Fall 2022

MEMS 411: CNC Fabric Dispenser

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Mechanical Engineering Design Project
MEMS 411, Fall 2022

CNC Fabric Dispenser

This project aims to help Mary Ruppert-Stroescu with her zero-waste fashion project. The goal of this tool is to help Mary efficiently lay down fabric across a sheet of sticky paper to make a yard of reused fabric. The goal of our team was to create a machine that can work alongside Mary, rather than having her spend all her time at the machine. We wanted to make a machine that can work independently of Mary, so that she can focus her time on other things.

100s of lbs of fabric waste is part of American today. Mary's mission is to be able to reused used and unwanted fabric, and make it into a new article of clothing. Mary has created a multi-step process that allows her to take fabric scarps, and turn them into new yard of fabric. This process includes laying strips of fabric meticulously on a sticky backing that is then sewn together. The part that takes the most time for Mary, and what she considers the bottle-neck of her project, is that laying the fabric takes a lot of time. She would like an invention or tool that would aid her in laying fabric down faster.

Our team wanted to work outside of the box. Rather than just make a simple tape dispenser mechanism, we wanted to generate a fully autonomous machine that would lay fabric for her in many rows. This was done by making a metal frame, 3D printed components, electronics, and code to generate a machine similar to a CNC or 3D printer, that moves a head and lays fabric on the table.

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1 Introduction

Our project started with Mary Ruppert-Stroescu, who gave us a general explanation of her needs. Her current work focuses on sustainability in fashion, and works to limit textile waste in the fashion industry. One way she does this is by taking old clothing, converting them into strips, and generating new clothing. Her process is very intricate, and involves a lot of time dedicating herself to cutting strips of fabric and laying them down intricately. [**ReimagineTextile**].

This is where our team comes in. Mary approached us to make a device that will minimize the time she has to spend cutting and laying strips of fabric. Mary has developed an efficient way to roll the fabric, but would like help laying down the fabric onto a sticky biodegradable fabric. [**ZeroWasteFashion**].

2 Problem Understanding

2.1 Existing Devices

Some existing devices that are similar to our fabric applicator are the CNC machine, the tape dispenser machine, and

2.1.1 Existing Device #1: CNC Machine

Figure 1: CNC Router (Source: stylecnc.com)

Link: https://www.uti.edu/blog/cnc/6-cnc-machines
Description: One existing device similar to what we envision creating is a CNC router. CNCs (computer numerical control) are computer controlled machines that are used in the manufacturing industry. A CNC router generally consists of two axis that move a spindle tool to cut material as predetermined by a program. CNCs automate work and make mass production much easier. We plan to have 2 axis as well to move a fabric applicator across a surface.

2.1.2 Existing Device #2: Tape Dispenser

Figure 2: Tape Dispenser (Source: tach-it.com)

noindent Link: https://tach-it.com/product/tape-dispensers-4125/
Description: Another existing device similar to our fabric dispenser is a tape dispenser. This tape dispenser takes tapes up to 2 inches wide and has a natural rubber roller for smooth application. The tape dispenser has a corrugated blade for cutting heavy duty tape and also has gears for reliable application. Our fabric applicator will be similar to the tape dispenser but it may have a pulley system instead of gears for controlling the roller.

2.1.3 Existing Device #3: Disposable paper sheet roll

Figure 3: Disposable paper sheet roll (Source: https://www.twinriverspaper.com)

Link: https://www.twinriverspaper.com/products/technical-papers/doctor-roll/
Description: The third existing device similar to what we have in mind is the medical table paper commonly used in a doctor's office as exam table paper. These tables have a roll of paper at the end that can be pulled to replace a clean sheet after each use. We expect our adhesive paper to be pulled out in the same manner.

2.2 Patents

2.2.1 US 7501601B2 - Automated Laser Engraver

This patent is for a laser engraver that allows the laser module to travel in any direction along the xy plane of the cutting bed. The laser module can slide horizontally along rails above the cutting bed (in the x direction), and the rails above the cutting bed can slide vertically along rails on the sides of the frame of the laser engraver (in the y direction).

Link: https://patents.google.com/patent/US7501601

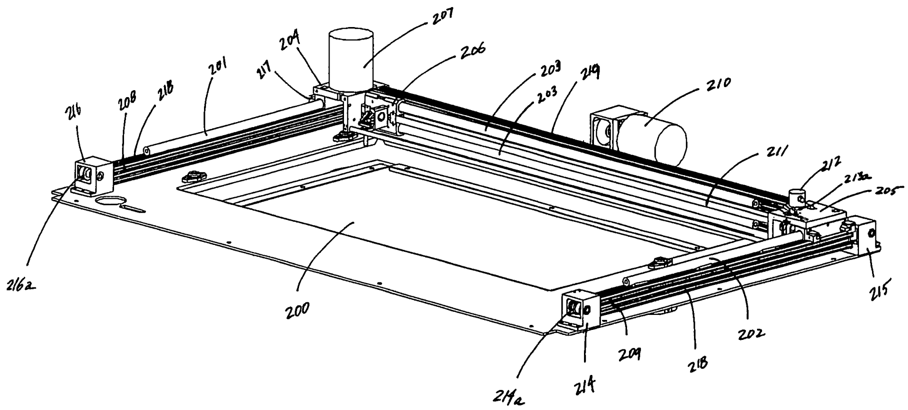


Figure 4: US Patent 7501601B2 - Automated Laser Engraver

2.2.2 US 10473915 - 3D Printer

This patent is for a 3D printer that allows the filament module to travel in any direction along the xy plane of the print bed. The filament module can slide horizontally along rails above the print bed (in the x direction), and the rails above the cutting bed can slide vertically along rails on the sides of the frame of the 3D printer (in the y direction).

Link: https://tecnica.com/tecnica-received-fourth-us-patent-for-its-sls-print-head/

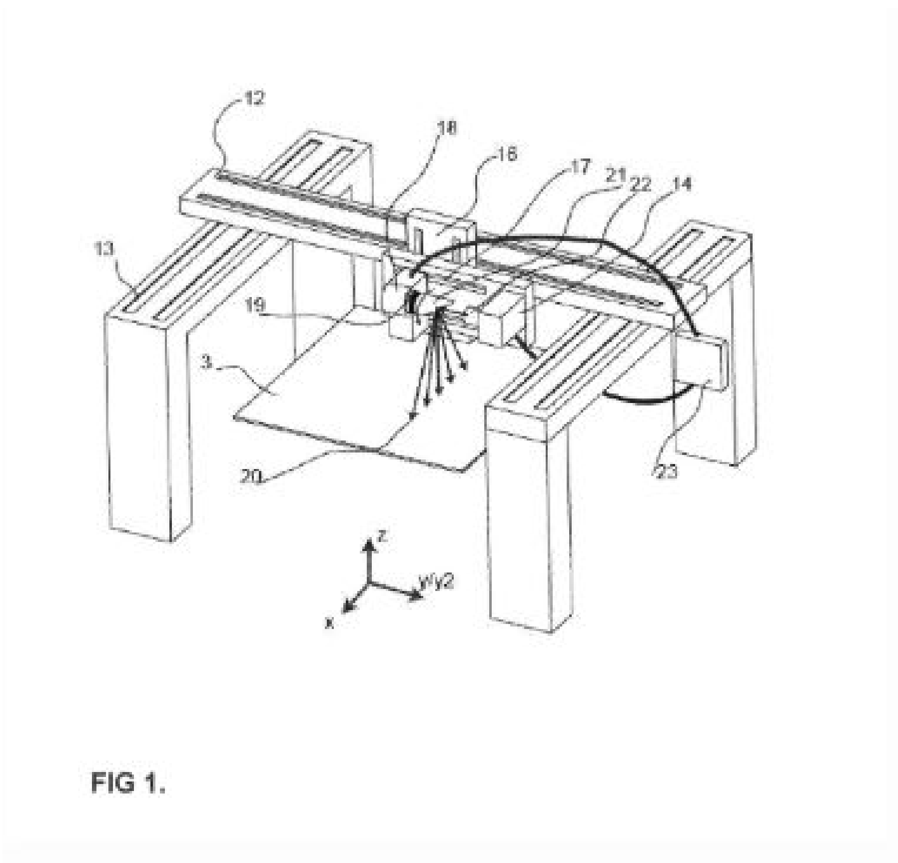


Figure 5: US Patent 10473915 - 3D Printer

2.3 Codes & Standards

2.3.1 Information technology equipment - Safety - Part 1: General requirements (IEC 60950-1)

This international standard defines the different classes of electrical equipment by their efficiency and power consumption. This applies to our project because we might choose to use a power supply to power our fabric-laying CNC machine. This standard includes regulations for grounding certain electrical products and tests for electrical shock and fire.

2.3.2 Standard Specification for Roller, Bearing, Needle, Ferrous, Solid, Spherical End (ASTM F2443-04)

This standard pertains to different types of bearing components with spherical shapes. This would apply to our project because we have want to maintain constant motion of the fabric as it is laid out, and a combination of rollers and rails would be a good option for this. The standard would provide information like standard loads and dimensions that we could expect.

2.4 User Needs

2.4.1 Customer Interview

Interviewee: Mary Ruppert-Stroescu
Location: Bixby 110, Washington University in St. Louis, Danforth Campus
Date: September 9^{th}, 2022
Setting: The interview took place in a fashion studio classroom. Mary introduced us to the different materials the device will work with for example the adhesive, water-soluble tape, the rolls of hand cut fabric, and a few pieces of clothing that were produced using the technique we are modeling. The meeting lasted around ∼45 min.

Interview Notes:
What are the typical uses of the device?

– Facilitate the process of laying out strips of fabric to be sewn together.

What are some things we should watch out for?

– You absolutely cannot stretch the fabric because it will curl.

Do you want the strips to be straight??

– Sure. But having curves would be amazing.

