ME 491 Conceptual Design Report

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Team Plover

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Overview Statement

The conceptual approach was broken down into four actions: locate, acquire, translate, and drop the figurine. The provided inkjet printer's carriage was repurposed into a rotating tower with a cantilevered gripping mechanism attached to the print head. Three stepper motors performed the four actions: one moved the cantilevered arm up and down the carriage while a second rotated the arm into position from the starting position to the tower and finally to the stretcher; a third drove a spool of fishing line which actuated the clamp, gripping and releasing the figurine.

The printer was used as the sole source of structural components. This resulted in a relatively heavy but cheap design - a measured tradeoff in competition points. It was also decided that speed would be sacrificed for the sake of accuracy; the automated controls moved slowly and with sufficient delays, avoiding uncontrolled vibrations. There was an inherent risk in the automation strategy; if the gripper is improperly placed it could easily tip the figurine. The contingency plan was to implement an override to drive the stepper motors manually.

Conceptual Design

The print carriage belt-drive mechanism (Figure 2) was left intact and used to drive a cantilevered arm up and down. The paper-feed motor and gear train were also left intact and used to rotate the print carriage, allowing the cantilevered arm to pivot (Figure 3) between its starting position, the tower, and the stretcher. A third stepper motor was purchased and installed on the print carriage and used to wind fishing line onto a spool. Tension on the fishing line was used to plastically deform a primitive gripper constructed from printer case parts (Figures 4 & 5). Felt pads from the printhead wiper were used to cushion the grip. An Arduino Uno (Figure 6) was used to control the three stepper motors using a third TB6612 breakout board. Power to the Arduino and motors was supplied by a 12 volt AC adapter. The structure (Figure 7) was comprised entirely of repurposed printer parts - namely the internal sheet metal frame and injection molded case parts. Care was taken to leave the key printer subsystems intact while removing unnecessary parts to save weight.

The primary challenge of pinning down an acquiring mechanism was to have an automated and reliable mechanism that would be lightweight enough to be cantilevered at the end of the arm made from material in our possession. A Pugh table (Table 1) for the acquiring mechanism is included in the Appendix. Most of the ideas were relatively light weight, which is reflected by the scoring criteria of the Pugh table (evident by the weight of 2 points). Emphasis was placed on accessibility and accuracy due to a heavy scoring weight in the competition criteria. We initially chose to make a solenoid rather than use the idea of a fishing line and other less notable ideas, again due to the scoring criteria (Table 1). We thought that using a fishing line as a noose would be more difficult to acquire the figurine than using a solenoid to clamp it down. In the Pugh table (Table 1) this translated to docked points from accuracy for the fishing line. Although this is true, the decision was close (1 point difference) because we docked the solenoid for having plausible hiccups due to our lack of understanding in magnetic tools. Later on in the project we chose to scrap the solenoid idea because it was not able to create enough force to clamp down onto the figurine. Since we had discussed the accessibility of the fishing line noose in previous stages of our design process, we chose to re-engage in talks to implement fishing line in our acquiring mechanism. This idea evolved into the gripping mechanism that is implemented on the machine now (Figures 4 & 5).

The primary challenge we faced in designing a transportation mechanism was to have an accessible, secure, lightweight and automated system. The swiveling tower was our chosen design after our internal research because it was superior in most of our desired criteria (Table 2). Accessibility and cost were most vital because of the competition requirements (weighing in at 15 points) and the time constraint (less than 2 months). The swiveling tower had beaten out an idea of a slide by 4 points (Table 2) because it was more creative and we thought we would get more points in the craftsmanship and innovation part of the competition. We initially thought that the inkjet printer was competitive in terms of weight but it was determined late in the construction of the system that the design was too heavy. This is described in more detail in the following section.

To obtain a maximum amount of points for automation we had to design for the use of no more than two button presses without any further manual input. Our original design concept was an RC controller instead of full automation due to accuracy requirements in the design competition. However, this would have increased the budget necessary to do the project, which would have affected our cost effectiveness negatively. When the structure was designed, we found that automation using an Arduino was a feasible concept and it also met our goal for a cheap design. The challenge was to create a code that could do precise rotations and create up-down motions for the cantilevered arm. The strength of our automation design was due to the precision accuracy of the stepper. A simple test was done to prove the accuracy of the stepper. When the running speed of a stepper is constant, the only variable is the step of a stepper. The test was run with the tower, stretcher, and our device in fixed positions. From data collected on the distance from the device to the target, the dimensions of the gear we used on the device, and the performances of steppers, the approximate values of the steps were computed. After several trials, an average step of the steppers was calculated. With this information, accurate rotation can be outputted with code specific to the number of steps. The data of trials can be found in Table 3 of the Appendix. Another advantage we experienced in using an Arduino is that coding the three stepper motors was relatively easy.

Unrealized Features

The following list itemizes features of the design that were either scrapped or unfinished at the time of the competition.

1. The original plan was to make a solenoid to actuate the gripping mechanism. The design proved feasible after constructing a prototype. However, it could not provide sufficient force to grab the figurine and overcome a spring mechanism to open the jaws back up. To make this work a new solenoid could have been made with more coils to generate more force. Another solenoid would have taken about a week to construct given the amount of time needed to construct the first one.

