Technology Engineering
MICHIGAN STATE UNIVERSITY

The Process of Designing and Troubleshooting a Robotic Arm

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Abstract

The project involved the design, fabrication, and assembly of a robotic arm that can be controlled by a user. The purpose of the project was to build a successful, working robotic arm, while learning necessary engineering skills such as CAD, 3D printing, soldering, and troubleshooting. The robotic arm is built completely of either PLA or resin 3D-printed parts. The robotic arm has four servos and four potentiometers, with an Arduino translating the resistance of the potentiometers into servo movement. This allows the robotic arm to be controlled by a user. All the electrical components are soldered and connected to a PCB housed in the base of the robotic arm. The final product was a working robotic arm with great range of motion that is capable of picking up small objects.

Project Objectives

The main objective of the project was to design and build a working robotic arm that can be controlled by the user. Throughout the project, the team hoped to learn many different engineering skills. These skills included 3D modelling and printing, soldering with electrical components, and troubleshooting and design refinement skills. There were complete projects from past students that the team was able to use as references for multiple parts of the project.

Design and Fabrication Process

When designing the Base, Base Cover, Central Axis, and Axis Cover, multiple tools were used. Provided part drawings and calibers were used to find correct dimensions of the parts. The parts were then designed in Siemens NX. Multiple iterations of parts were created during the design process. The largest improvements were the mounting holes and connecting points between the Base and Base Cover to ensure a proper fit. Figures 1-4 show the before and after of these iterations. Also, the Central Axis was put through many iterations due to printing failures, seen in Figure 5. To find the location of the printing failure, the printing process was watched and stopped once the layer shifting occurred. The Central Axis needed a complete redesign before it would successfully print. Once the Central Axis was completed, it was copied and edited to make the Axis Cover, ensuring a perfect fit between the two parts. The team was provided with .STL files for the Arm, Forearm, Claw Base, Claw Bar, Gear 1, Gear 2, Rubber Band Mount, Knob, Knob Insert, Claw 1, and Claw 2. All the parts that were printed with PLA were sliced with Prusa Slicer. In Prusa Slicer, the team had to ensure the part was oriented to have a flat side against the build plate, otherwise the print would fail. Some parts required organic support to be generated. All the PLA parts were printed on Prusa 3D printers, and can be seen in PrusaSlicer in Figure 6. Some parts, determined by the team for quality and aesthetic purposes, were printed with resin. Resin prints had better quality gears and could be printed in clear or gray resin. These parts were sliced on Preform. In Preform, the team was able to utilize auto orienting and auto generating support features to ensure the prints were good quality. The resin prints were printed on Formlabs resin printers. The resin prints were post-processed in Formlabs washing and curing stations. For all parts, quality was checked and if the print had supporting materials, they were removed with needle nose pliers and diagonal cutting pliers. A Base Cover part that was printed with clear resin can be seen in Figure 7. The team also experimented with injection molding the Axis Cover. The molds were designed in Fusion and then sliced on Formlabs and printed with resin. The molds were then washed and cured and the plastic was injected. During the process, the mold cracked due to some warping that occurred during the curing process. It was also very difficult to remove the part from the mold, so to avoid damaging both the part and the mold any further, the part was kept in the mold. The part and the mold can be seen in Figure 8.

Assembly and Integration

After all the parts were printed and gathered, assembly was started. All parts were secured and installed using screws. First, the circuit board and the first servo were installed into the Base. The Arduino was placed into the female heads of the circuit board. Next, assembly moves onto the Central Axis. A servo bracket had to be cut to fit into the bottom of the Central Axis and was screwed in, and another servo and servo bracket were installed into the top of the Central Axis. The servo bracket was then connected to the Forearm with screws. Assembly then moved onto the claw section. A servo and servo bracket were installed into the Claw Base. Gear 1 was installed onto the servo bracket, and Gear 2 was installed next to Gear 1 on the Claw Base. It was important to make sure both Gear parts moved together to the front and back positions and had full range of motion. If they didn't have full range of motion, the gear teeth weren't lined up correctly and they had to be adjusted. Next, the Claw Bars were installed onto the Claw Base, then Claw 1 and Claw 2 were attached to their respective Gear and Claw Bar. Once the claw section was completed, it was tested again to make sure the claw could fully open and close. Next, the Claw base was attached to the Arm without a servo, so it stays in a fixed position. The servo cable attached to the Claw Base was routed through the Arm, and then the final servo and servo bracket were installed onto the Arm. The servo bracket was then connected to the open side of the Forearm. Next, all the servo cables were routed through the Arm and Central Axis. Then, the Axis Cover was installed onto the Central Axis, and the Rubber Band Mount was installed onto the Forearm, and the rubber band was put in place. Next, the servo cables had to be plugged into their respective male headers on the circuit board. To test which servo cable was connected to each servo, power was given to the power adapter, and the servos were manually checked by plugging in the Cover's 6 pin ribbon cable to the circuit board and adjusting the potentiometers to see which servo moved. Once the Cover and all the servos were plugged into the circuit board, the Cover was installed onto the Base. Finally, the Central Axis was installed onto the servo bracket on the Base. Jake's robotic arm can be seen in Figure 9, Tomas' robotic arm can be seen in Figure 10.

