control over the high-level product requirements. The team not only keeps Celestial Theory informed of the project status but also maintains consistent communication to understand and deliver on customer needs. The design team has singular control over actual actions taken to satisfy the customer requirements. The team members have an interest in delivering a quality product or design, fulfilling academic requirements, and obtaining practice in product design. Georgia Tech as an institution holds a minor share of power as the governing entity of the entire process, and it is assumed the Institute aims to have all students successfully complete the Capstone Design course. Dr. Green, as the design team's advisor, provides input that the design team may incorporate into the project effort.

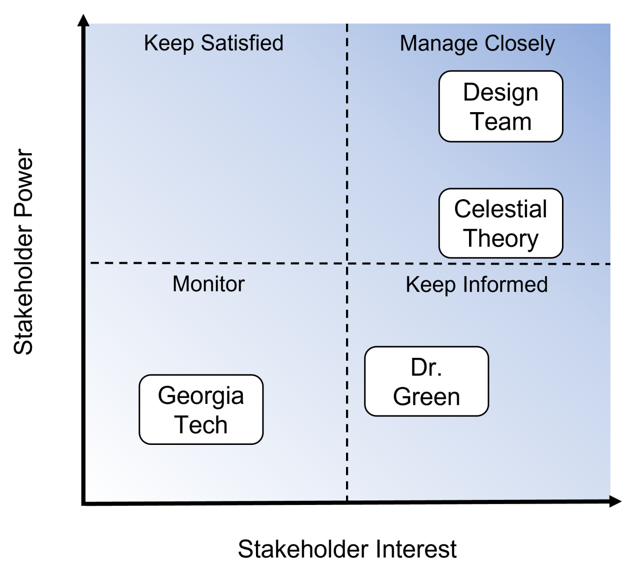


Figure B-1. Stakeholder Power versus Interest

Celestial Theory provided a summary of desired system characteristics and specified a basic functional framework. The sponsor asks for "a rapid scanning solution that can be used to sort a large number of garments into separate bins based on the composition." The sponsor also stipulates that the system must mechanically move garments to sort them, that the tags are to be scanned by a human using a scanning device, that the system evaluates tag information, and that the system makes the data available for retrieval and viewing by the user. The design team considers these functional requests constraints on the space of possible designs. The list in **Table B-1** encompasses all customer requirements provided by Celestial Theory.

Table B-1. Customer Requirements provided by Celestial Theory

Customer Requirement	Notes
Safe for operators	OSHA: Enclosed gears
Expandable	
Energy efficient	Sponsor: no more power than a golf cart battery
Transportable	Sponsor: must fit inside a Jeep Wrangler
Rapid	
Carryable by one person	OSHA: no more than 40 pounds
Easy to operate	Sponsor: no more than 15 minutes of training required
Reliable	

Overall, Celestial Theory required that the design be safe to work and operate and is small enough that a person could lift it. OSHA requires this weight to be less than 40lbs. Celestial Theory also requires that a new employee could learn how to use the machine in a short amount of time, around 15 minutes. In other words, the device should be straightforward and user-friendly. To translate needs to actionable design considerations, the team developed a set of engineering requirements against which to evaluate the fulfillment of customer requirements. Dependencies were identified, and the relationships are shown in the house of quality in **Figure B-2** on the next page. The team assigned relative importance weights to each customer requirement based on discussions with the sponsor. These weights were multiplied by a rating of the relationship between the customer requirement and engineering requirement and summed for each engineering requirement. Using this method, the most important aspects of the design are reducing energy consumption, regulating rotational or translational speed, and limiting the bounding dimensions. These three major aspects of the design have broad impacts on the entire performance of the system. For instance, energy consumption correlates positively with throughput (garments per time) and reduces the individual garment cycle time. It should also be noted that, while not obvious, interface ease of use is important for its effects on safety, ease of operation, and making data available for viewing.