2. Our design took roughly 50 seconds to move the figurine and return to the starting position. The motors could have been driven faster but the design was not rigid enough to support itself when operated at a faster speed. A more rigid design with additional support would have taken about two weeks to design and construct based on how long it took to make the first structure.
3. The final design weighed in at 2.6kg. This could have been made lighter by cutting off a lot of excess metal and plastic not crucial to the structure. This would have taken about a week to accomplish. A new frame could also have been constructed out of lighter materials - this would have taken about two weeks to accomplish.
4. When first testing the gripping mechanism the motor was not strong enough to close the jaws completely. This was overcome by removing plastic in order to decrease the force needed to close the jaws. However, a stronger motor would have been a better solution and would not have compromised the structural integrity of our grabber. It would have taken about a week to purchase and implement the new motor.

Team Roles and Contributions

- **Tixin Xue** - Arduino Programmer. With his programming skills, Tixin tackled the challenge of programming the Arduino to control the three stepper motors. He was also placed in charge of automating the entire process, ensuring maximum points in that category.
- **Thomas Hollingworth** - Gripping Mechanism Creator. Thomas originally took on the task of building the solenoid (the initial actuator for the gripping mechanism) before it was deemed too weak. He then completely re-designed the gripping mechanism, ensuring that the figurine would be secured between the felt pads as it was transported across the playing field.
- **Calvin Young** - Team Leader / Assembly Support. Calvin took lead in the reports, and construction of the tower. He was tasked to fasten the cantilevered arm to the ink cartridge, the motor and gripper to the arm and the tower to the base, and to ensure stability in the structure.
- **Ace Leben** - Tower Design and Manufacturing. After conceptualizing the tower design, Ace was tasked to cut and hammer the printer parts to form and fit. He had a role in helping Calvin fasten the motor and gripper to the arm, and in stabilizing the frame. Along with the others, Ace also contributed to the conceptual design report; he helped write the conceptual design, and functional decomposition sections.
- **Matthew Stone** - Concept Architect / Problem Solver. After honing in on the approach to the design problem, Matthew was critical in brainstorming the design architecture and helped identify and overcome key flaws. His oversight of each subassembly ensured proper integration which ensured a successful run on competition day.