2.4.2 Interpreted User Needs

We listed the following user needs mentioned in the interview in Table 1 below.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	FM lays out strips along one axis	5
2	FM applies minimal tension to the fabric	5
3	FM runs autonomously	3
4	FM has the ability to adjust the length of fabric strips	4
5	FM is easy to use	4
6	FM has the ability to lay out multiple strips at once	2
7	FM smoothly applies the fabric to the adhesive	4

2.5 Design Metrics

When looking at the design of our product, we must take into considerations Mary's needs. From her interview, we can conclude the following metrics that she would want her product to accomplish, and how important those metrics are to her, and how attainable they are to our team.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	5	Total weight	lbs	25	15
2	1,3	Rate of feed layup	in^2/s	.5	1
3	5	Noise level of machine	dB	60	40
4	3,6	Overlap between strips	in	1/4	3/8
5	2	Change in Fabric Width	in	1/4	1/8
6	1	Maximum Horizontal Displacement of Fabric	in	1/4	1/8
8	5,7	Ease of use & survey results from a focus group	integer 1-5	3	5

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

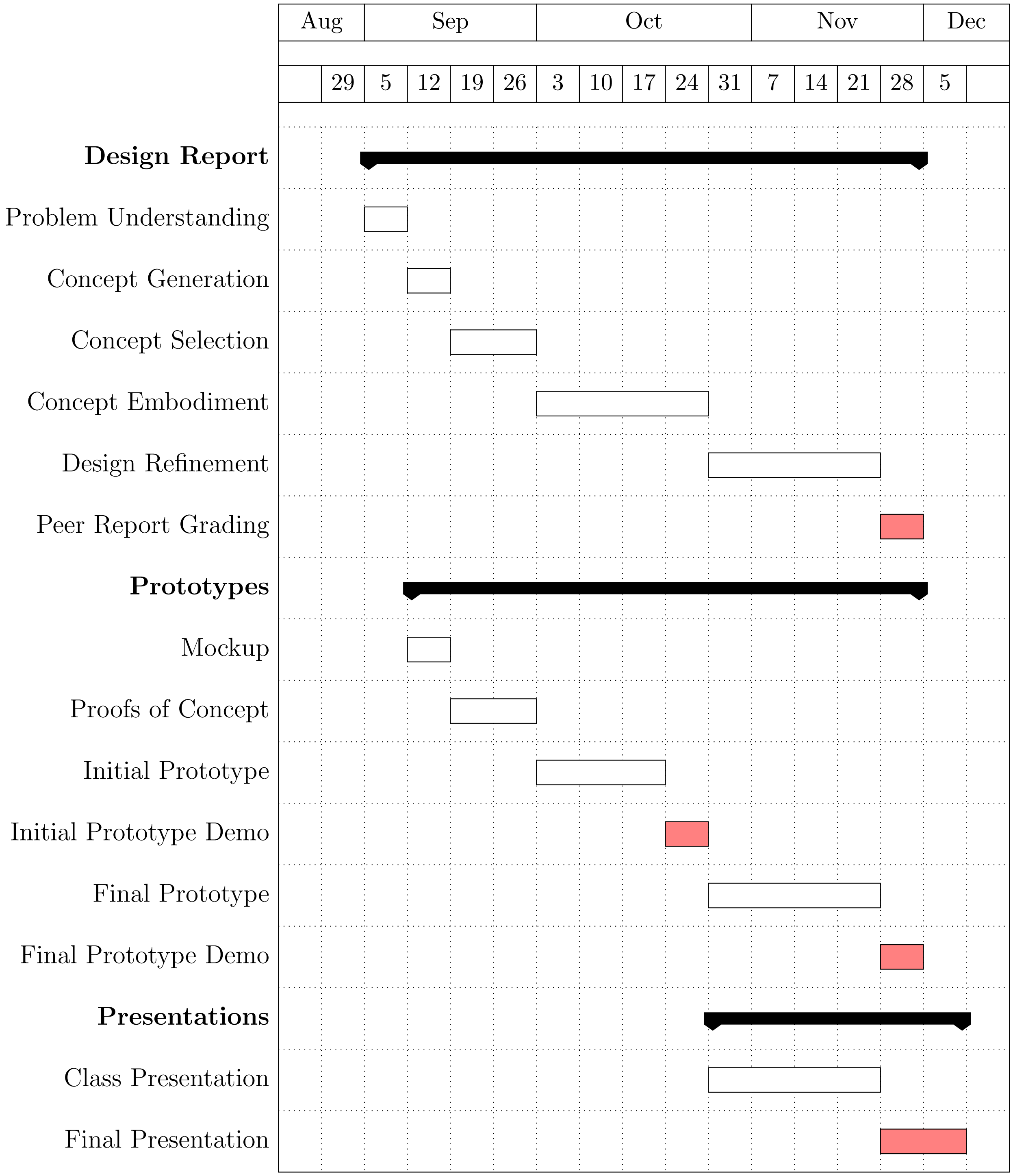


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

Our mock up was meant to get a general sense of possible ideas that could complete the task of laying down fabric. We used simple materials (i.e. no electronics or motors), to get a general idea of what we were thinking of building.

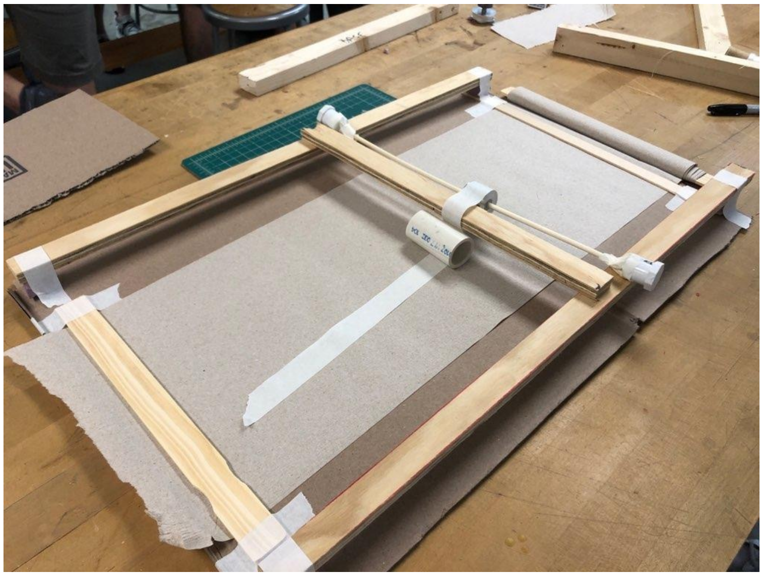


Figure 7: Cavalier perspective our mock up

We first made a general platform of wood to mimic the table we would be working on, and the sides of the machine. We also used scrap paper to mimic the sticky adhesive fabric that Mary uses, and rolled it up as a potential solution for creating long strips of fabric. Then we made a arm out of dowel that would hols the roll of fabric. We did not think of how to move that roll of fabric, as this was a very general beginning stage of a prototype.

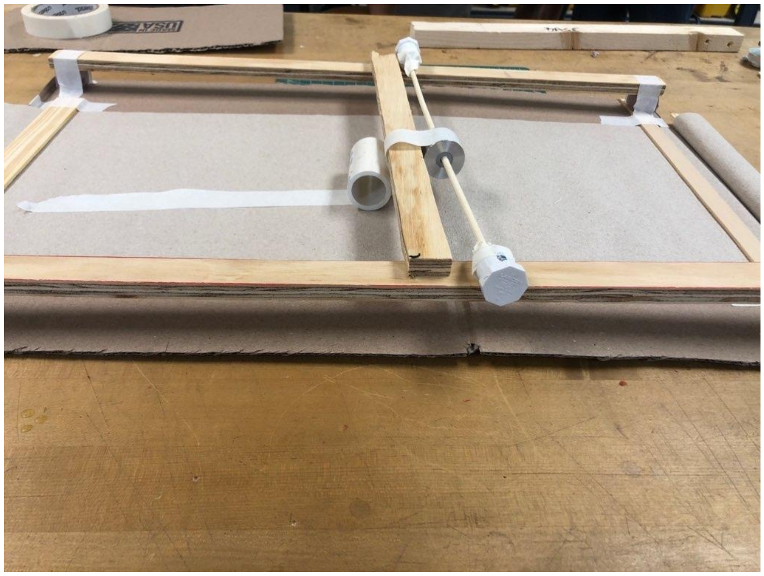


Figure 8: Front view perspective of our mock up

What we did focus on however, was try and get a second roller in front of the fabric dispenser so that it can stabilize the fabric as it was placed on the sticky fabric. Our biggest concern is making sure the fabric does not roll up, and we believe that if we used something to stabilize the dispensed fabric, that would eliminate rolling.

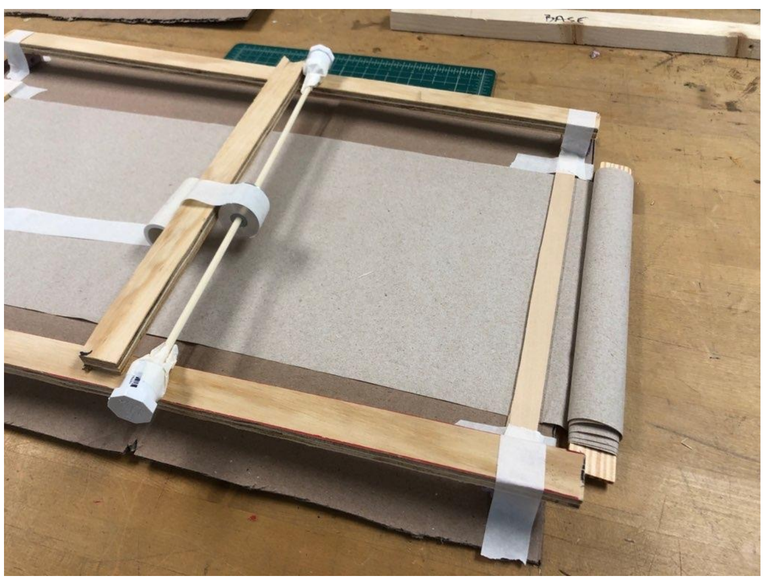


Figure 9: Close up of our storage and fabric dispensing tool

Overall, the mock up gave us an idea of what we all value in the product, and what would be difficult to implement in the final product. It also gave us an opportunity to get a physical object on the table for everyone to discuss.