Figure B-2. House of Quality

The functions of the system were further defined from Celestial Theory's requests by analyzing the requirements. The first major function of the device is to scan the garment tags. The device should be able to evaluate and store information and display any important information (i.e. number of pure cotton garments, total clothes passed through, etc.) to the user. The scanner should be easily accessible to an operator. The second major function is passing clothes through the machine and sorting them. The functions are fully broken down in the function tree shown in **Figure B-3.**

Design goals were quantified by developing engineering specifications, shown in the specification sheet in **Table B-2**. Some specifications were derived directly from very specific sponsor requests, such as bounding dimensions such that the entire system could fit in the trunk of a Jeep Wrangler. Maximum continuous power requirements were estimated from the sponsor's suggestion that the system should be able to run on a golf cart battery if necessary. Throughput and maximum cycle time specifications were derived from the desire that the system should be "rapid." In the team's interpretation, this means that the system is not limited by machine delay. Instead, the human-machine interface should only experience lag as a result of human slowness in picking up, scanning, and depositing garments. A brief study was done to determine the average time a human took to complete these tasks. This yields an estimate that the sorter mechanism should be able to accept garments in eight-second intervals, using the time for the most simple garments with easy-to-find tags. Similarly, taking the case of most difficult-to-sort garments, target throughput should be above 225 garments per hour.