Appendix

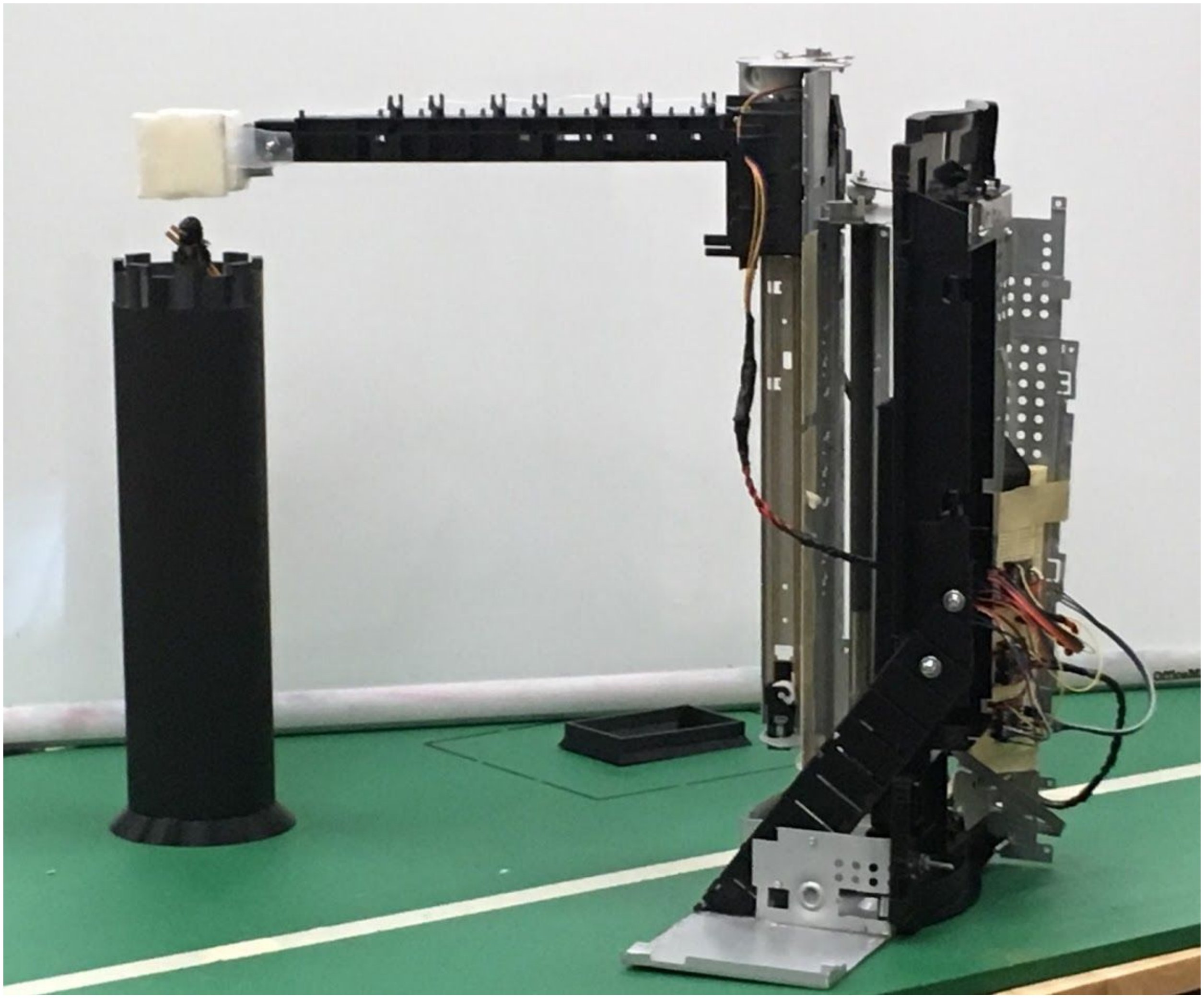

Figure 1: Mechanism on playing field.

Figure 2: Carriage driver mechanism. This was left in-tact from the printer, and drives the cantilevered gripper up and down.

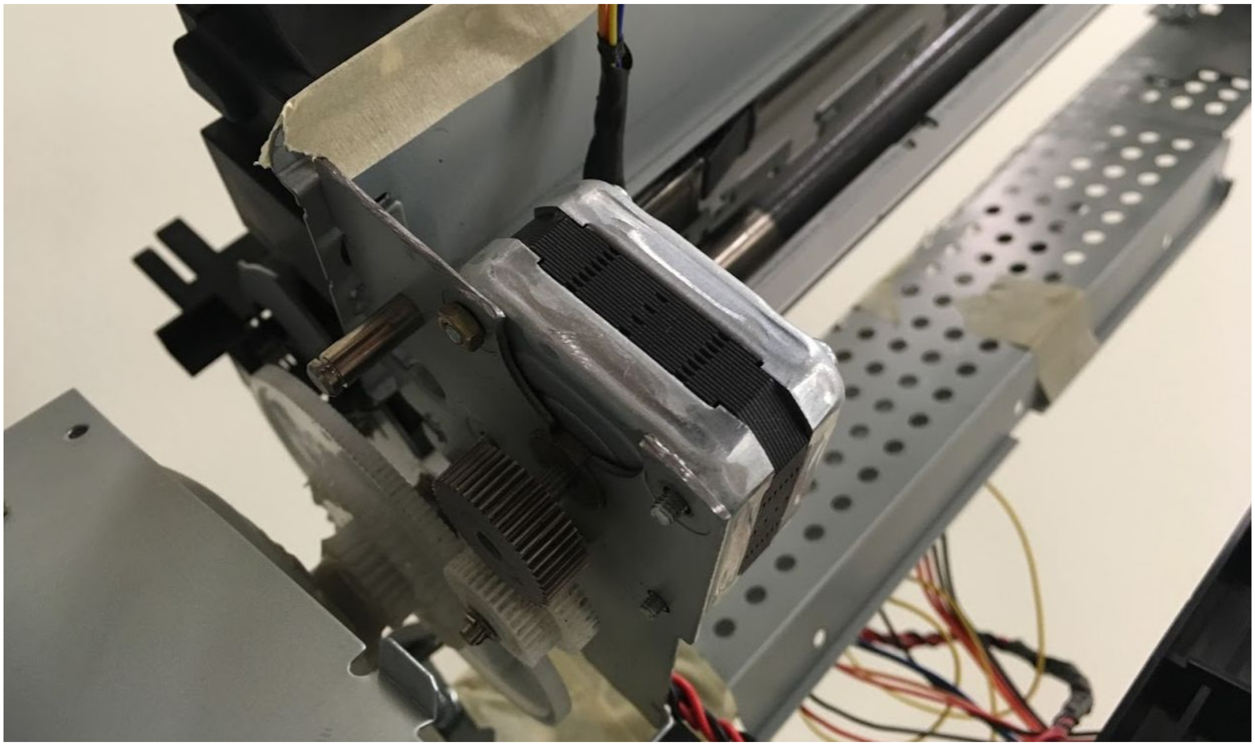

Figure 3: Arm rotation mechanism. This used the paper-feed motor and gear train to pivot the cantilevered gripper between the tower and the stretcher.