3.2 Functional Decomposition

We came up with a few functions that our fabric applicator should have. We also came up with potential solutions to these requirements. The generated fuction tree is shown below in Fig. 10

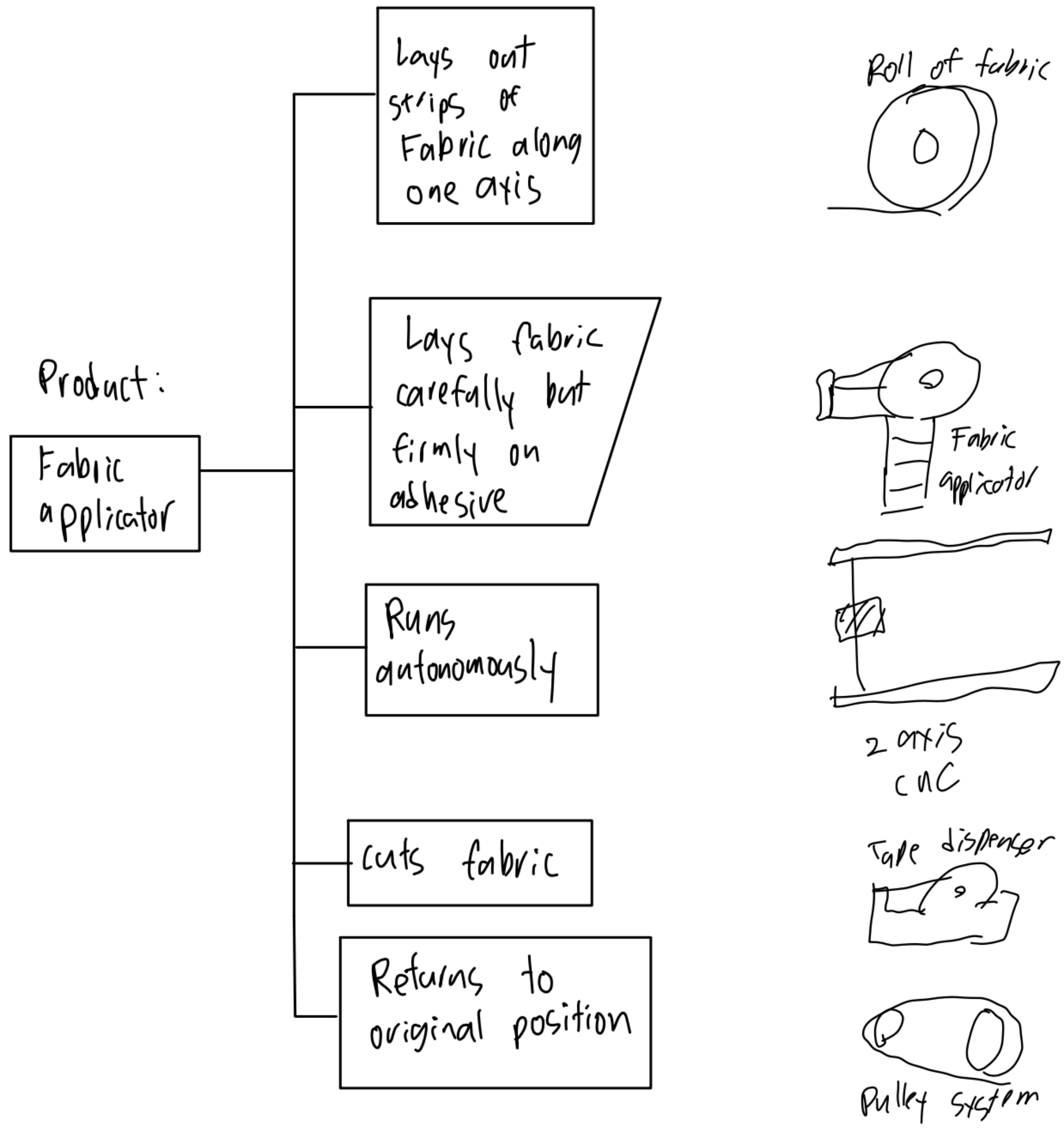


Figure 10: Function tree for fabric applicator

3.3 Morphological Chart

The following morphological chart lays out some of the basic functions our product needs to have, and a few potential solutions to each need.

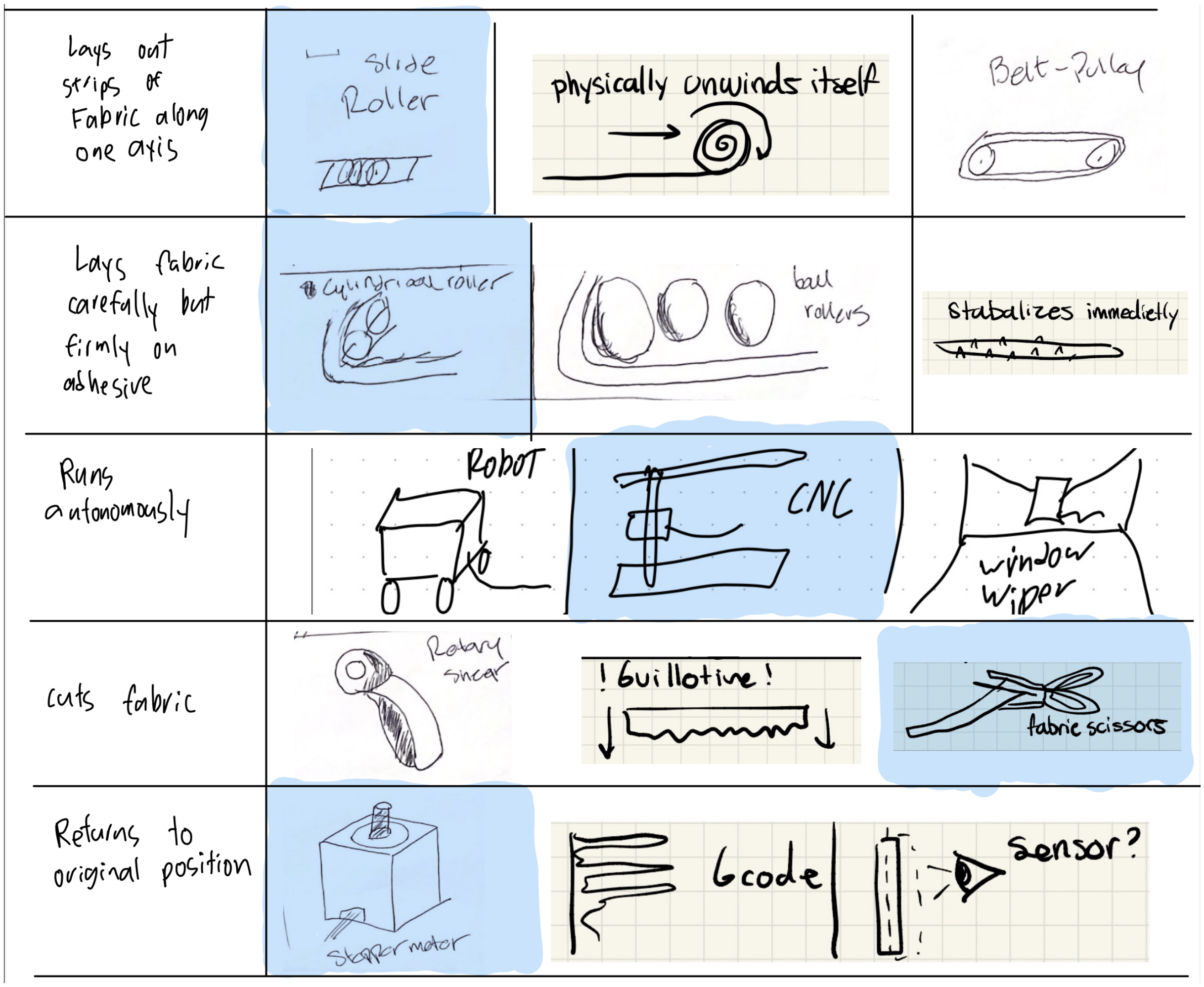


Figure 11: Morphological Chart for fabric applicator

3.4 Alternative Design Concepts

3.4.1 Concept #1: Guillotine <3

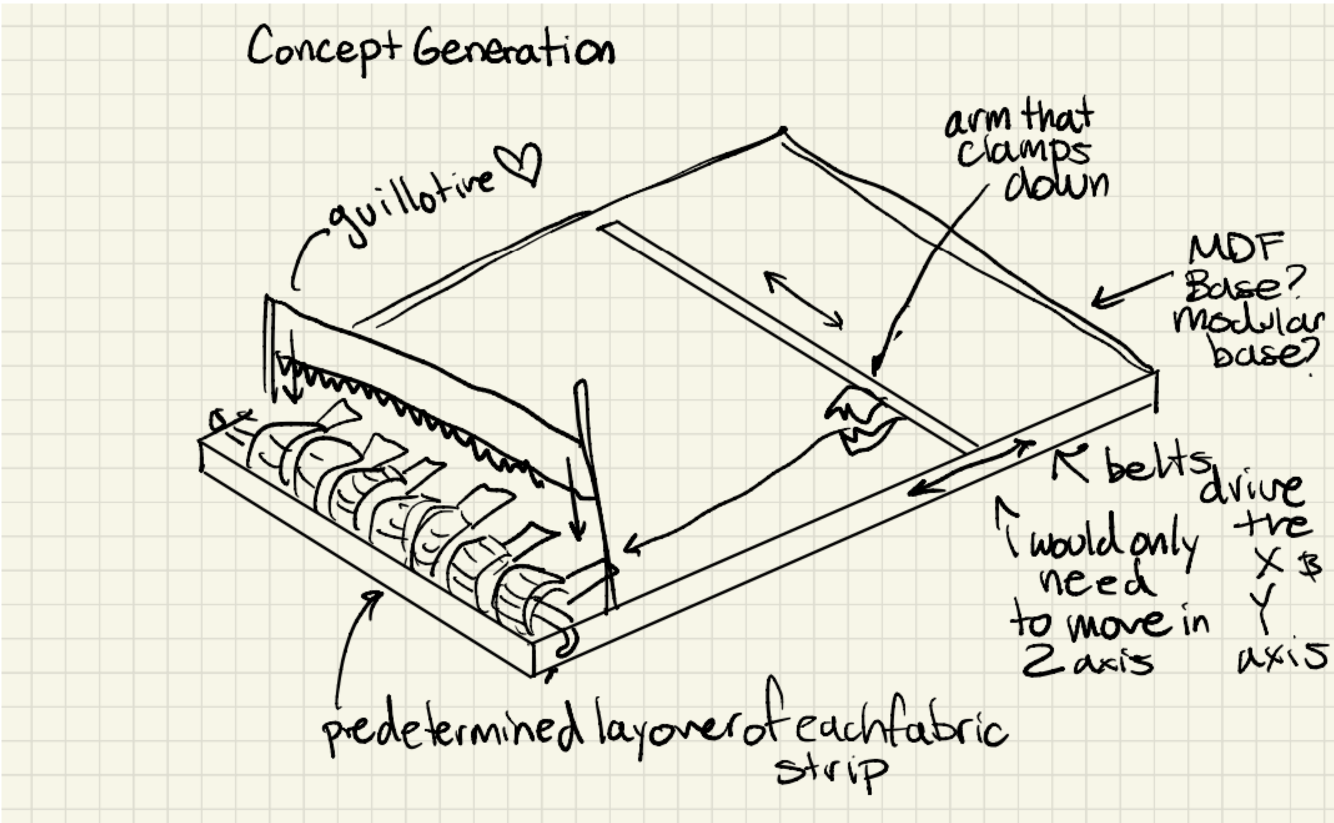


Figure 12: Sketch of Lizbet's Concept

Description: The base is similar to all the other concepts, including our mock up presentation. But what makes this concept unique is that there is a single, large blade that cuts all the lines of fabric at once. I thought it would be more fun that way. This design also adds the ability to use multiple rolls of fabric at once, increasing efficiency, and allowing the user to use multiple colors if desired. The arm would be the only thing traveling in the X and Y axis, meaning it can be very fast, and potentially pull the fabric along both axis at once, generating organic, diagonal shapes.