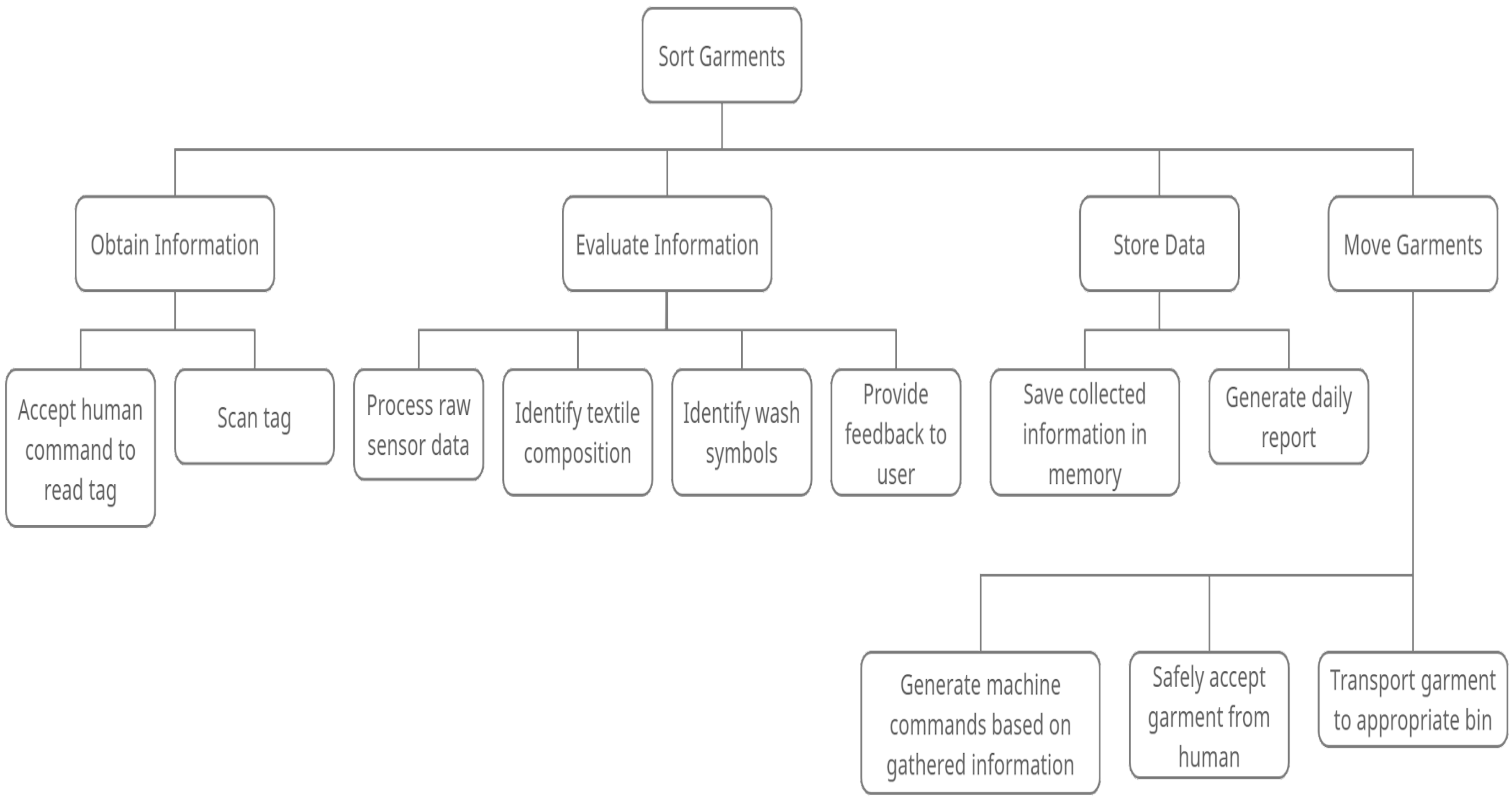


Figure B-3. Function Tree for automatic garment sorting based on garment tag information

Table B-2. Specification Sheet

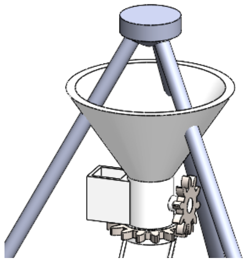
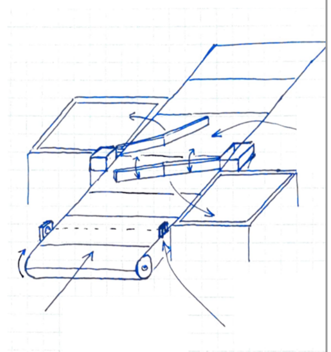
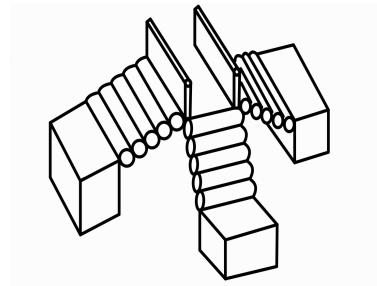
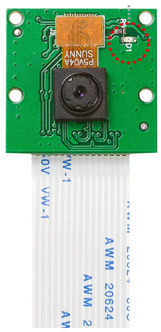
No.	Date	Demand/ Want	Specifications	Responsible Member(s)	Source	How Validated/Tested
General						
1	1/25/22	Demand	Cost less than or equal to $1000	Team	Funding from ME department	Final Budget
Physical Characteristics						
2	1/25/22	Demand	Train employee for use in under 15 minutes	Mechanical Design Team	Sponsor	Explain user inputs and functions to strangers
3	1/25/22	Want	Storage dimensions less than 40.25 in x 35.5 in x 34.5 in	Mechanical Design Team	Sponsor's Jeep Dimensions	Fit inside sponsor's car
4	1/25/22	Want	Weigh less than 40 lb		OSHA	Weigh
Electrical						
5	1/25/22	Demand	Continuous operation under 70 W		Sponsor, based on golf cart battery	
Mechanical						
6	1/25/22	Demand	Safe for use by operator	Mechanical Design Team	OSHA	
7	1/25/22	Demand	Be structurally sound under load	Mechanical Design Team		

Performance						
8	1/25/22	Want	Is able to process a clothing item in 20-25 seconds	Mechanical Design Team	Sponsor, estimation based on human-limited goal	
9	1/25/22	Demand	Can store data of at least 3600 clothes processed	Software Design Team	Sponsor, estimation based on human-limited goal	Laundry symbols and fiber composition
10	1/25/22	Demand	Printed final report of types of garment processed each day	Software Design Team	Sponsor	
11	1/25/22	Want	Expandability for larger-scale performance	Team	Sponsor	Sort > 1 clothing at a time

