V3 Centrifuge Design Cycle Documentation Team 12

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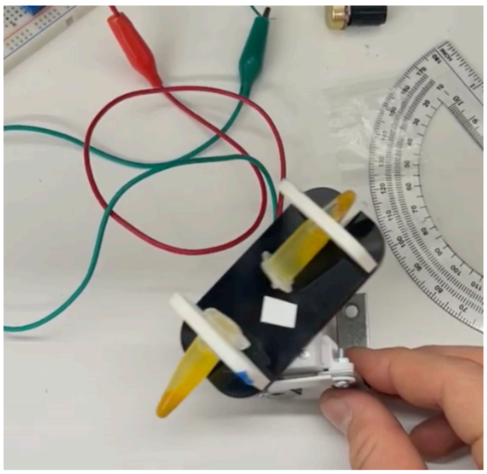
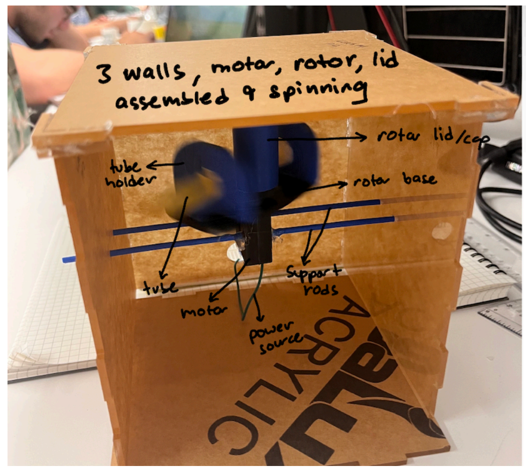
1. **Requirements**
2. **Planning**
3. **Building**
4. **Testing**
5. **Assessing**

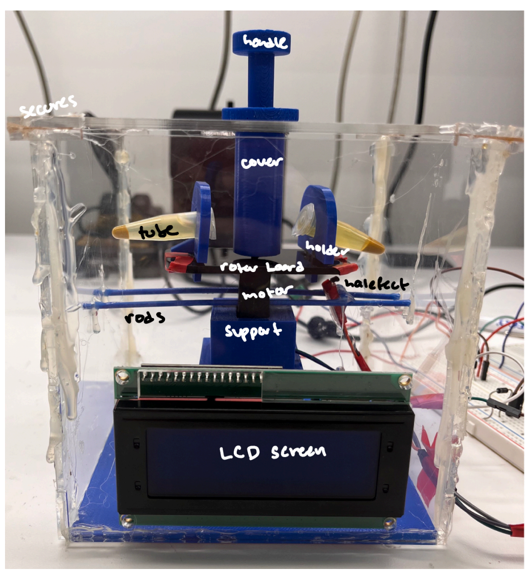
LINK TO PRESENTATION, AS A **TL;DR** SIMPLIFICATION OF V3: **LINK**



V1A



V2



V3

Section 1: Requirements (full document link)

Although the V2 requirements are extensive, there are multiple new requirements we wanted to consider, that we believe will improve the user experience of the centrifuge usage.

Requirement Category 8: New V3 Requirements

- 8.1: Standalone Operation: The centrifuge will no longer require a computer for control. Users will set RPM and run time via a paired mobile/desktop application. Real-time status updates (current RPM and time remaining) will be displayed within the app.

- 8.2 Indication of Termination (sound): Centrifuge must successfully audibly notify the user upon completion of centrifugation.

- 8.3 Indication of Termination (ping): Centrifuge must successfully send a notification to the user through the app upon completion of the centrifugation cycle.

Section 2: Planning

Similar to V2, we planned V3 in 3 main steps: the proposal, a block diagram, and then the planning of tests through our trace matrix. See below.

a. **V3 Project Proposal Final (full document LINK)**

b. **Block Diagrams (full document LINK)**

c. **Complete Trace Matrix (full document LINK)**

    - Please note for our trace matrix, all the updated tests are in **RED,** as we built on the already functioning V2 system.

d. **V2 Hazard Analysis Planning (full document LINK)**

e. **Full Artifacts Drive (LINK)**

Section 3: Building

a. Mechanical Parts Build

To quote Ross regarding the V2 skewer stability system: “I was 100% sure this was going to break. This was a terrible idea!” This prompted us to rethink how to use the critically flawed component we had already printed–what we referred to as the “fatal skewers.” In V2, these skewers were responsible for what we called the “trampoline effect,” in which the motor base would bounce at high speeds. This caused major errors in the interrupt protocol because the gap between the photodiode-LED sensor and the rotor became too large for the system to register each spin as an interrupt. As a result, the centrifuge could not accurately detect its spinning speed. For V3, we decided to repurpose the skewers as part of a new design, specifically for positioning the Hall-effect sensor. By keeping the skewers but also 3D-printing new bases, we were able to mount the sensor less than 1 cm from the rotor base. This resulted in a clean signal, which significantly minimized errors in the Arduino’s RPM readings.