During installation, it was important to check the position of the servos and compare it to the range of motion each part required before installing the servo brackets onto the servos. If the position wasn't checked, then the part wouldn't be able to move in its intended way.

The parts had very good fit with another. It was important that the stable parts, such as the Base and Cover, had a very low tolerance and fit very closely. It was also important that the moving parts, such as the Arm and Forearm, and the parts in the claw section were fastened tight enough to stay together but had enough space that they could still move. If the parts were fastened too tightly, they overpower the servo and don't move. If they are too loose, they can fall apart from each other.

The Knobs and Knob Inserts were left out of installation because the team thought the bare potentiometer was both easier to use and was more aesthetically pleasing. Jake left the rubber band out of his robotic arm. The rubber bands on past projects had all been snapped, making it clear that it wouldn't last long. Also, the past projects could still function without the rubber band, so it was unnecessary.

Electronics and Wiring

There were 2 main steps to assembling the electronics. The first step was to solder the necessary parts to the circuit board. The DC Jack Connector is necessary to provide power to the circuit. A capacitor was added to store some power and then release it to the correct servo for quick movement. The resistors are necessary to regulate the amount of power going to the parts, so they don't break. The two 15-Pin Female Headers connect the Arduino to the circuit board. The Arduino has 15 pins on both sides of it that fit into the 15-Pin Female Headers. The 6-Pin Female Header connects the ribbon cable and potentiometers to the circuit board. Finally, the three 4-Pin Male Headers connect the servos to the circuit board. Each servo has a 3-Pin Female header on it, so each 4-Pin Male header is connected to part of the servo. Additionally, there were 4-Pin Push Buttons that were added to the circuit board to allow extra functionality to be added. The second step to assembling the electronics was connecting one side of the ribbon cable to the potentiometers, and the other side of the ribbon cable to a 6-Pin Male Header. The wiring between the ribbon cable and potentiometers is shown in Figure 11. The team's completed wiring and soldering can be seen in Figure 12.

By using a past project that worked, the team could troubleshoot their own circuit. Plugging the ribbon cable and potentiometers into the circuit board of a past project determined the functionality of the potentiometer connections. Plugging the ribbon cable and potentiometers of a past project into the team's circuit board tested the functionality of the circuit board. The past projects were very useful with troubleshooting because it allowed the team to determine what part of the circuit was causing errors and either fixing or redoing the electronics in the errant part.

The team also got a chance to use PCB printing and CNC router to create a circuit board. The team used a Voltera PCB printing machine. The blank PCB was installed into the machine, and then the machine was run through its probing cycle. Then, the probe was replaced with a nozzle and printed conductive ink onto the PCB. The team noticed that the conductive ink wasn't perfectly centered on the PCB because they had to do their best to manually center it. The PCB with conductive ink is shown in Figure 13. To CNC the PCB, the team had to design the circuit board cutout in Fusion. Then, the team went through the process of using the Tormach CNC router. The CNC router cut through some of the conductive ink on the PCB because it hadn't been properly centered in the first step. The PCB was just used for practice, but the team learned how important it is to have the conductive ink centered in the future. The final PCB can be seen in Figure 14.

Calibration and Programming

The potentiometers allowed varying amounts of power to flow from the power supply to the circuit board. The varying amounts of power determined the position of the respective servo. The Arduino was used to control the position of the servo based on the power received from the potentiometers. Every 25 milliseconds, the Arduino read the values of the potentiometers and stored the values. With the new values, the Arduino moved the servos to the correct position. There was also functionality to record movement and play it back. After holding the play mode button, the Arduino would enter play mode, where it would record and store the values of the potentiometers at different time intervals. Once the pause button was pressed, the recorded movements were put together into a smooth movement. The recorded movements could then be played. The Arduino UI can be seen in Figure 15.

Testing and Troubleshooting

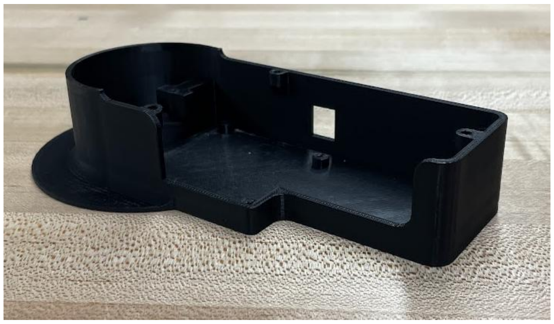
There were multiple troubleshooting tasks that went into building the robotic arm. First of all, all the cable connections had to be checked because if the ribbon cable or any servo cables were plugged in backwards, the robotic arm would not work. Also, as mentioned in the Assembly and Integration section, it was very important that the range of motion was checked when assembling the servo brackets to the servos. If the range of motion was not checked, the arm would not be able to move as intended and would get stuck. Also, friction between parts was an issue when testing the robotic arm's movement and claw performance. Friction in the claw was caused by small bumps on the different parts that were left from the supports on the resin printed parts. These parts had to have the bumps removed for smooth movement. The other place where friction played a role in movement was the tightness of the connection between parts. If the parts are too tightly connected to the servo mount, they would cause friction between themselves and the part holding the servo. This was an issue with the connection between the Cover and Central Axis, the Central Axis and Forearm, and between the Forearm and Arm. To fix the issue, the screws between the servo bracket and the part were loosened so it was tight enough to stay together, but not too tight that it restricted movement. Finally, using a power supply that has too much amperage or wattage can cause the components on the circuit board to break, removing functionality from the robotic arm. The robotic arm was functional with all movements controlled by the user. It was able to pick up items such as screws and other plastic parts. If the object was too large or so small that the claw couldn't get a grip on it, the robotic arm could not pick it up. Also, if the arm was fully extended when the power was turned off, the arm would not stay in its exact position because it didn't have the support from the rubber band.