3.4.2 Concept #2: CNContraption

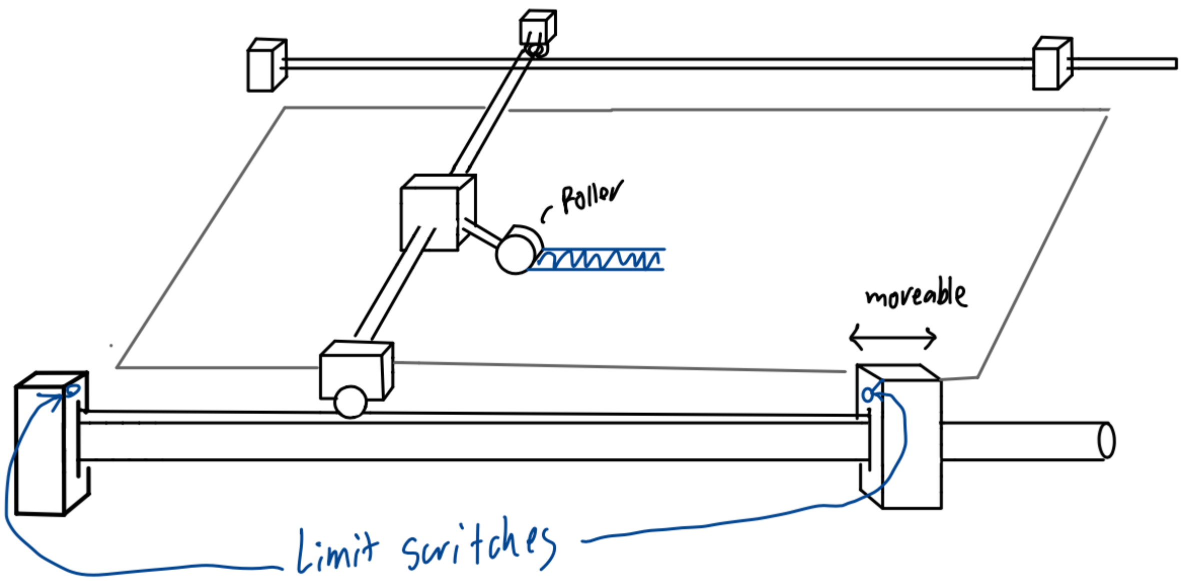


Figure 13: Sketch of Hayato's CNContraption

Description: This concept is similar to a 2 axis CNC machine. It has two rods that hold up a third rod for the other axis. The feet are moveable and have limit switches that stop the roller. The center rod rolls on the two rails using wheels. The roller's position in controlled using a pulley and all moving parts are controlled with stepper motores.

3.4.3 Concept #3: Fabric Dispenser

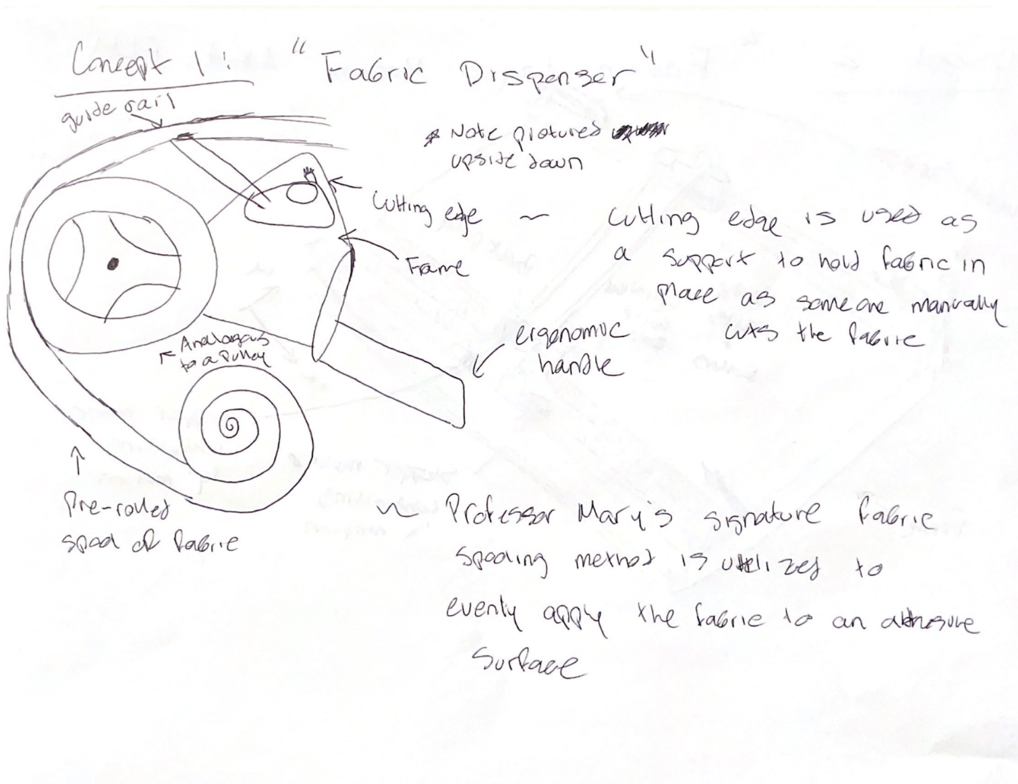


Figure 14: sketch of fabric dispenser concept

Description: This concept differs from the CNC ideas in that it would be a manual application of fabric strips. It has a guide rail for even application of the fabric, and a cutting edge for cutting the fabric at the ends. The main issue I can see with something like this is that the user might become tired after doing several strips one after another.

3.4.4 Concept #4: 2 Axis Fabric Router with Wheel Applicator

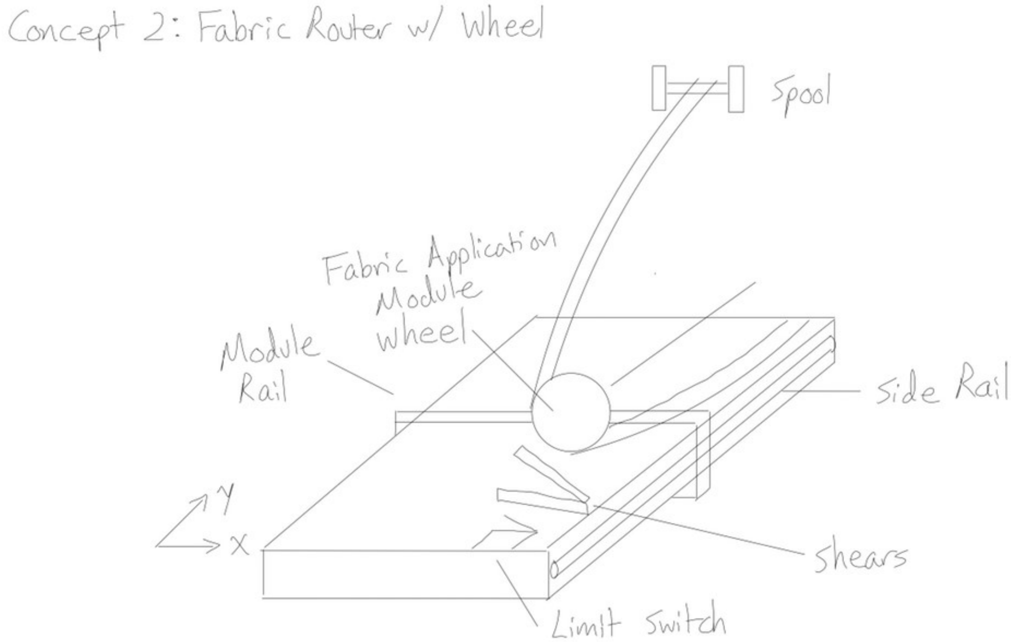


Figure 15: 2 Axis Fabric Router with Wheel Applicator based on 2 Axis Laser Engravers and CNC Machines

Description: This concept uses rails on the sides of the frame to roll the wheel that lays down the fabric, and an actuation mechanism will be used to translate the wheel laterally, similar to a 2 axis laser engraver or CNC machine. The fabric will be threaded from a spool to the wheel, limit switches on both ends will be used to reverse the direction of the wheel, and shears or other cutting blades will be used to cut the strips of fabric.

4 Concept Selection

4.1 Selection Criteria

The five criteria for our fabric applicator were compared to each other in an analytical hierarchy process to determine their weights for the scoring matrix. A summary of this process is shown in Fig. 16 below.

	Lays out fabric along 1 axis	Lays fabric firmly on adhesive	Runs autonomously	Cuts fabric	Portable	Row Total	Weight Value	Weight (%)
Lays out fabric along 1 axis	**1.00**	0.20	5.00	3.00	5.00	14.20	0.25	25.36
Lays fabric firmly on adhesive	5.00	**1.00**	9.00	7.00	7.00	29.00	0.52	51.79
Runs autonomously	0.20	0.11	**1.00**	0.33	1.00	2.64	0.05	4.72
Cuts fabric	0.33	0.14	3.00	**1.00**	3.00	7.48	0.13	13.35
Portable	0.20	0.14	1.00	0.33	**1.00**	2.68	0.05	4.78
					Column Total:	**56.00**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

The four concepts for the fabric applicator were compared in a weighted scoring matrix using the criteria chosen in the analytical hierarchy process. Each concept was given a score for each criteria and the best concept was chosen. A summary of this process is shown in Fig. 26.

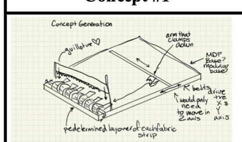
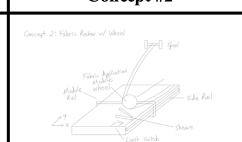
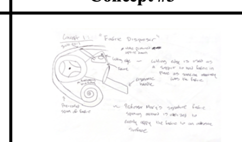
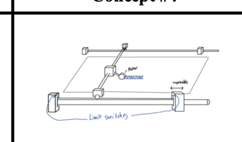
Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Lays out fabric along 1 axis	25.36	5	1.27	5	1.27	2	0.51	5	1.27
Lays fabric firmly on adhesive	51.79	1	0.52	5	2.59	5	2.59	5	2.59
Runs autonomously	4.72	5	0.24	5	0.24	1	0.05	5	0.24
Cuts fabric	13.35	3	0.40	5	0.67	5	0.67	1	0.13
Portable	4.78	2	0.10	2	0.10	5	0.24	4	0.19
	Total score	**2.518**		**4.857**		**4.050**		**4.418**	
	Rank	**4**		**1**		**3**		**2**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

Of these result, the ones that worked the best for us was concept 2. This concept scored high for laying the fabric along one axis, firmly laying the fabric on the adhesive paper, cutting the fabric and it even runs autonomously. The only thing that it did not score too hot in was portability. We plan on taking characteristics from the fourth concept to make our second concept more portable. The first and third concept did not score well because they did not lay the fabric firmly on the adhesive and did not lay out the fabric along one axis respectively.