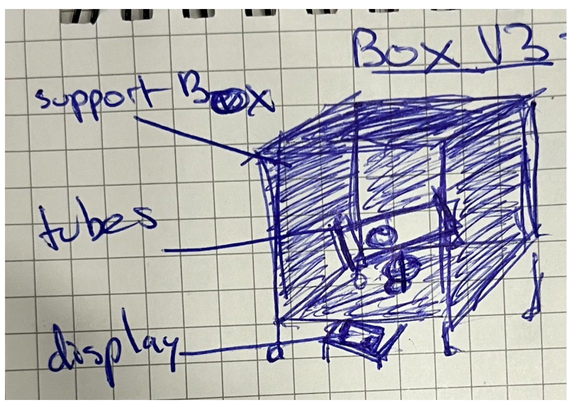


Figure 1.01: Initial Sketch of the V3 box stability design

Figure 1.1 Centrifuge Lid Components (Onshape)

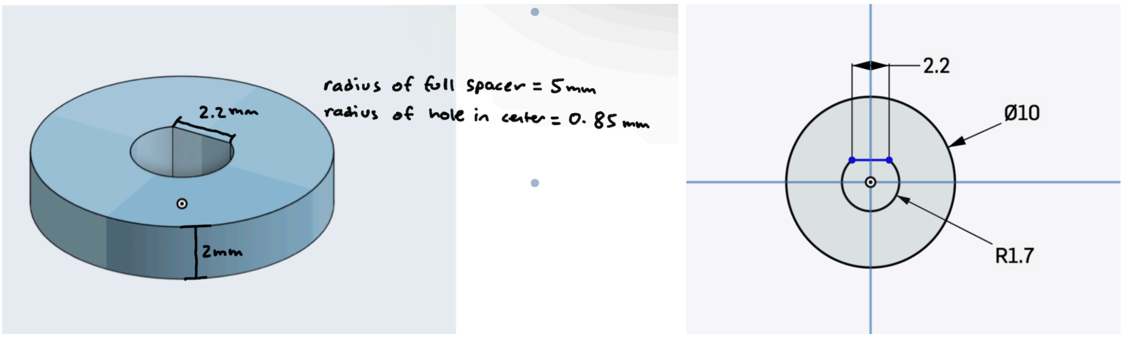


Figure 1.11 Spacer [LINK](#) - placed between motor and rotor board to keep it balanced.

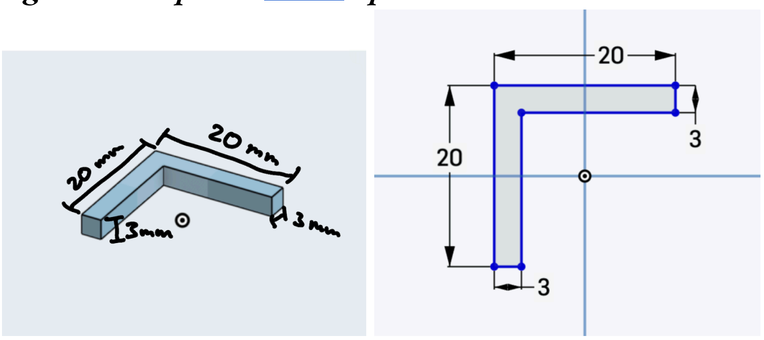


Figure 1.12 Lid Secure [LINK](#) - glued on outside of the lid body so that the lid sits securely on the box.