Concept Ideation

The design is centered around scanning tags and sorting the clothes. The scanner must be accessible to an operator and while feeding clothes through, the process should be quick and sort the clothes. The client also requested that the device be easy to train an employee on and to keep a long-term goal of an assembly line in mind. With these design considerations, the team came up with two main ways to feed clothes through. The first is a chute that allows gravity to pull the clothes down. Either a flap will direct the clothes or the chute itself will be able to rotate to allow for easy sorting. The second idea is a conveyor belt with bins placed along the side for sorting. All of these designs can be seen in **Table B-3**.

For the scanning system, the team needs to handle both text recognition to identify the material composition of the clothing and symbol translation to interpret laundry care needs. There are several pre-packaged programs available online that perform optical character recognition (OCR). All of them, however, are based around the open library Tesseract. There are two main options for this: write unique code which utilizes the Tesseract library, or subscribe to Google Cloud and use the Google Cloud OCR program. For laundry symbol translation, the team will need to use a program that is structured similarly to text recognition programs but with free inputs and outputs. For hardware, the project requires a camera that can take images or live video feed of the tags and a processor which can manipulate and store the data collected from the tags. Within the budget of this project, the only two options are Arduino and RaspberryPi, two common microcontrollers designed for education and hobby. All concept ideations can be seen in the morphological chart in **Figure B-3**.

<table>
<tr><td>Feeding</td><td>Gravity
</td><td>Conveyor
</td><td colspan="2">Roller
</td></tr>
<tr><td>Scanning</td><td>Live Camera Feed
</td><td>Single Image

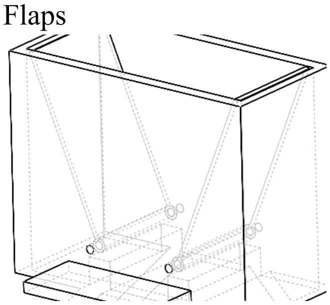
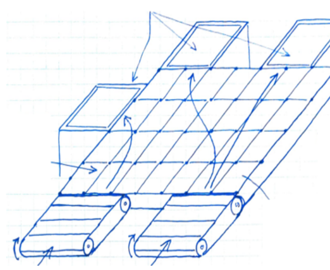
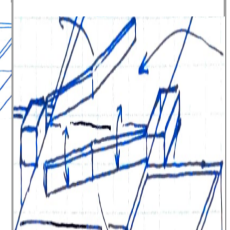
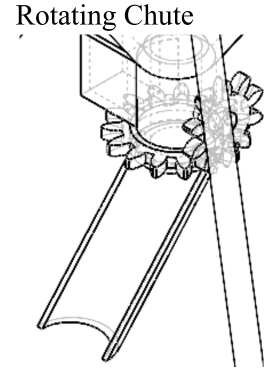
</td><td colspan="2">Rapid Fire Images</td></tr>
<tr><td>Sorting</td><td>Flaps
</td><td>Conveyor
</td><td>Arms
</td><td>Rotating Chute
</td></tr>
</table>