Reflection and Evaluation

There were many challenges and accomplishments that occurred throughout the robotic arm project. Many of the challenges involved troubleshooting to find a fix. When printing errors occurred, it could be anything from the file being broken, the objects not being aligned to be flat against the print board, or an issue with supports. When prototyping to make sure the prints fit well with one another, there were lots of new iterations created until the parts fit nicely. When soldering, there could be bridging between contact points, there could be cables that came loose from the solder, and there were parts that were melted from the heat. When assembling the robotic arm, there were servos that were broken, there were servos with restricted range of motion, and there were incorrect connections between cables that all compromised the functionality of the robotic arm. There were many challenges throughout the project, but each of those challenges had an accomplishment when the team fixed it. The largest accomplishment was when all the little challenges and accomplishments were put to the test, and the arm ended up working.

The project taught the team many new skills with CAD, 3D printing, soldering, circuitry, programming, and assembling parts. With all these skills, troubleshooting, persistence, and critical thinking skills were also further developed. While not all the engineering skills may transfer to real-world careers, the core soft skills are transferable to any career. All real-world projects will have errors that must be troubleshooted, problems that take persistence to solve, and issues that must be resolved with carefully constructed solutions.

Part Appendix



Base: PLA printed Base part

Cover: PLA printed Cover part

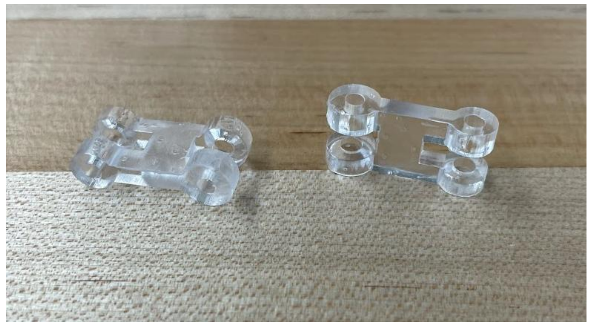
Central Axis: PLA printed Central Axis part