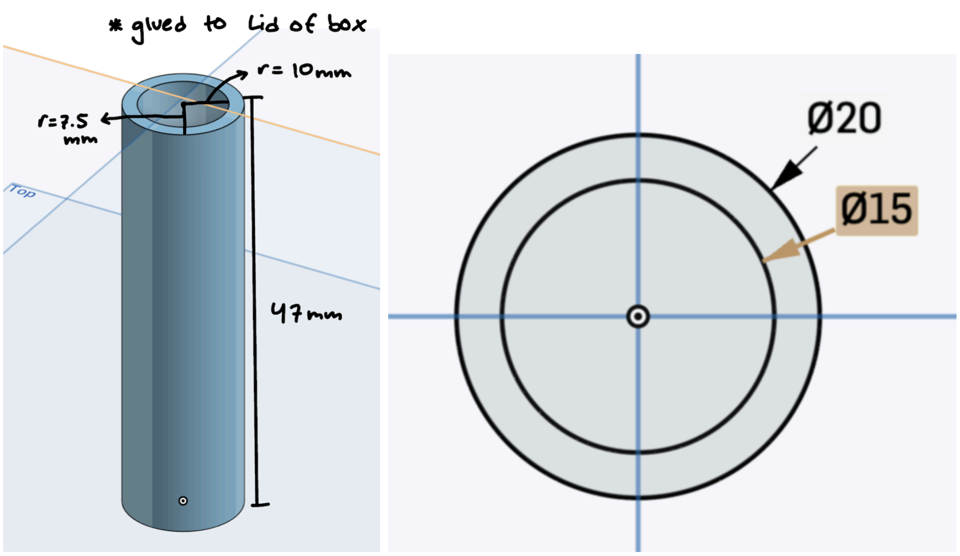


Figure 1.13 Rotor Cover/Cap [LINK](#) - hovers over the center of the rotor board, so that if the rotor board moves up the motor shaft, this piece keeps it in place.

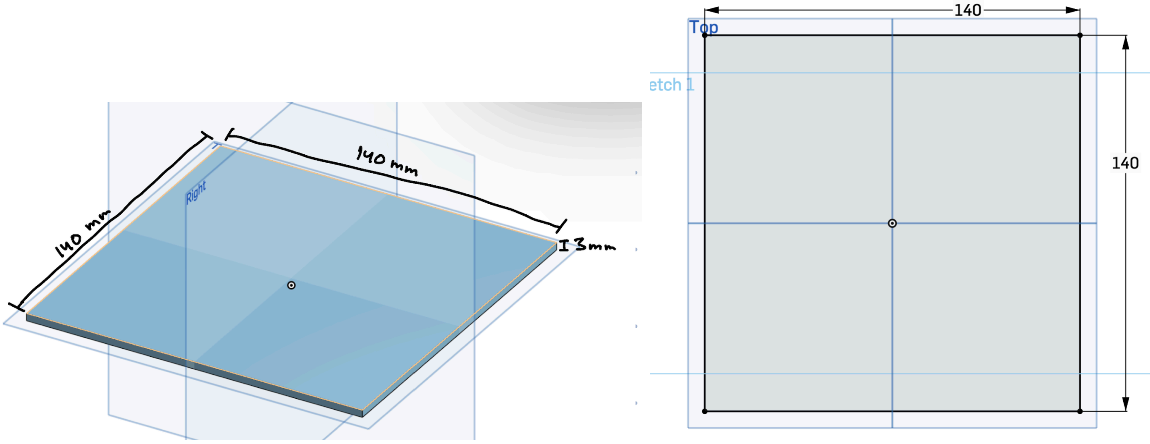


Figure 1.14 Centrifuge Lid Body LINK - all lid pieces are attached to this.

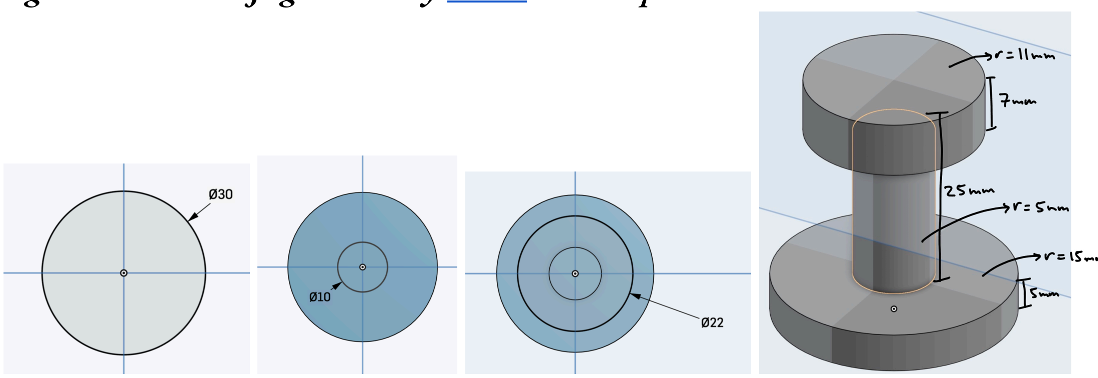
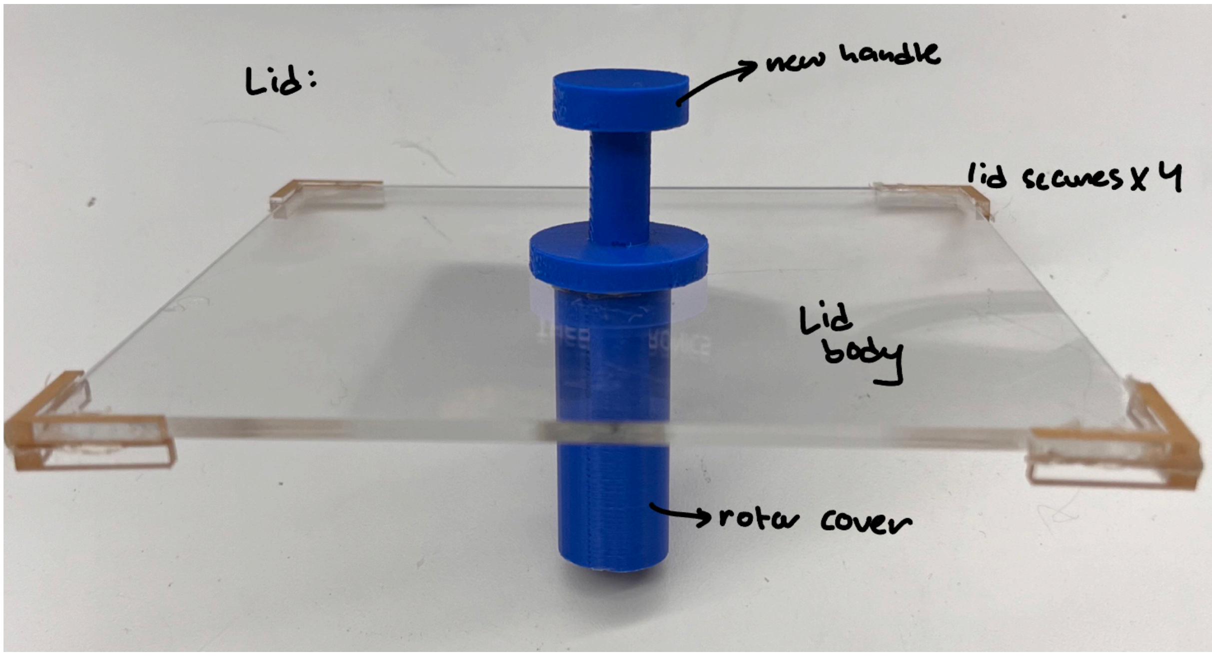