4.4 Engineering Models/Relationships

Formulas that we believe will be useful for us are as follows:

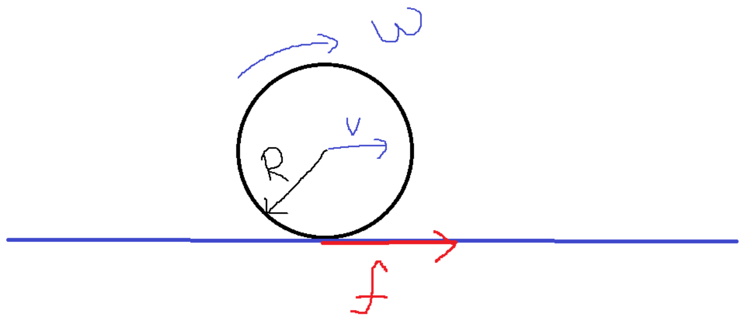


Figure 18: Diagram of the roller component and related variables

$$v_r = \frac{v_0}{1 + \frac{I}{mR^2}} \tag{1}$$

$$F_{friction} - \mu_k FN = \mu_k mg \tag{2}$$

$$t_r = \frac{v_0}{\mu_k g(1 + \frac{mR^2}{I})} \tag{3}$$

The model above allows us to analyze the rolling element of our design, and model when slipping would occur. This is very relevant in determining the optimal speed the roller should travel, and the shape of the element because the moment of inertia will effect the rotation. Where v_0 is the initial linear velocity, m is the mass of the roller, R is the radius, I is the moment of inertia, mu_k is the kinetic coefficient of friction, F_N is the normal force, g is gravitational acceleration, t_r is the time when the object is fully rolling, and v_r is the final rolling velocity.

$$\frac{\omega_1}{\omega_2} = \frac{D_1}{D_2} \tag{4}$$

where ω are the angular velocity and D is the diameter of the pulleys. The reason we would want to use this formula is because it allows us to calculate the proper wheel ratios. We do plan on using pulleys to connect the main roller to the dispenser rollers to limit the risk of the fabric getting stuck in between the rollers and rollers getting caught on the fabric as it travels, so we want to make sure we have the rollers moving consistently.

$$Voltage \times Amperage = Wattage \tag{5}$$

While this formula is simple, it is the most critical for the fabric applicator because it allows us to calculate the necessary power rating for our power supply. We also plan on including a factor of safety for our maximum power rating so we do not overheat our power supply.

5 Concept Embodiment

5.1 Initial Embodiment

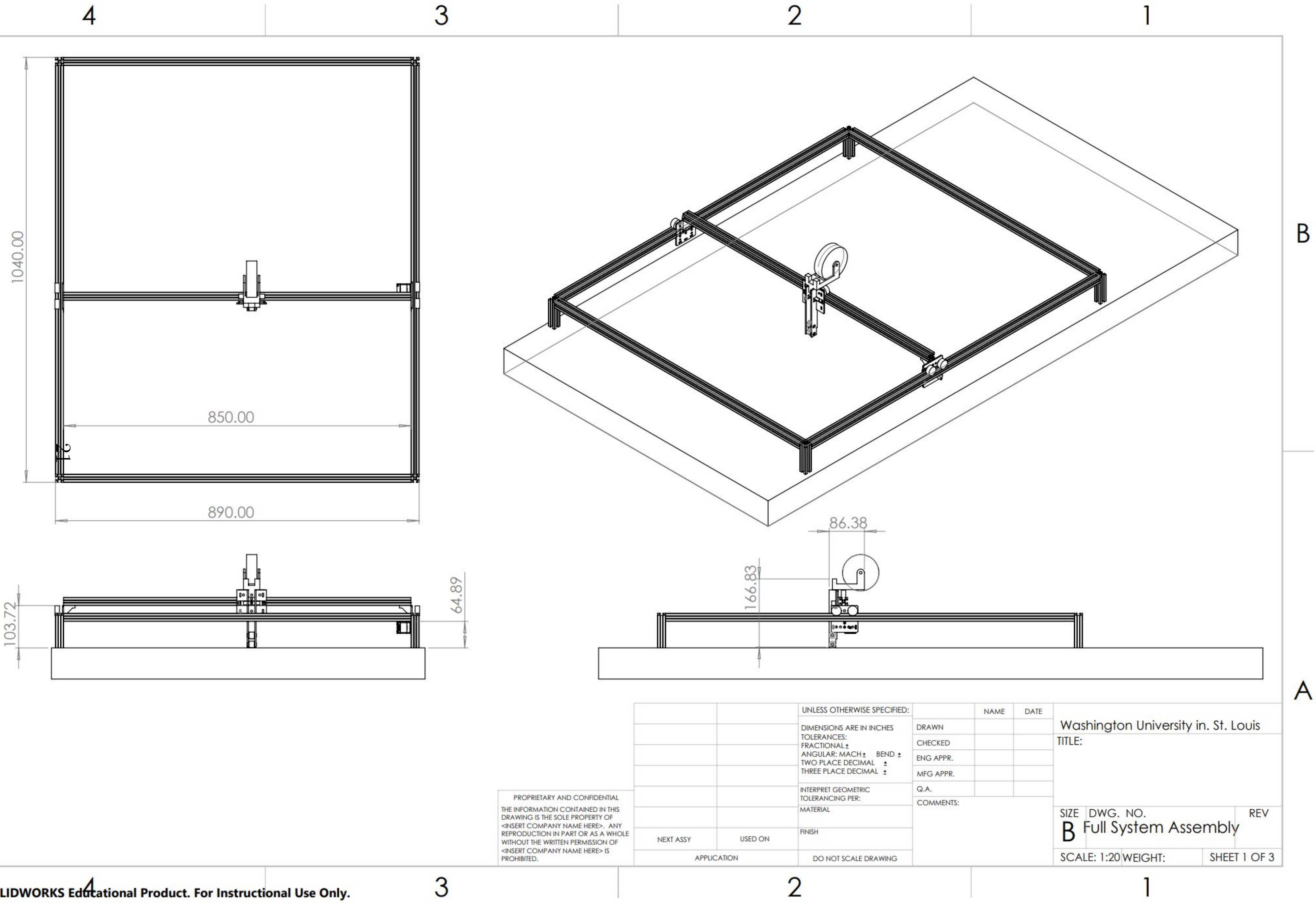
In our initial prototype, we had three performance goals that were critical for us and our costumer. They were the following:

-Lay the fabric firmly, and in a straight line to limit fabric shrinkage

-The prototype can lay multiple strips side by side

-The prototype can run autonomously for ease of use

Our initial prototype was able to accomplish the first two goals but was not capable of the third yet due to the circuitry not being complete. We manufactured a PCB design to accomplish this for our final prototype.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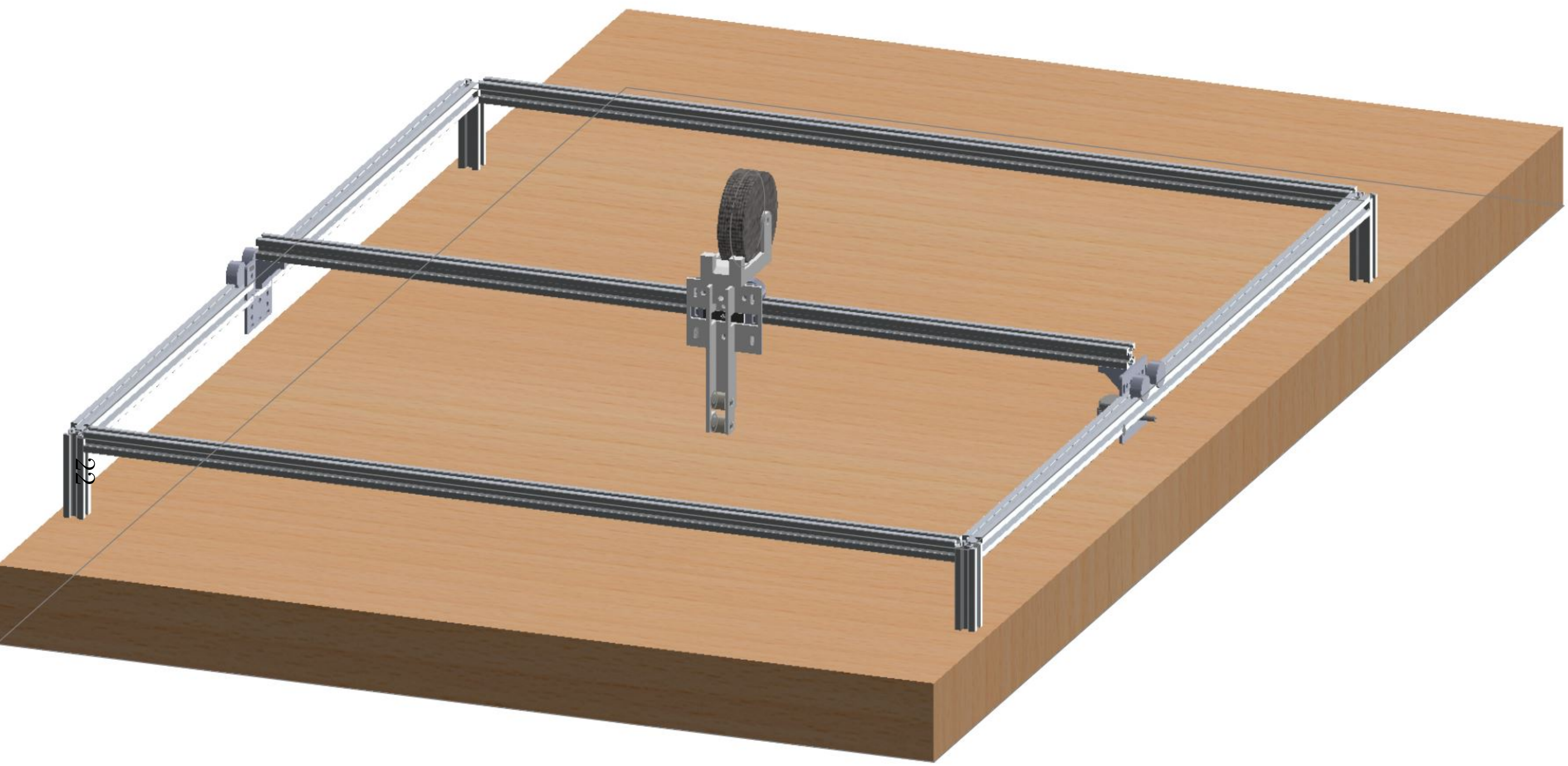