Axis Cover: PLA printed Axis Cover Part

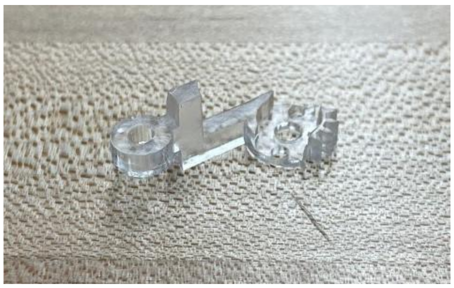
Forearm: PLA printed Forearm part

Arm: PLA printed Forearm Part

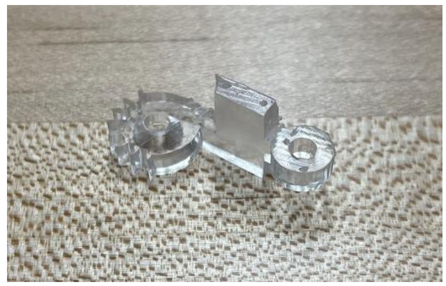
Claw Base: PLA printed Claw Base part



Claw Bar: Two resin printed Claw Bar parts



Gear 1: Resin printed Gear 1 part



Gear 2: Resin printed Gear 2 part

Rubber Band Mount: Resin printed Rubber Band Mount part

Knob: Two resin printed Knob parts

Knob Insert: Two resin printed Knob Insert parts

Claw 1: Resin printed Claw 1 part

Claw 2: Resin printed Claw 2 part

Figure Appendix