Figure B-4: Morphological Matrix

Appendix C

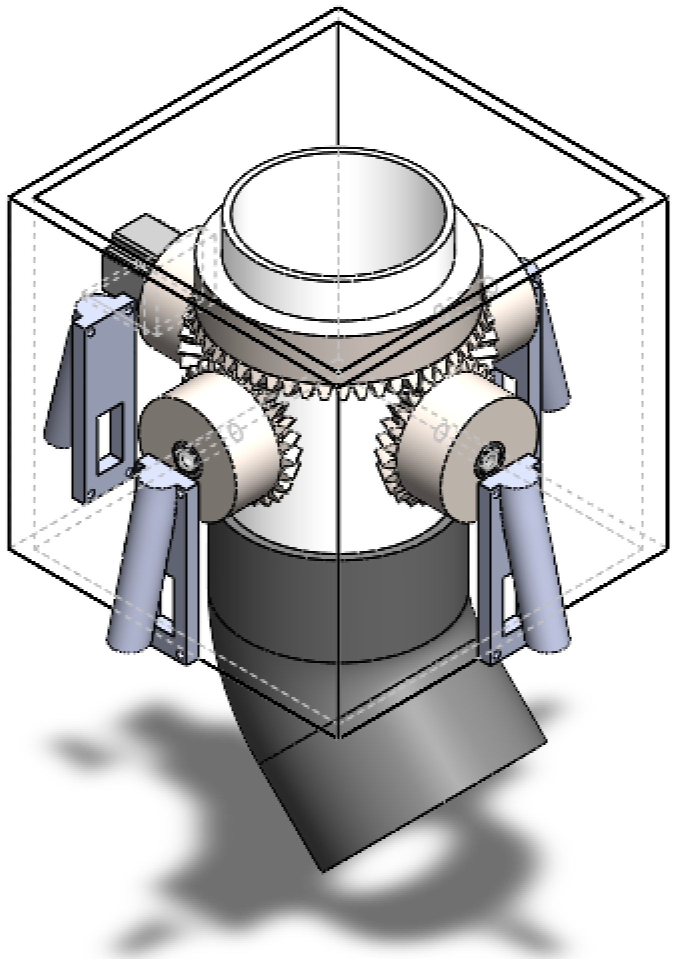


Figure C-1. Fully assembled rotating funnel initial design concept

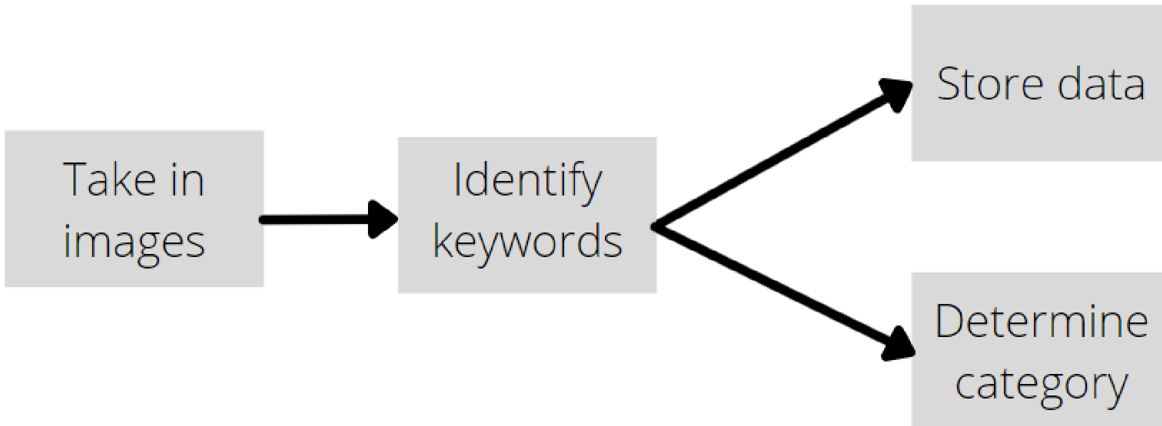


Figure C-3. Basic algorithm flowchart for tag scanning

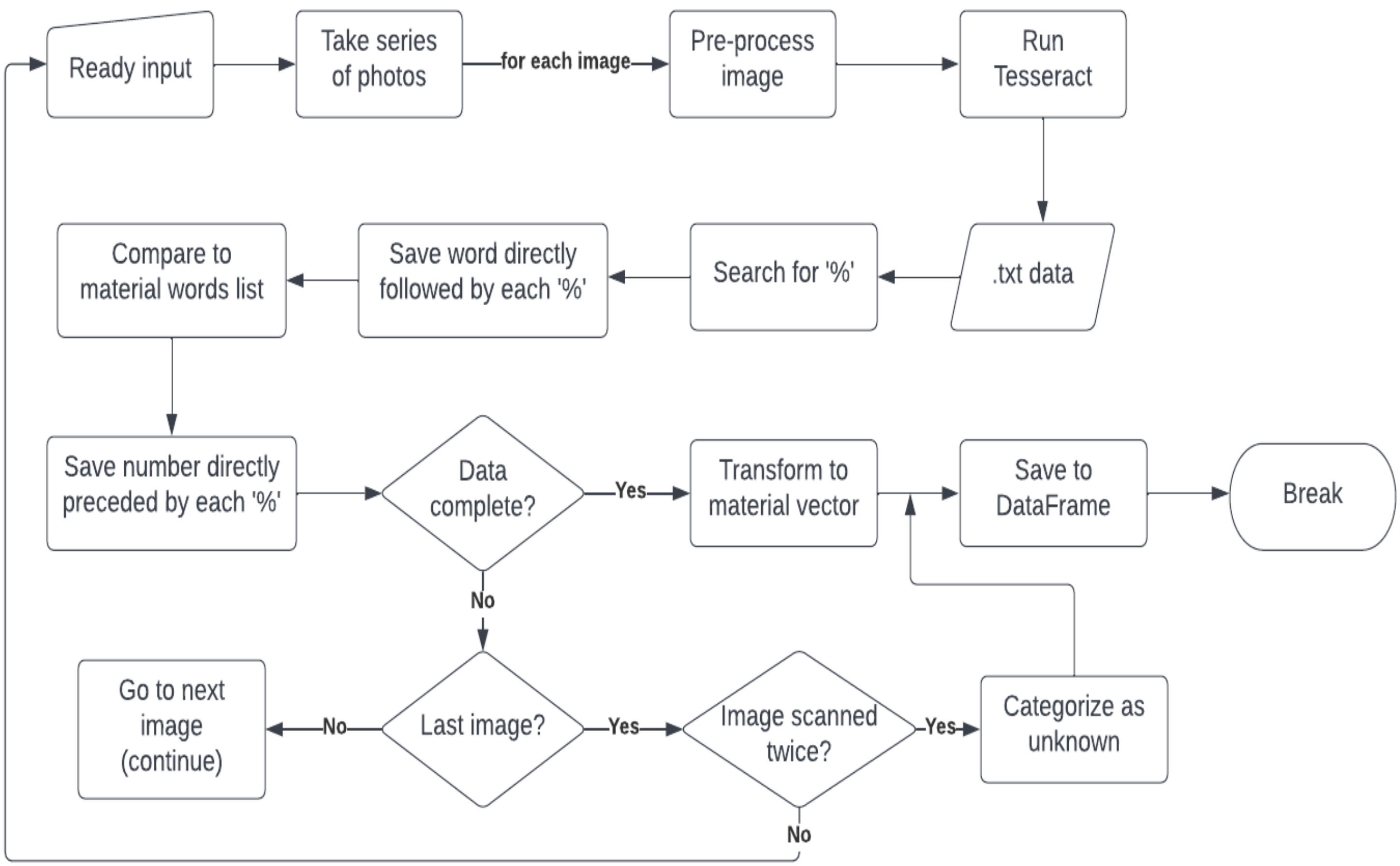


Figure C-4. Complex algorithm flowchart for tag scanning

Appendix D: Social Impact Assessment

Social Impact Assessment (SIA) Results

I. Goal and Scope

Table 1: Goal and Scope Section Summary

Objective of Assessment	Design Function	Functional Unit	Lifecycle Stages Considered	Associated Activities
Ensure that our product aligns with the sustainability goals of Celestial Theory. We are particularly concerned about power consumption. This assessment is being performed in the prototyping stage to inform electronics selection.	This design captures an image of a tag, processes the information in that image, and then rotates a chute which directs an item of clothing into a bin. Essentially, the machine sorts clothing into bins based on information found on the tags.	The main focus will be the power system and electronics. This includes the Raspberry Pi, motor, motor controller, voltage converters, lights, and power supply.	Product Use	Running idle
				Running active
				Powering on/off
			End of use	Replacement
				Disposal