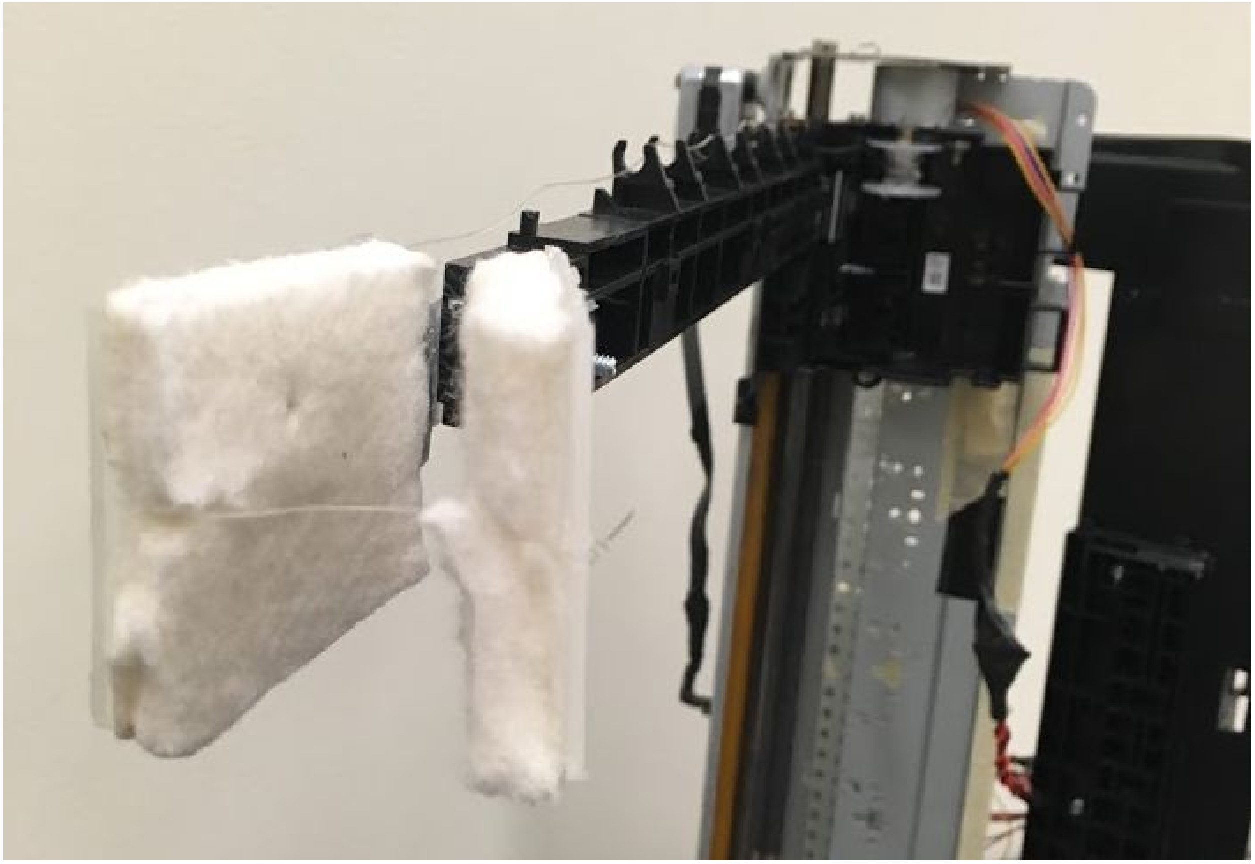

Figure 4: Gripping mechanism. The felt pads (from printhead cleaning mechanism) are clamped shut as a stepper motor winds fishing line onto a spool.

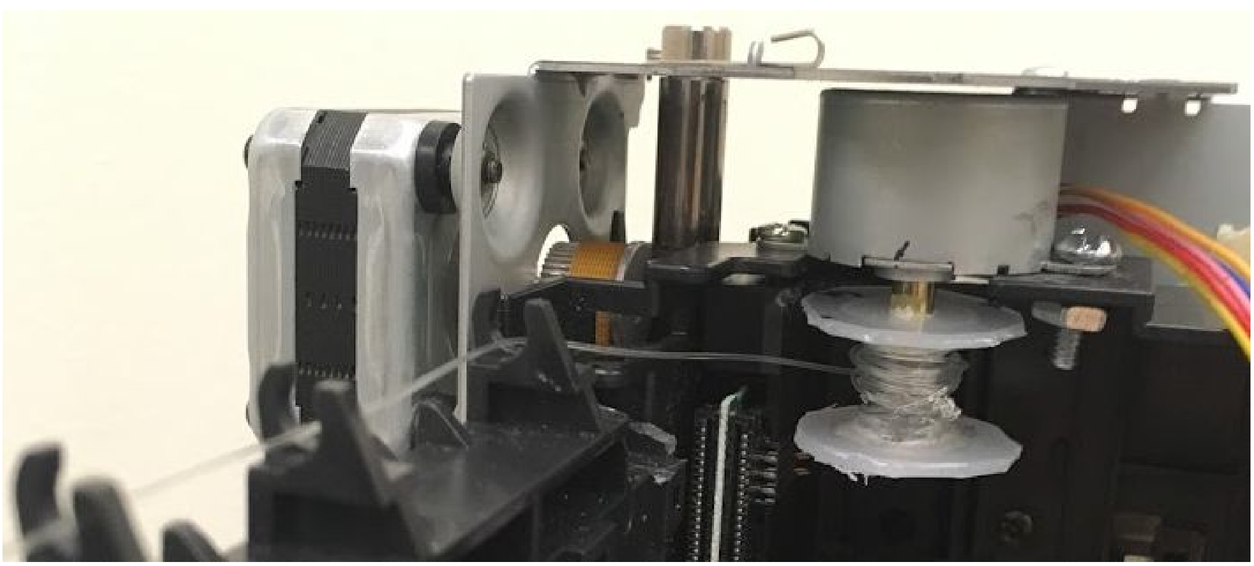

Figure 5: Close-up of the fishing line, spool, and stepper motor (right).