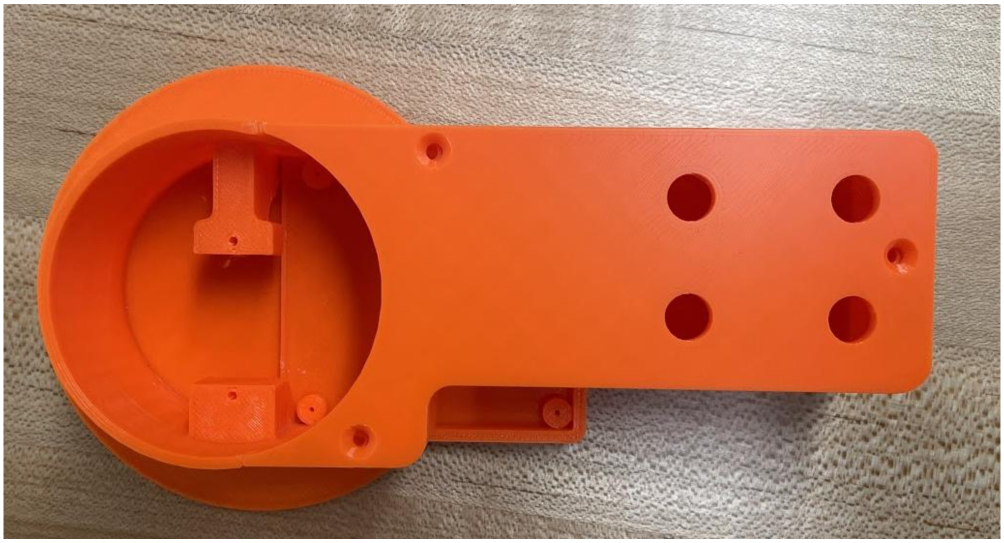


Figure 1: Unaligned mounting holes between the Base and Base Cover

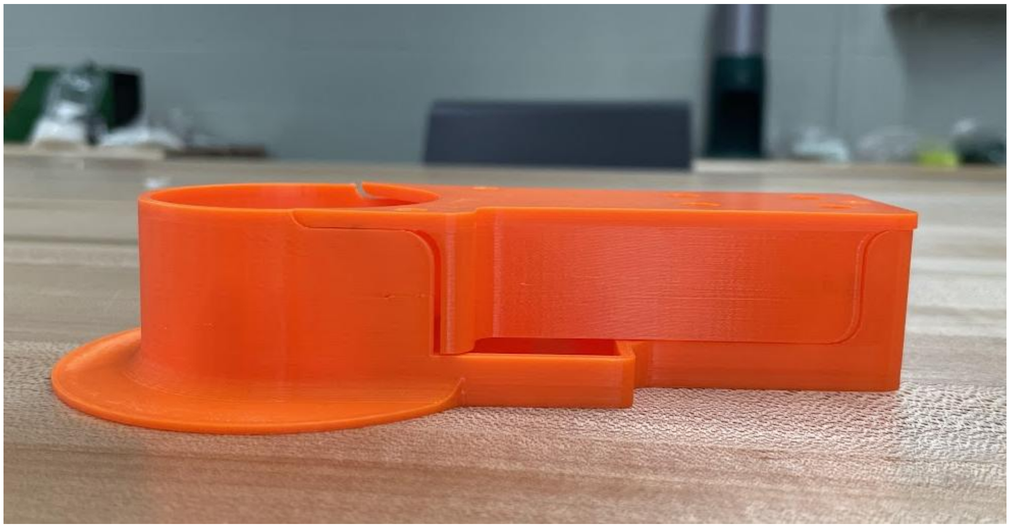


Figure 2: Improper fit between the Base and Base Cover

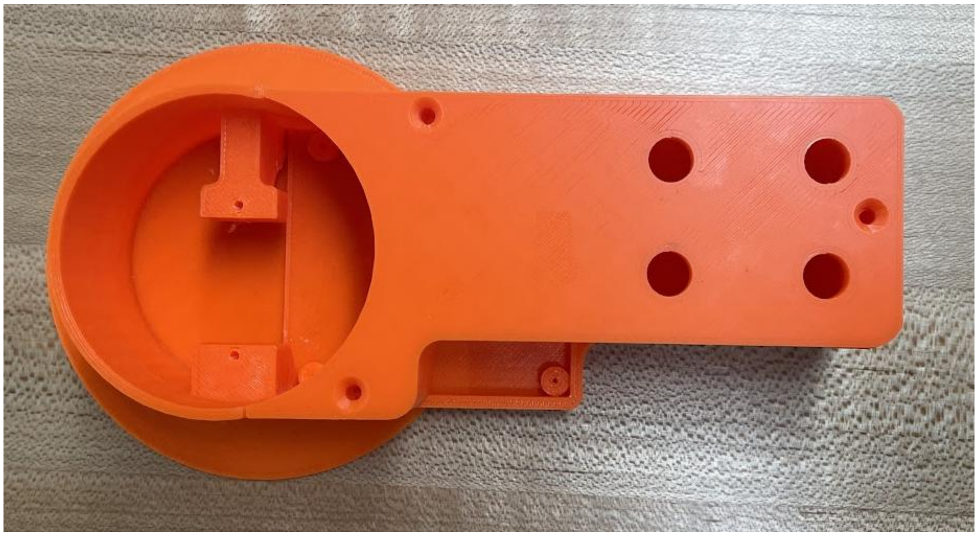


Figure 3: Aligned mounting holes between the Base and Base Cover

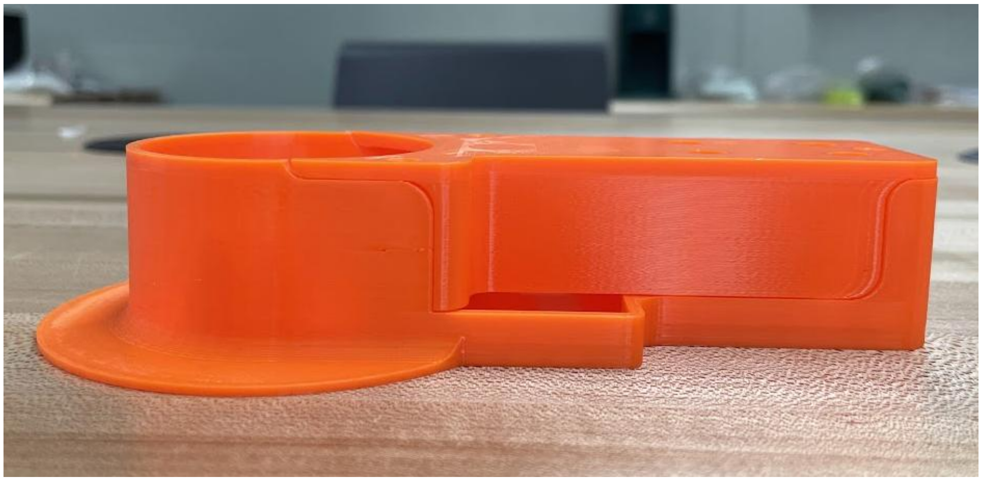


Figure 4: Proper fit between the Base and Base Cover

Figure 5: All iterations of Central Axis

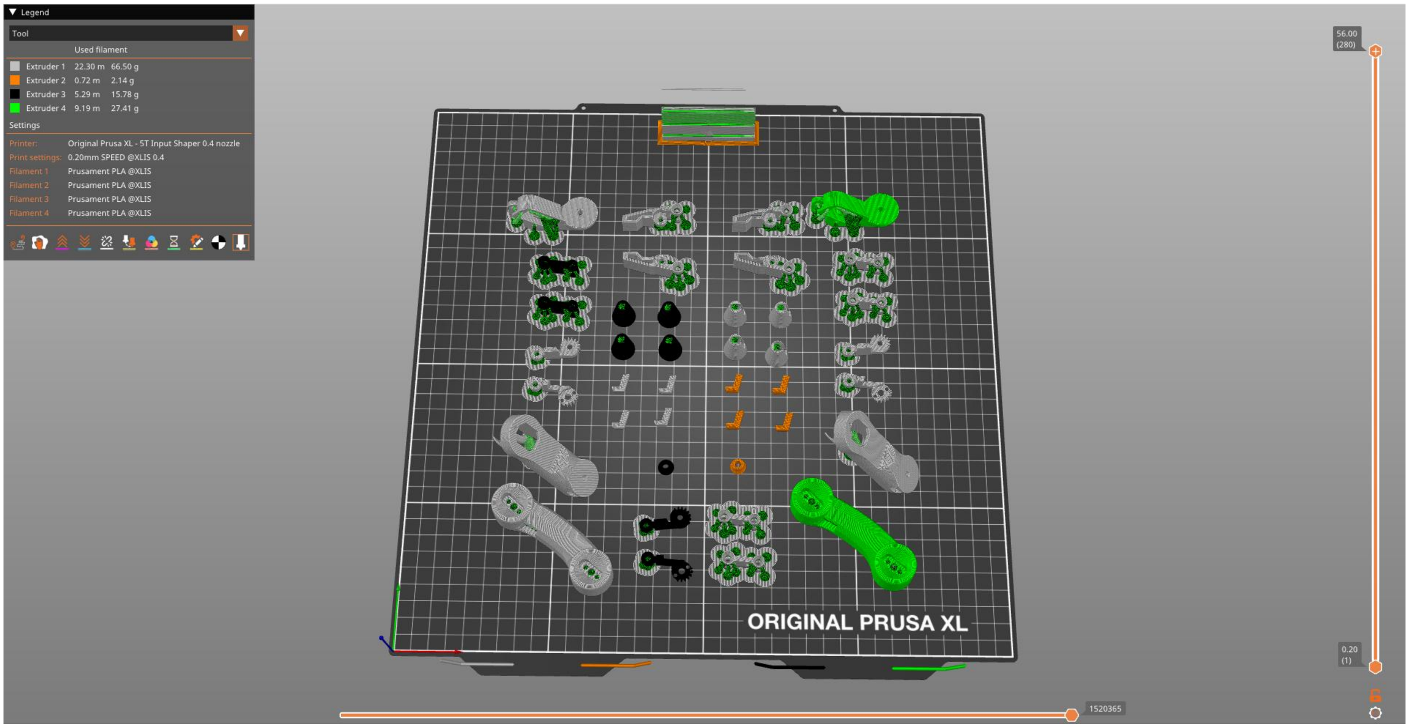


Figure 6: PLA printed parts aligned with the build plate and with organic supports in PrusaSlicer