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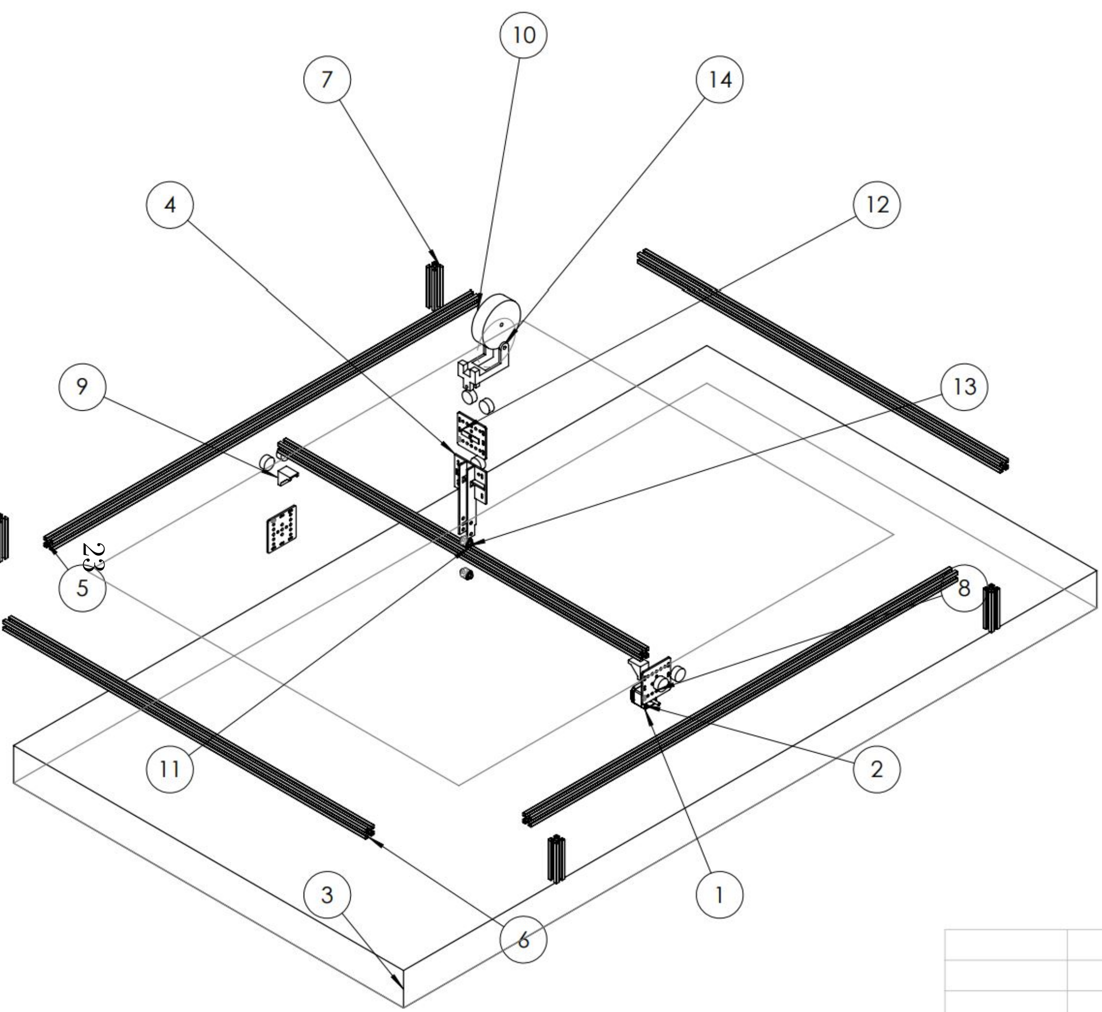
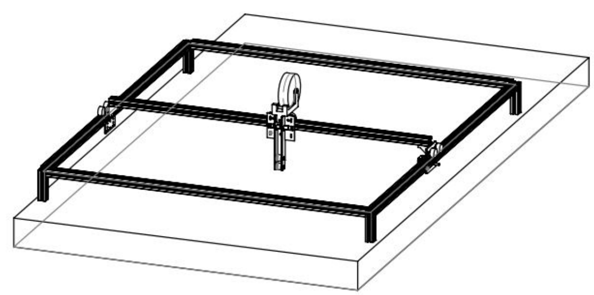


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6627T37	Stepper motor	1
2	Gantry_Plate	Plates for mounting wheels	3
3	Mock_Table	Model tabletop	1
4	Gantry_Backing	3D printed mount for fabric applicator	1
5	3D_Alu_20_20_1000	V-slotted channel, 1000mm	2
6	3D_Alu_20_20_900	V-slotted channel, 900mm	3
7	3D_Alu_20_20_80	V-slotted channel, 80mm	4
8	Gantry_wheels	Wheels for V-slotted channel	7
9	Square_Brackets	Brackets for joining channels	2
10	Fabric_Roll	Mock roll of fabric strips	1
11	Roller	Cylindrical rollers for fabric	2
12	Pulley_Backing	Bracket for supporting pulley belt	1
13	6659K66	Oil-Embedded Flanged Sleeve Bearing	4
14	Fabric_Mount	3D printed mount for fabric roll	1



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COMMENTS:

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Item Name	Unit Cost	Quantity	Item Cost		
V Channels 1000Mm 2020	50.99	1	50.99		
V-Wheel Plate 2020	14.15	3	42.45		
Arduino Pro Mini	16.99	1	16.99		
X-Axis Belt Tensioner	11.99	1	11.99		
Stepper Motor Driver	19.99	1	19.99		
Timing Belt Kit	15.99	1	15.99		
Fabric Scissors	16.97	1	16.97		
Wiring	15.99	1	15.99		
Buck Converter	11.99	1	11.99		
Stepper Motor Driver	9.99	3	29.97		
5Mm Rod Connector	10.99	1	10.99		
Aluminum 90 Degree Bracket	10.97	1	10.97		
5Mm Steel Rod	13.49	1	13.49		
Pin Header	8.99	1	8.99		
Motor Mount	13.98	1	13.98		
Limit Switches	5.99	1	5.99		
Pcb Board	24.55	1	24.55		
Bearings	9.99	1	9.99	Total	332.27

Figure 22: BOM List

5.2 Proofs-of-Concept

As we conducted our proof of concepts, we noticed that we needed a second support face to hold the rotating axis. The axles that supported the rollers tend to bend down as we moved the roller, causing a lot of friction and now allowing the fabric to be dispensed properly.

Our proof of concept also showed us that we needed to update the tolerance on the holes for the rotating shafts. Our gaps were too large, and made the overall structure wobbly.

The tests we conducted did show us however, that our dispensing mechanism did work. We were able to lay pieces of fabric down evenly.

The proof of concepts also showed us that a autonomous running is definitely tangible. We were able to get our drivers working properly , and all that is left is come code and electronics.

5.3 Design Changes

The initial prototype is pretty similar to concept 2, the selected concept from section 4. One difference is that the prototype has four extrusions under the corners of the frame in order to create enough space for the fabric applicator. These will be fastened together using aluminum corner brackets. Another difference is that there are wheels above and below the rails on the side that roll the lateral extrusion across the machine rather than one set of wheels that sit atop the rails. This change was made to reduce the wheels from slipping. The final difference is that we will be putting limit switches on the rollers itself. This will ensure that all electronics are close together which will make wire management a lot more manageable.

6 Design Refinement

6.1 Model-Based Design Decisions

This section outlines the mathematical and engineering models and relations used for analyzing the performance of our prototype.

6.1.1 Model #1: Rolling without Slipping

The first model we analyzed was identified in section 4.4 of the report. This model focuses on the cylindrical roller component, and determines the maximum longitudinal velocity before the roller begins to slip. This model uses the work energy principle to relate frictional force, to rotational kinetic energy and translational kinetic energy.

The main equation used was: 1

Where, v_0, the initial reference velocity was: 0.1016 m/s m, the mass of the roller was: 0.013 kg R, the radius was: 0.0508 m and, I, the moment of inertia was: $5.23 * 10^-6$ m4

Plugging in and solving for the maximum velocity yields an ideal value: 0.0879 m/s or in ratio form:

$$v_r = v_0 0.8651 \tag{6}$$

This provides us insight as to the maximum roller velocities we can use before we'd expect slipping.

6.1.2 Model #2: Electrical Power

The second was also outlined vaguely in section 4.4. Here we wanted to observe the maximum possible power draw from our system's electronics, to ensure that we avoid the risk of overheating our power supply. This model uses Watt's law: 5

in addition to the expression for shaft output work:

$$P = \tau\omega \tag{7}$$

This model operates under the assumption that the motors have 100 percent efficiency which is obviously untrue, however it simplifies analysis such that P equals wattage. First we look at the maximum possible shaft velocity resulting from the stepper motors' rated voltages and currents.