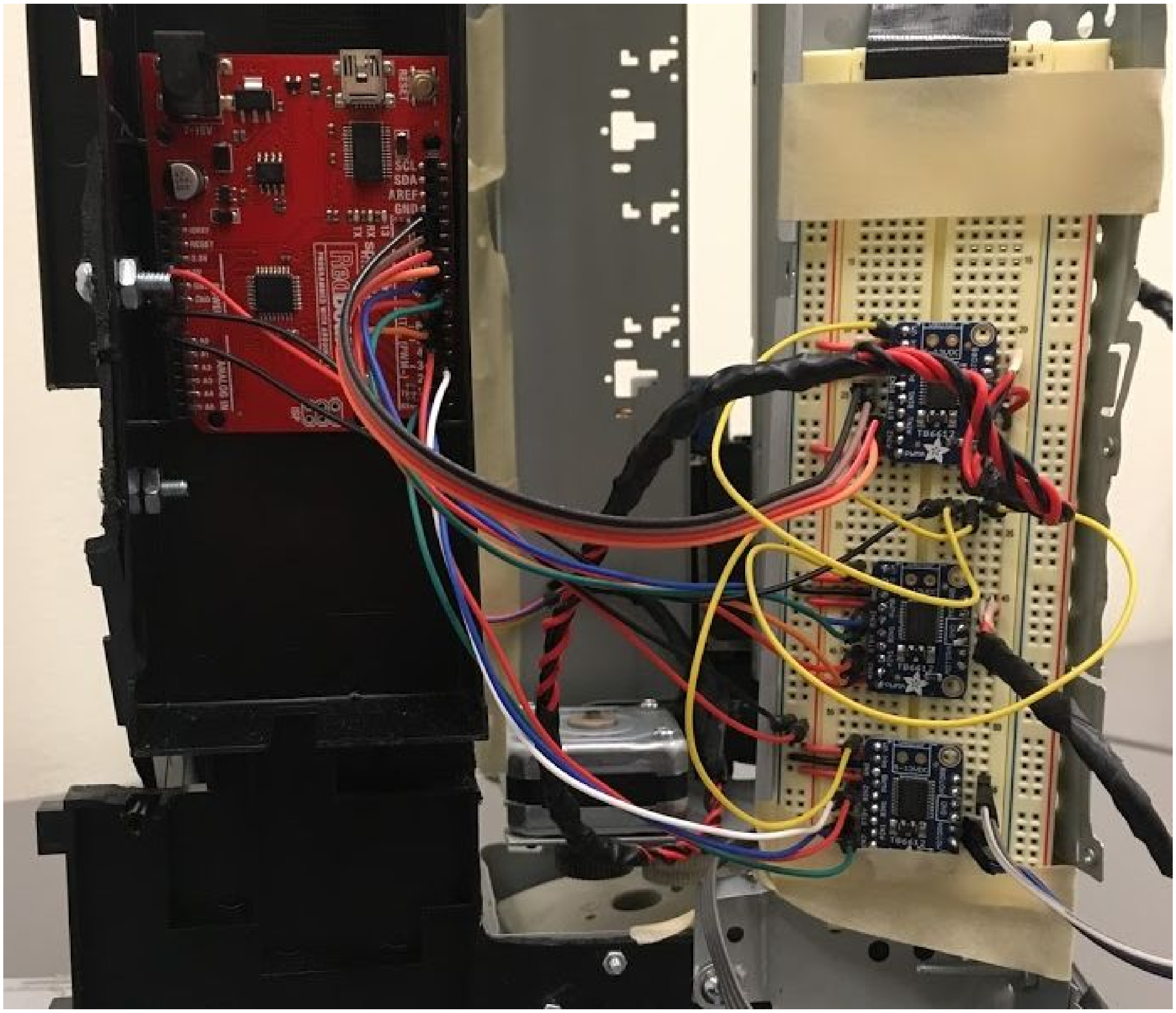

Figure 6: Arduino and motor controllers attached to the back of the structure.