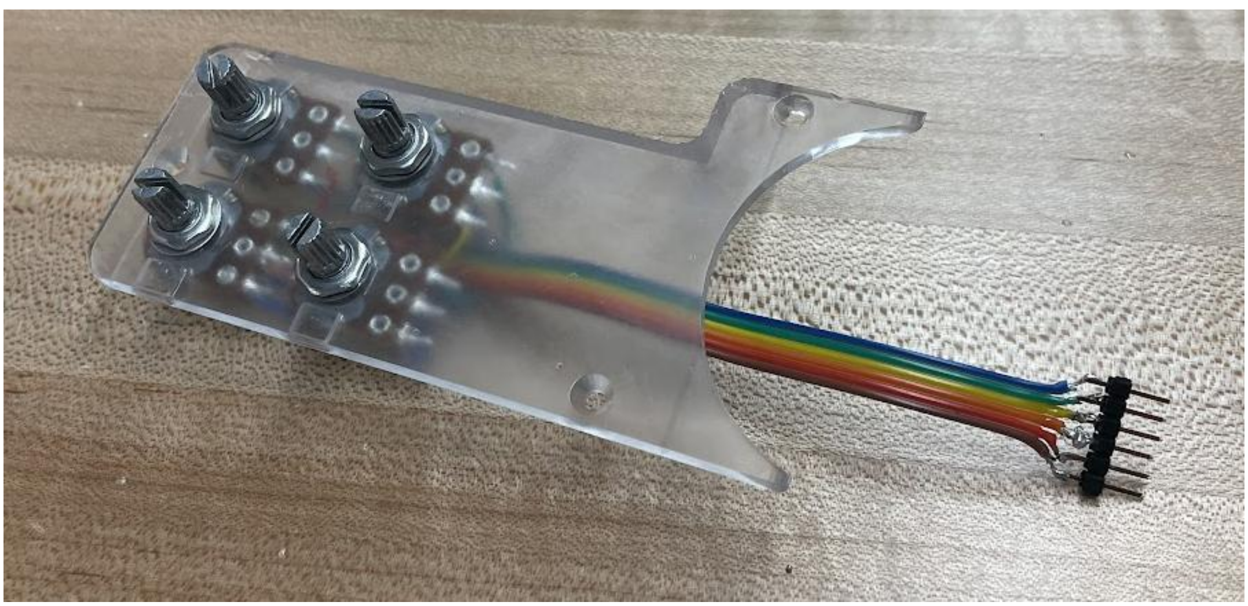


Figure 7: Base Cover printed in clear resin with the potentiometers and ribbon cable attached

Figure 8: Injection mold and part. There is a visible crack on the top right side of the mold