II. Inventory Analysis

Table 2: Inventory Analysis Section Summary

<table>
<tr><th>Product Lifecycle Stage</th><th>Stakeholder Group</th><th>Social Impact Category</th><th>Impact Indicators</th></tr>
<tr><td>Product Use</td><td>Celestial Theory</td><td>Energy Consumption</td><td>Amount of energy used when idle and when operating</td></tr>
<tr><td rowspan="4">End of Use</td><td>Celestial Theory</td><td>End-of-Life Responsibility</td><td>How well informed employees are about recycling practices</td></tr>
<tr><td>Society</td><td>Policy Adherence</td><td>Quality of plans for safe recycling</td></tr>
<tr><td rowspan="2">Local Community</td><td rowspan="2">Health and Safety</td><td>Quality of plans for safe recycling</td></tr>
<tr><td>Levels of toxic chemicals in local landfills</td></tr>
</table>

III. Interpreting the Results

The purpose of this product is to assist in a recycling process, helping to keep textile waste out of landfills. Most of the components in it are able to be sustainably sourced and recycled, but the electronics are a point of concern. Because this product is currently very small scale, we elected to only study the product use and end of use lifestyle phases, since the sponsor will be able to manage those better than production and processing. If the product is scaled up, analysis on those two phases is advised. The main concerns with electronics are power consumption and recycling once the components have expired. Circuit boards are notoriously difficult to dispose of as they cannot decompose and often contain harmful chemicals. Therefore, the stakeholder groups for end of use included society and local communities, meaning the communities near the disposal site of the materials. The potential harms of using these products can be mitigated by developing a well-structured plan to dispose of these products at the end of their life, and then following that plan. Local e-recycling facilities will likely be able to assist. Additionally, the design team will work to minimize energy consumption both while the machine is idling (power required to keep the machine turned on) and while it is in operation (power required to move components and run the algorithms). This will involve shutting down systems like the camera when not immediately in use to minimize power draw, and examining the balance between power consumption and startup energy use to determine when it is most efficient to put the machine to "sleep" and automatically turn it off.

Appendix E

Table 2. Bill of Materials

Item	Specifications	Quantity	Cost per unit	Total cost	Location	Lead Time
Raspberry Pi	4, 128 gB	1	$228.90	$228.90	Raspberry Pi 4 Desktop Kit with Display	5-8 days
Camera	5 MP, for Raspberry Pi	1	$19.00	$19.00	link	1 day
Stepper Motor	1.26 Nm, 2.8 A	1	$35.00	$35.00		2 days
Raspberry Pi Breakout Board	4, wiring breakout	1	$18.00	$18.00		1 day
acrylic	sample	3	$2.00	$15.45	link	
USB-C Screw Terminal Adaptor		1	$9.96	$9.96	link	
LED Array	Lumenati 90L, 3 LEDs apiece	4	$5.25	$37.36	link	
Logic Level Converter		1	$3.50	$3.50	link	
Power Supply	12 V, 5 A	1	$15.02	$15.02	link	
Motor driver	5.6 A, 5-24 V	1	$21.99	$21.99	link	
Buck Converters (6 pack)		1	$14.11	$14.11	link	
Bearings		1	$12.83	$12.83		
Caleb Homedepot/walmart	screws, rods, etc	1	$62.37	$62.37		
old camera		1	$10.88	$10.88		
Post Brackets and rods		1	64.54	$64.54		
Plywood	2 sheets	1	50.44	$50.44		
Lowes pipe	45 degree	1	42.78	$42.78		
Austin home depot	pipes	1	$47.87	$47.87		
Austin’s redesign	Bearings extrusions etc	1	$145	$145		
Ryan redesign	Motor driver,	1	$145	$145		

	lights, etc					
			Total	$1,000		
Budget Given	$1,000.00		Budget Left	$0		