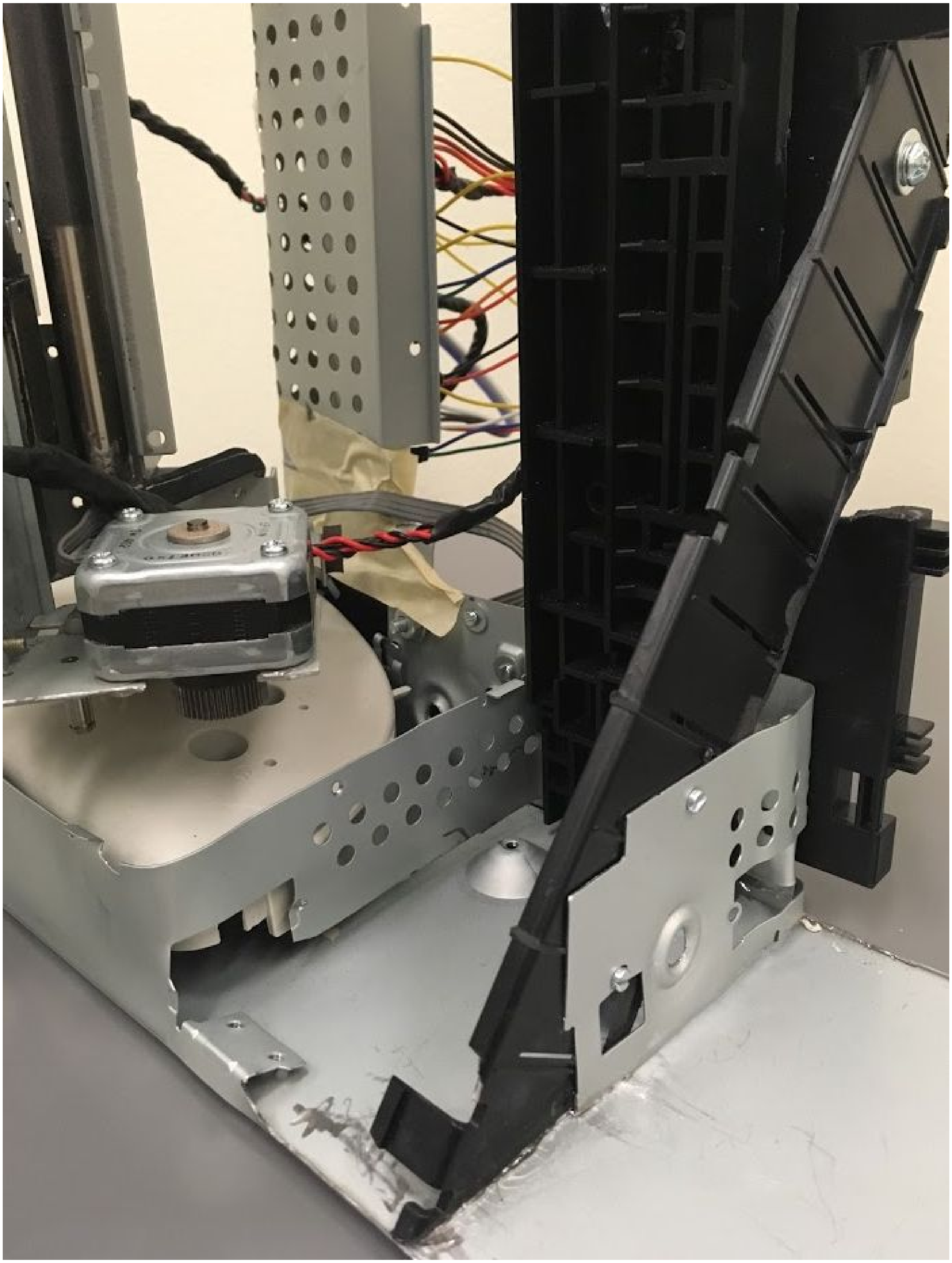

Figure 7: Detail of repurposed printer case-parts. Sheet metal was cut, bent, and fastened to support a vertical print carriage.

Arduino Code:

```
#include <Stepper.h>

Stepper stepper1(STEPS, 2,3,4,5);
Stepper stepper2(STEPS, 6,7,8,9);
Stepper stepper3(STEPS, 10,11,12,13);

int n = 0;

void setup()
{
  Serial.begin(9600);
  stepper1.setSpeed(100);
  stepper2.setSpeed(40);
  stepper3.setSpeed(100);
}

void loop()
{
  if ( n == 0){
    stepper1.step(1350);
    delay(1000);
    stepper2.step(335);
    delay(1000);
    stepper1.step(-170);
    delay(1000);
    stepper3.step(1000);
    delay(1000);
    stepper1.step(170);
    delay(1000);
    stepper2.step(-150);
    delay(1000);
    stepper1.step(-1340);
    delay(1000);
    stepper3.step(-1000);
    delay(500);
    stepper2.step(-190);

    n = n+1;
  }
```