Using a voltage of: 12 volts a current of: 1.7 amps a maximum shaft torque of: 2.94 N-m

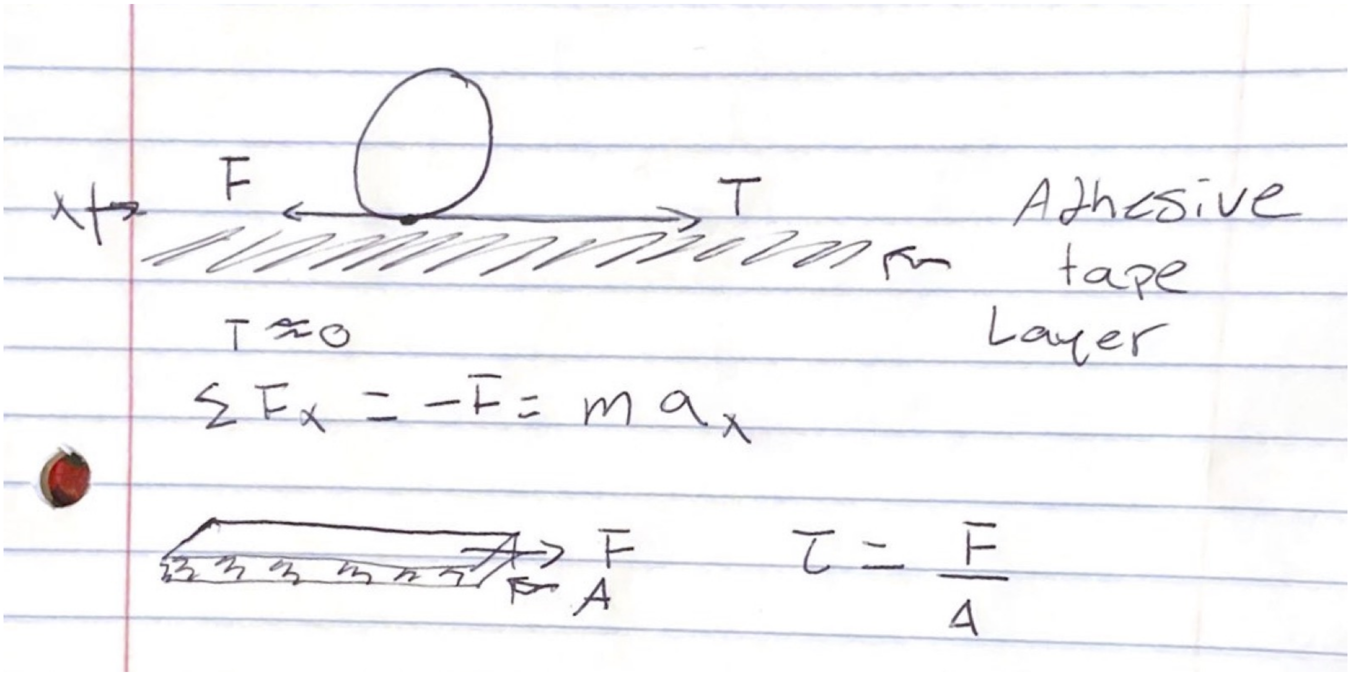
yields a maximum angular velocity of: 6.93 rad/s or 66 RPM. This provides a theoretical maximum rotational and therefore translational velocity for our rollers.

6.1.3 Model #3: Lap-Shear Stress of Adhesive Layer

This final model looks at the shear stress interaction between the fabric and the adhesive layer as seen below.

Note that we're neglecting the friction forces, and the forces of gravity in this analysis. This is under the assumption that the applied force F is significantly larger than the friction.

The goal here is to determine the maximum possible acceleration of the roller and fabric without overcoming the adhesive's material strength. It was assumed the adhesive layer was 3M™ Paper Tape 200. The mass was assumed to be the mass of the entire roller-upright assembly. In order to



model the maximum possible lap-shear stress, the smallest potential surface area of a 1 inch by 1 inch square.

The mass used was: 0.2 pounds The area was: 1 inch squared and the shear strength was the material was: 19 lb/square inch

The result was an acceleration of 95 in/$second^2$. This proves that the limiting factor with the fabric adhesive is definitively not the acceleration.

6.2 Design for Safety

Safety is critical and should be noted in all designs. Thus, when we designed our product, we wanted to take into considerations all potential areas of harm to the machine and the operator. The following risks are explained.

6.2.1 Risk #1: Entanglement

Description: The risk of entanglement is specifically for someone's fingers if they were to stick them near the rollers while the machine was on. There is a location where this could be very easy for someone with small to medium size fingers, This is especially a risk as there is the potential for the fabric to get stuck, and the common human instinct is to stick your finger in there to help the fabric.

Severity: The severity of the risk is marginal to critical. It is more a harm to the operator than to the machine, and there is the risk of severely hurting a child's finger if they were to get stuck. The actual pressure the rollers apply to the fingers is currently not strong, but could be if the code were to change. There is also no stopping mechanism for the machine if someone where to get their fingers stuck.

Probability: The probability is actually pretty common. So the risk is occasional. This is because, as stated previously, the fabric currently gets stuck, so the human reaction is to stick your fingers in there to help.

Mitigating Steps: We are thinking of putting an acrylic shield to make sure that fingers cannot get near the rollers. Also making the mechanism better overall so that the fabric doesn't get stuck in the first place.

6.2.2 Risk #2: Loose Belts

Description: In our machine, we have multiple belts that aid in the movement of the carriage in both the X and Y dimension. While the belts are fairly tight, they are still loose enough for a finger to get stuck in between the belt system and the track. This is especially dangerous when the carriage is moving and the belts are moving.

Severity: If this accident were to happen, it is not as dangerous as the other risks. The belts do not move that fast, and they do not have the potential to move fast. The gap is also very small, and the movement of the belt usually just pushes the fingers out of the way. So the level of severity is just marginal.

Probability: The probability of this risk occurring is also very minimal. Thus we will say the risk will Seldom happen. This is because there is really no reason for someone to be messing with the belts in the first place, and they are concealed well withing the tracks.

Mitigating Steps: What we have done to mitigate this accident from occurring is making the track the same color as the belt. There is an amazing affect of camouflage and one can barely see the belts at all. This makes it a lot easier for people not noticing the belts and thus wanting to stick their fingers there.

6.2.3 Risk #3: Scissors

Description: In our final design, we hope to implement scissors that automatically close at the end of a line to cut off the fabric, making the entire system automated. Obviously, there is a giant risk in that these scissors need to be very sharp, so they cut fabric at any placement, and they will be automatically closing, so if someone where to put their hand in there, it could be very dangerous.

Severity: This is potentially the most dangerous mechanism on the machine. The severity of the accident could being catastrophic to the user, depending on the speed in which the scissors close.

Probability: The probability of this risk becoming a reality is likely. The reason for this is because once the fabric is cut, the user comes into close contact with the scissors and the rollers to start the next line of fabric.

Mitigating Steps: To mitigate this accident happening, there are a lot of safety measures that should be in place. A guard is possible, but potentially will be more in the way that it's worth. A sensor can be useful, but what tells the difference between a finger and a strip of fabric? The possible solution would be making that part of the mechanism manual. It is a small part and that way the machine is never responsible for the action.

6.2.4 Risk #4: Falling Frame

Description: When building the frame for the final prototype, we took into consideration the size of a standard table. We wanted to make sure that the final size of the product was small enough to fit on a standard table, but large enough to maximize working space. There is however, the real fear of the machine falling off of smaller tables, and possible damaging the machine, or the operator

Severity: The severity of this happening is pretty marginal, as the frame itself is not that heavy, and there are not a lot of unique items. Thus, things can be easily replaced.

Probability: The probability of this happening really depends on the table the machine is set on, but in general, it should be seldom if used on the correct workspace.

Mitigating Steps: A way we could mitigate this is by making the frame customizable. Making one axis adjustable would make the product compatible for more tables.

6.2.5 Risk #5: Sharp Edges

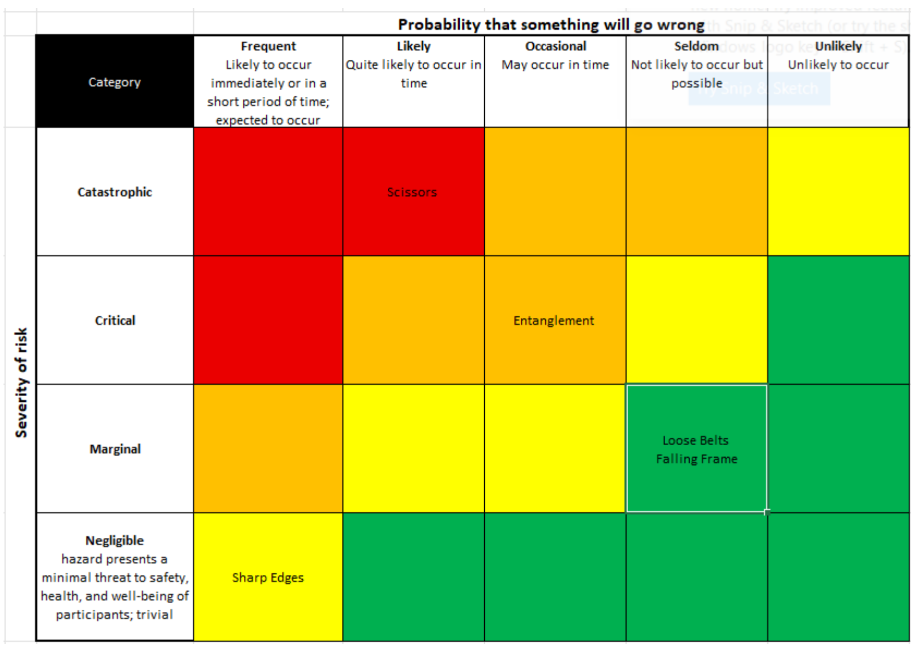
Description: When building our machine, we noticed a lot of sharp corners. This is especially true in the 3D printed parts that we made. Thus someone could easily hurt themselves on the sharp corners.

Severity: The severity would be negligible. The sharp corners are not that dangerous compared to the other components on the dispenser.

Probability: This is actually a very frequent accident that could happen if we do not fix it.

Mitigating Steps: One way we can mitigate this is by rounding the corners, which is an easy fix.

Heat Map Image:



		Probability that something will go wrong				
	Category	Frequent Likely to occur immediately or in a short period of time; expected to occur	Likely Quite likely to occur in time	Occasional May occur in time	Seldom Not likely to occur but possible	Unlikely Unlikely to occur
Severity of risk	Catastrophic		Scissors			
	Critical			Entanglement		
	Marginal				Loose Belts Falling Frame	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial	Sharp Edges				

Figure 23: Heat Map of Final Risk Assessment

6.3 Design for Manufacturing

Number of Parts: 33

Number of Threaded Fasteners: 40

Theoretically Necessary Components (TNC): Extrusion Rollers Belt System 3D Printed Roller Carriage Frame Motors

The extrusion rollers must be separate pieces because the central extrusion needs to move longitudinally relative to the frame. The extrusion rollers are theoretically necessary because they move the central extrusion by rolling on the extrusions on the sides of the frame.

The belt that moves the fabric applicator along the central extrusion must be a separate piece because the fabric applicator needs to move laterally relative to the frame. The belt is theoretically necessary because it moves the fabric applicator by being actuated by a stepper motor.

The 3D printed roller carriage needs to be a separate piece because it needs to move laterally along the central extrusion with the belt and because it must be detachable for reloading fabric. The 3D printed roller carriage is theoretically necessary because it holds the spool and rollers that roll the fabric onto the work surface.

The frame must be a separate piece because all the components above need to move relative to the frame. The frame is theoretically necessary because it is what all the above components attach to.

Motors are theoretically necessary and need to be separate pieces because they control the motion of the central extrusion and the 3d printed roller carriage as described above.

Explanation of How Design Can be Reduced to TNCs Some of the TNCs consist of multiple pieces assembled together using fasteners. The spool on the 3D printed roller could be eliminated, but the roll of fabric unwinds more smoothly with the spool. The two axles for the fabric applicator could be replaced with one axle, and the two motors for these two axles could be replaced with one motor; however, we found that one axle and one motor was not stable enough.