Figure 9: Jake's Robotic Arm

Figure 10: Tomas' Robotic Arm

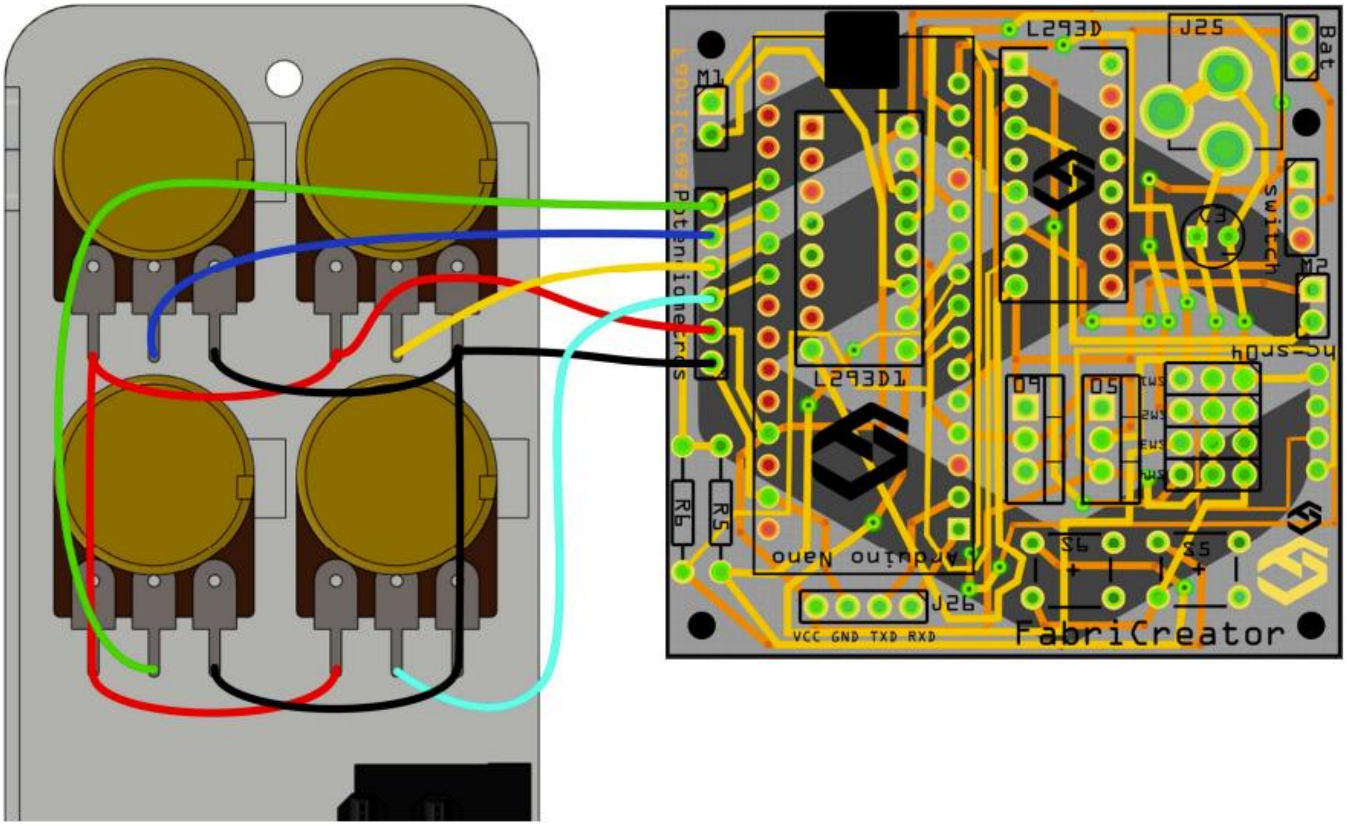


Figure 11: Wiring diagram between potentiometers and the circuit board

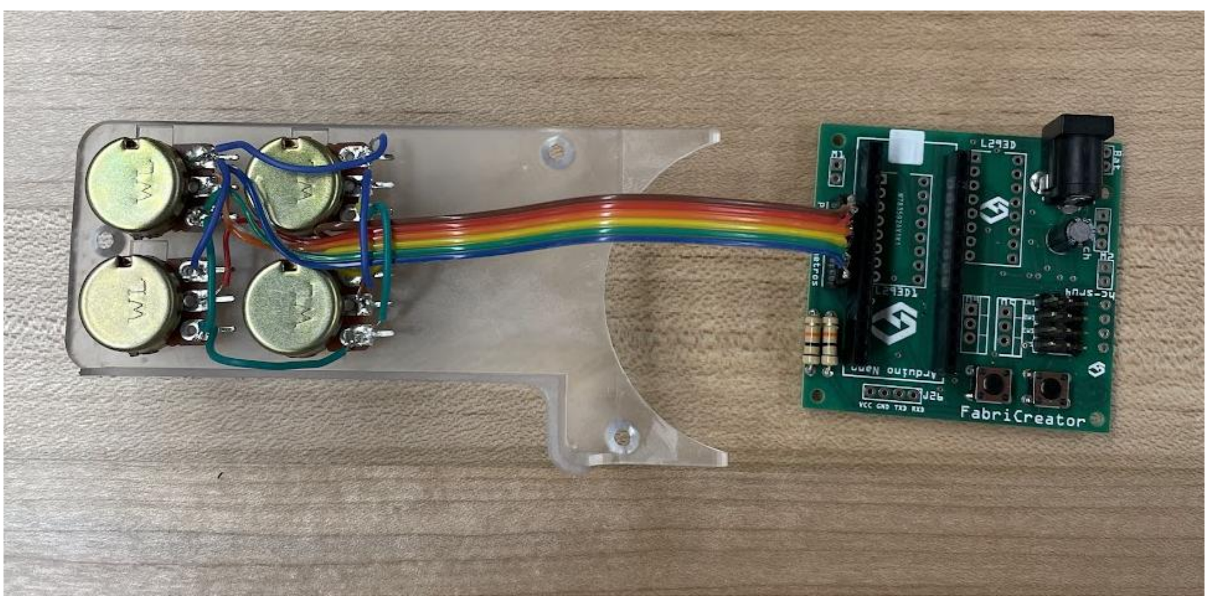


Figure 12: Team's completed wiring and soldering of potentiometers and the circuit board