Functional Decomposition

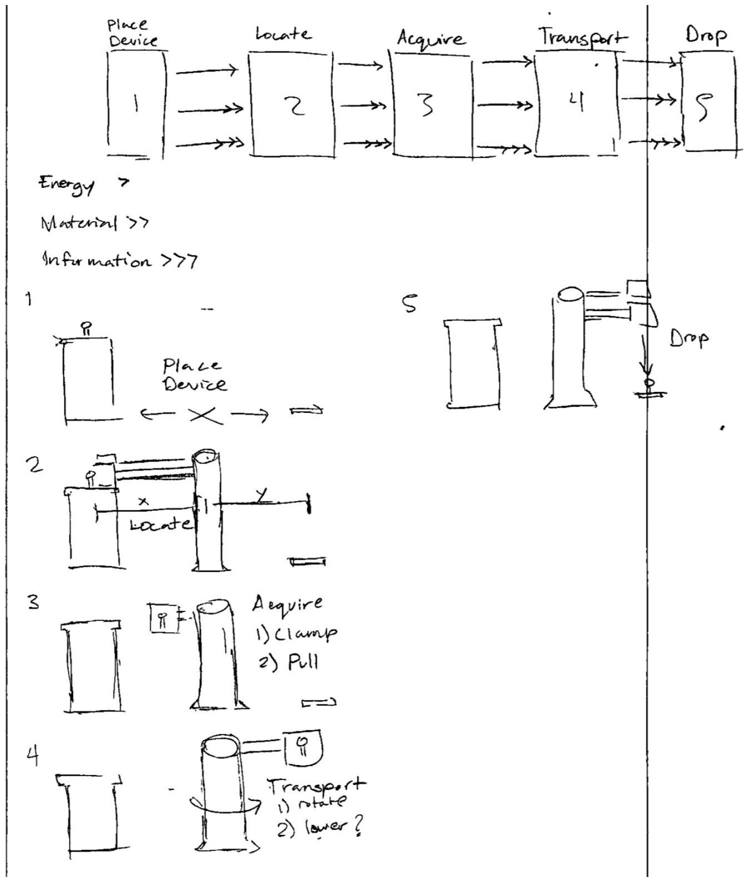

Figure 8: Functional decomposition draft

- **Placing device**

This is the process in which we position the tool in reference to the tower. The competition rules affected the design strategy of this function because the starting line rule was instituted. We adjusted our swivel tower accordingly to be able to rotate the arm behind the line. This plan worked out well due to the fact that the cantilevered arm and gripping mechanism combination reached the tower containing the figurine and the stretcher without any drastic changes.

- **Locating the Figurine**

This is the process in which the tool finds the figurine, and recalibrates itself with that reference. Although this was in consideration in our first outline, the competition rules did not emphasize that the device would need self-operated locating features because of flexible pre-run rules. More specifically, the team was able to orient the swing of the arm in reference to the figurine without rule restrictions before both of the competition runs. This took out the need to design for a self-operated locating feature into our device.

- **Acquiring Mechanism**

The process of getting the figurine off of the tower. It would need to be in a temporary location until it is dropped into the stretcher. Based on competition rules, the figurine cannot be separated from itself and its parts. See Table 4 for data collected while calibrating the stepper motor input values used to provide a the grip force necessary to secure the figurine. The Pugh table below reflects our design strategy for the acquiring mechanism. A large focus was on accessibility, accuracy and risk.

Table 1: Pugh for Acquiring Ideas

Acquiring mechanism						
	Weight	Solenoid	Hook	Fishing line noose	Forklift hook	Basket hoop
Accessability	5	+	-	+	-	-
Cost	2	+	+	+	+	+
Weight	1	+	+	+	+	+
Creativity	2	+	-	+	+	-
Accuracy	5	+	-	-	-	-
Risk	4	-	+	+	-	-
Totals	20	10	-6	9	-9	-13

This Pugh table accessed acquiring concepts arbitrarily by adding or subtracting points based on weighted categories. The positive or negative sign serves as a multiplier. The accessibility category is in reference to actual material the group was in possession of, positive points were assigned to ideas with material available for us to build from and negative points were assigned to ideas with no readily available building material. Cost and weight had similar criteria. If we thought the idea benefited in cost or weight effectiveness it was assigned positive points; if we thought the idea cost or weighed too much it was assigned negative points. Ideas with a lot of creativity were assigned positive points; ideas that lacked creativity were assigned negative points. The accuracy category was based on a simple criteria: if we thought that the idea could acquire a large array of different figurine position with as little manual input as possible it was assigned positive points but if not it was assigned negative points. The risk category was used to figure out which ideas had the least amount of plausible hiccups. Those with a few plausible hiccups(again, this is arbitrary) were given a positive multiplier; those with lots of plausible hiccups were given a negative multiplier.

Figure 9: Acquiring mechanism concept drawings

- **Transporting Mechanism**

The process of moving the figurine from the tower to the stretcher. These ideas take advantage of rotational and gravitational movement in respect of the tower. See Table 3 for data collected while calibrating the stepper motor input values to be used during autonomous operation. A large focus was on accessibility, cost and risk as evident in the Pugh table below.

Table 2: Pugh for Transportation Ideas

Transporting mechanism					
	Weight	Swivel tower	Ski lift	Gravity rail	Slide
Accessability	5	+	-	-	+

Cost	5	+	-	-	+
Weight	3	+	+	+	+
Creativity	2	+	+	+	-
Accuracy	3	+	+	+	+
Risk	4	+	-	-	+
Totals	22	22	-6	-6	18

Another Pugh table was created to access transportation concepts arbitrarily by adding or subtracting points based on weighted categories.