Figure 24: Two axles in the current design

6.4 Design for Usability

1. A vision impairment may influence the usability of our device because a user may knock into the device or not realize that the machine is in operation. We have added a buzzer that plays a tune when the machine is starting up in order to add some auditory feedback. A user with specific color blindness may not be able to discern the color of the indication light. one way to overcome this would be to make the "in operation" indicator light a blinking light. 2. A hearing impairment may influence the usability of our device because a user may not be aware that our machine is running due to not being able to hear the ambient sounds of the motors. We have implemented an LED indicator light to flash red while the machine is in operation and green when the machine is on standby. 3. A physical impairment may influence the usability of our device because it would make loading the unloading the spool of the machine much more difficult. It make also be more difficult to plug and unplug the power supply since the cord is has a small diameter. One way to improve the usability of the device for users with a physical impairment would be to add tabs that make loading and unloading the spool much more easy. 4. A control impairments may influence the usability of our device because getting too close to the moving parts of our device may lead to hair

or fingers getting caught. This could be reduced by adding warning stickers and by adding a guard that blocks the moving parts. Incorrect loading of the sticky paper may also make the machine to be unable to properly lay out the fabric.

7 Final Prototype

7.1 Overview

The final construction of the prototype consisted of bringing together aluminum channels, 3D printed components, motors, and code. There were minimal modifications that needed to be done after the final assembly. Some of which included making the 3D printed wheel slightly smaller and inserting bearings so that the entire mechanism can be free running. There was also some work that was done with the code to test and showcase the potentials of the mechanism.

In the end, we were able to achieve all of our design goals, listed below:

1. Lay fabric firmly, and in a straight line, with a shrinkage of less than 15%.

   – Our team calculated this by marking around 20 nodes on the roll of fabric. We measured the initial width of the fabric at each node, rolled the fabric up in the spool, and had our machine apply our fabric onto a sticky surface. The nodes were then measured and the initial widths were compared to the final width. We determined the average shrinkage due to tension in the fabric to be around 12%, which was below our design goal.

2. The maximum time it takes to lay out one full strip should be 16.5 seconds or under.

   – Our team calculated this by measuring the time it takes for the mechanism to complete a full yard, plus some time to cut the fabric. This took 15 seconds, which was faster than our goal.

3. The machine should be able to lay the strip along one axis for a range of t-shirt sizes: small (27.5in) to XXlarge (31.5 in).

   – By creating custom size settings in our code, we were able to program different lengths for our roller to travel. Our machine was able to lay out fabric to any length under 37 inches, which accompanies all of the t-shirt sizes that we aimed for.

7.2 Documentation

Figure 25 shows the final image of the fabric dispenser. There are 3D printed components that hold the fabric as well as support the carriage as it moves side to side on the gantry plate. There are also 3D printed components that support the fabric as it moves down onto the table surface.

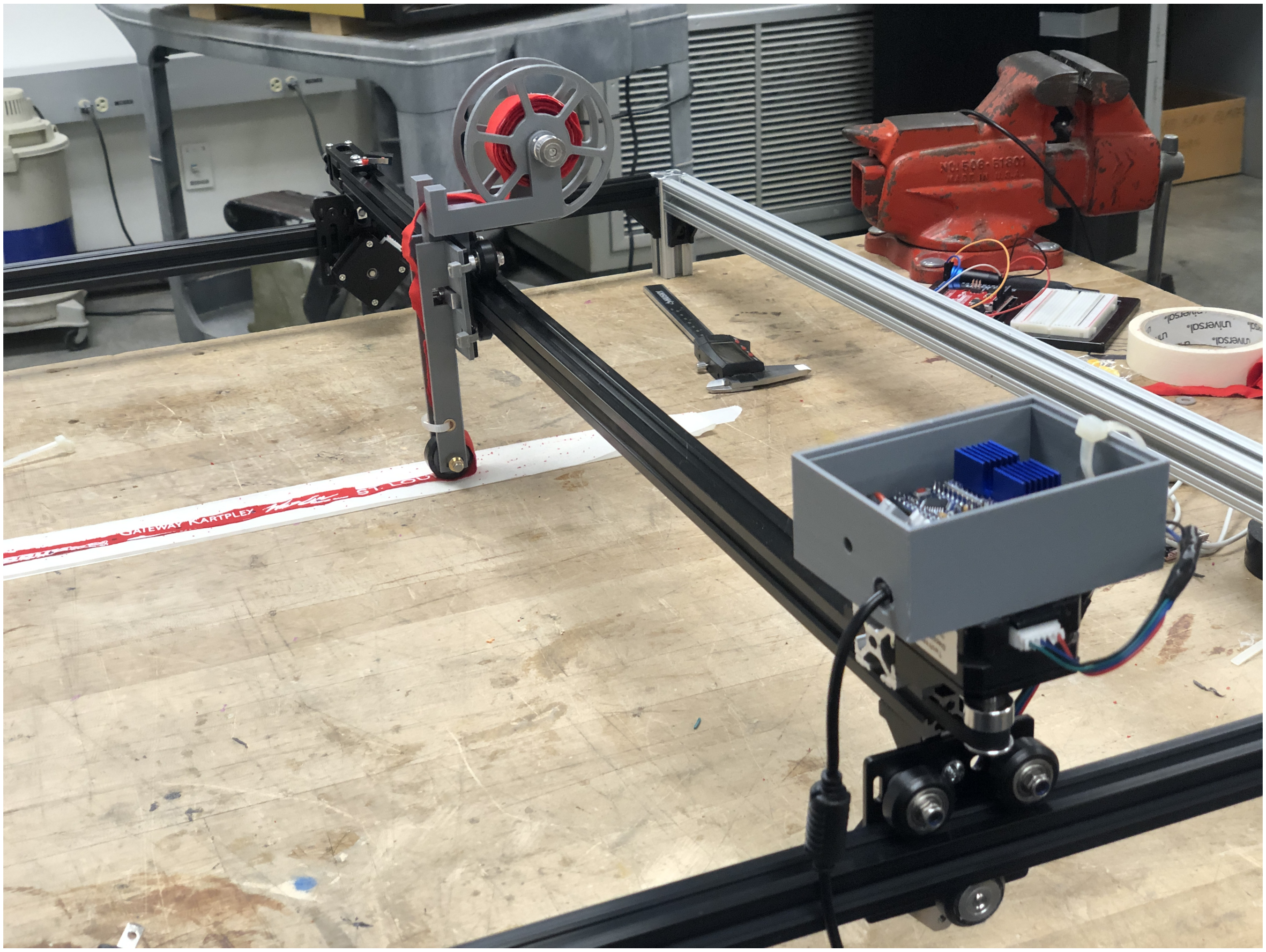


Figure 25: Final Iteration of Fabric Dispenser

The following is the final image of the electronics in the fabric dispenser.

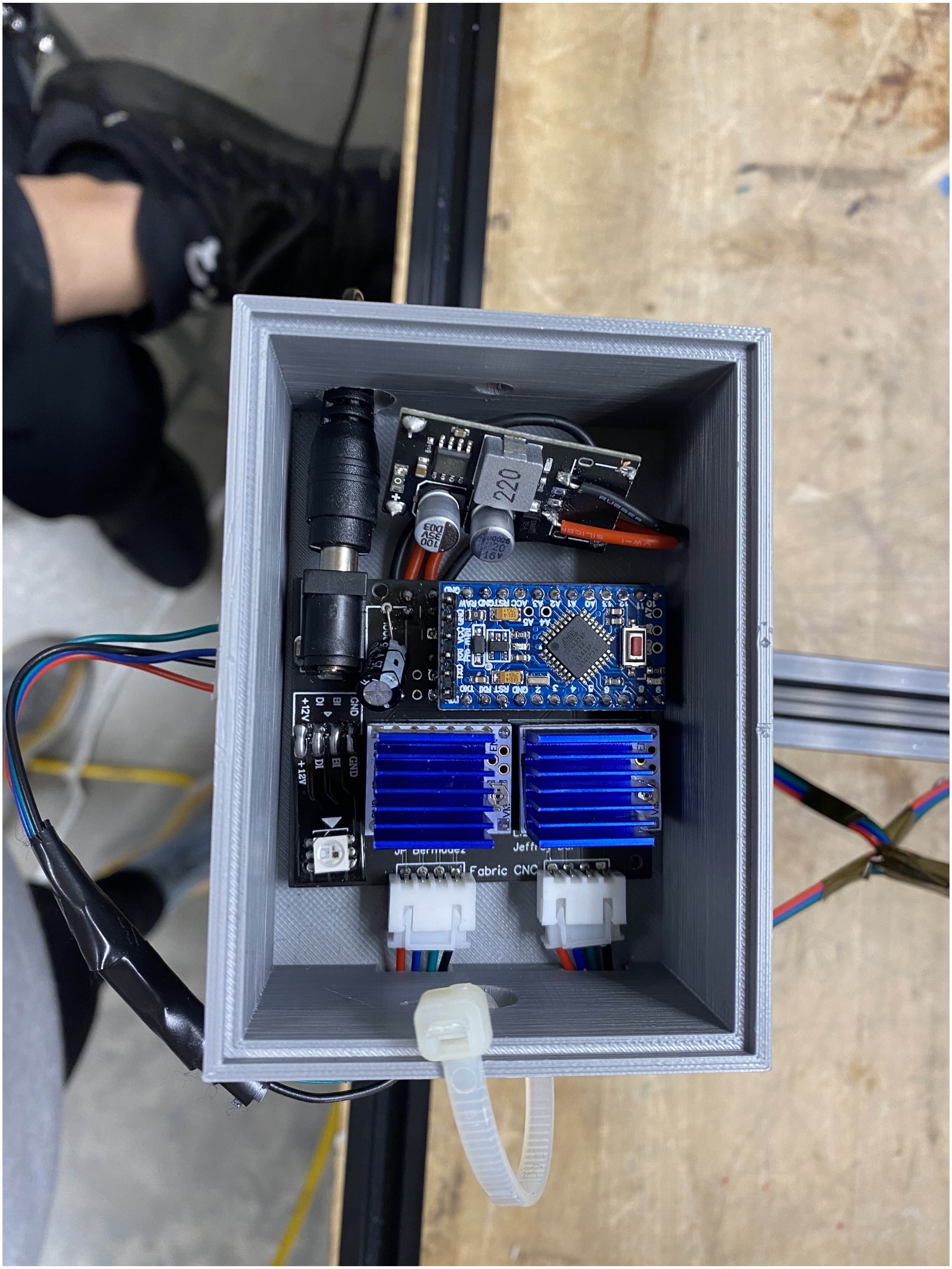


Figure 26: Electrical Components in the Fabric Dispenser