Figure 13: PCB with printed conductive ink

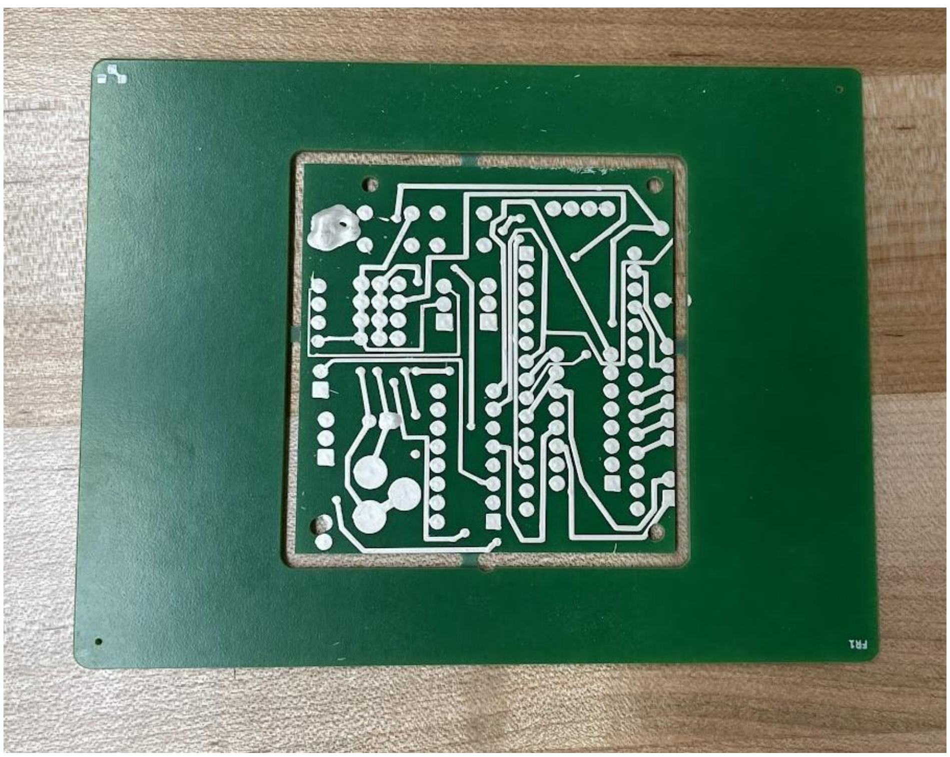


Figure 14: PCP after CNC routing, some conductive ink on the right side was cut through

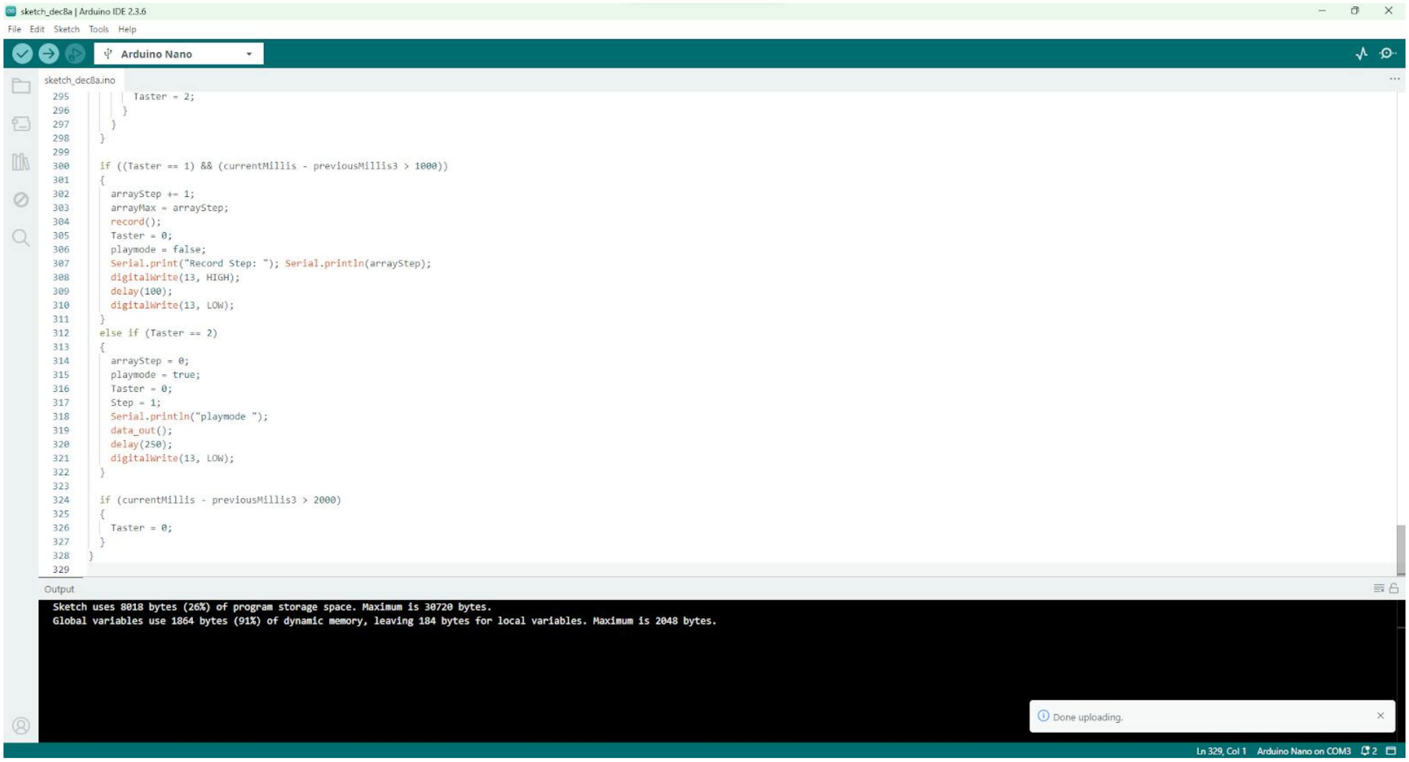


Figure 15: Arduino UI for uploading program to the Arduino