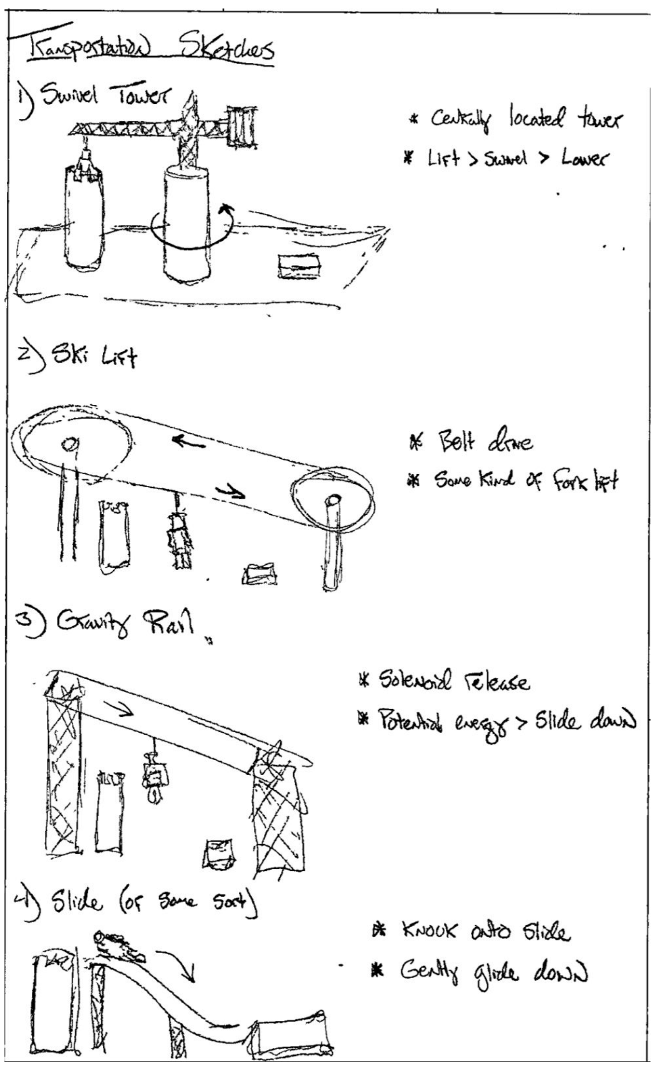

Figure 10: Transportation mechanism concept drawings

- **Releasing the Figurine**

The process in which the figurine is disengaged or out of contact of the acquiring mechanism, and placed in anyway possible onto the stretcher. The accuracy of dropping the figurine was seen as an extra constraint that would increase the cost and build time on the project. We knew the extra points were available if the dropping mechanism was efficient enough to drop the figurine standing up, but we weighed our decision and chose not to. As it is relevant in all our design strategies, time was a large factor because we had less than 2 months to build a working functional device.

Table 3: Automation Parameter Test Values

Trial	Rotation 1: Starting Position to Tower	Rotation 1 Results	Rotation 2: Tower to Stretcher	Rotation 2 Results	Figurine Drop Results	Elevation 1: Starting Position to Tower	Elevation 1 Results
1	300	Undershoot	140	Overshoot	Out of Stretcher	1100	Overshoot
2	300	Undershoot	170	Overshoot	Out of Stretcher	1120	Overshoot
3	310	Undershoot	170	Overshoot	Out of Stretcher	1140	Overshoot
4	310	Undershoot	170	Overshoot	Out of Stretcher	1160	Overshoot
5	310	Undershoot	170	Overshoot	Out of Stretcher	1180	Overshoot
6	315	Undershoot	170	Overshoot	Out of Stretcher	1200	Overshoot
7	315	Undershoot	170	Overshoot	Out of Stretcher	1220	Overshoot
8	320	Undershoot	170	Overshoot	Out of Stretcher	1240	Overshoot
9	320	Undershoot	170	Overshoot	Out of Stretcher	1260	Overshoot
10	325	Undershoot	160	Overshoot	Out of Stretcher	1280	Overshoot
11	325	Undershoot	160	Overshoot	Out of Stretcher	1300	Overshoot
12	330	Undershoot	160	Overshoot	Out of Stretcher	1320	Undershoot
13	330	Undershoot	155	Undershoot	Out of Stretcher	1340	Undershoot
14	360	Overshoot	155	Overshoot	Out of Stretcher	1360	Undershoot
15	350	Overshoot	150	Undershoot	Out of Stretcher	1350	Undershoot
16	345	Overshoot	150	Undershoot	Out of Stretcher	1350	Undershoot
17	340	Overshoot	150	Good	Touching Stretcher	1350	Good
18	330	Good	150	Good	Touching Stretcher	1350	Good
19	335	Good	150	Good	Good	1350	Good

20	335	Good	150	Good	Good	1350	Good

Table 4: Stepper Motor Test Values

Trial	Step	Grip Strength
1	500	Loose
2	600	Loose
3	700	Loose
4	850	Loose
5	1000	Tight
6	1100	Tight
7	1050	Tight
8	1000	Tight
9	1000	Good
10	1000	Good