Figure 1.15 Lid handle

Figure 1.2: Centrifuge Lid Physical Build



Sits on top of the centrifuge box, and plays an important role in our safety considerations.

Figure 1.3: Centrifuge Box Components (Onshape)

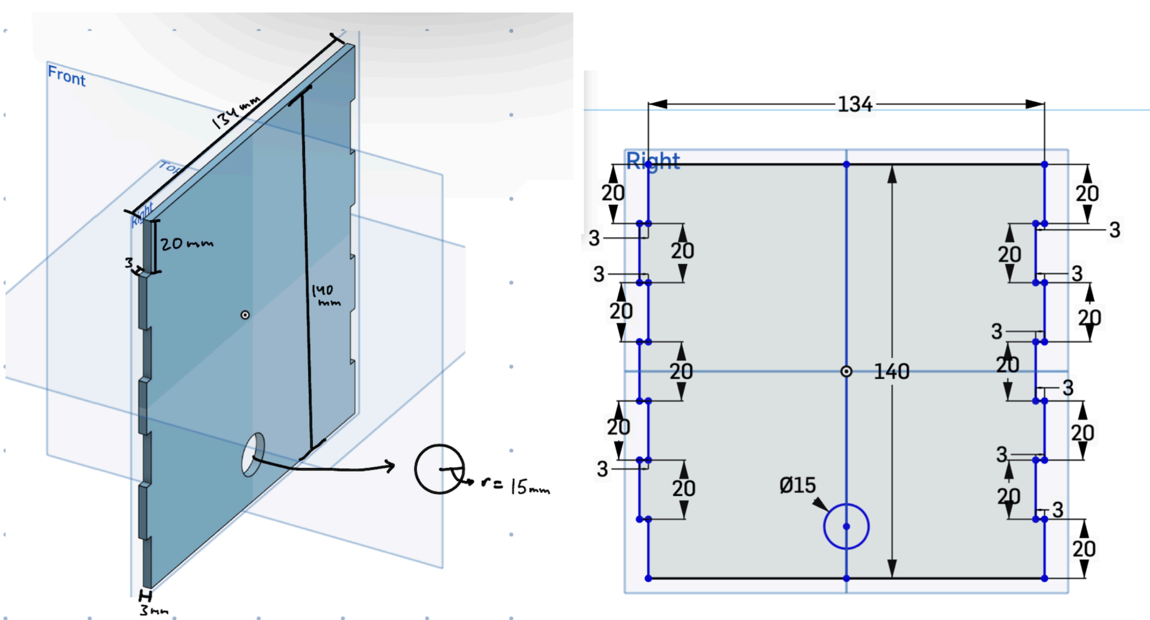


Figure 1.31 Wall, no support rods, with chord slot. [***LINK***]()

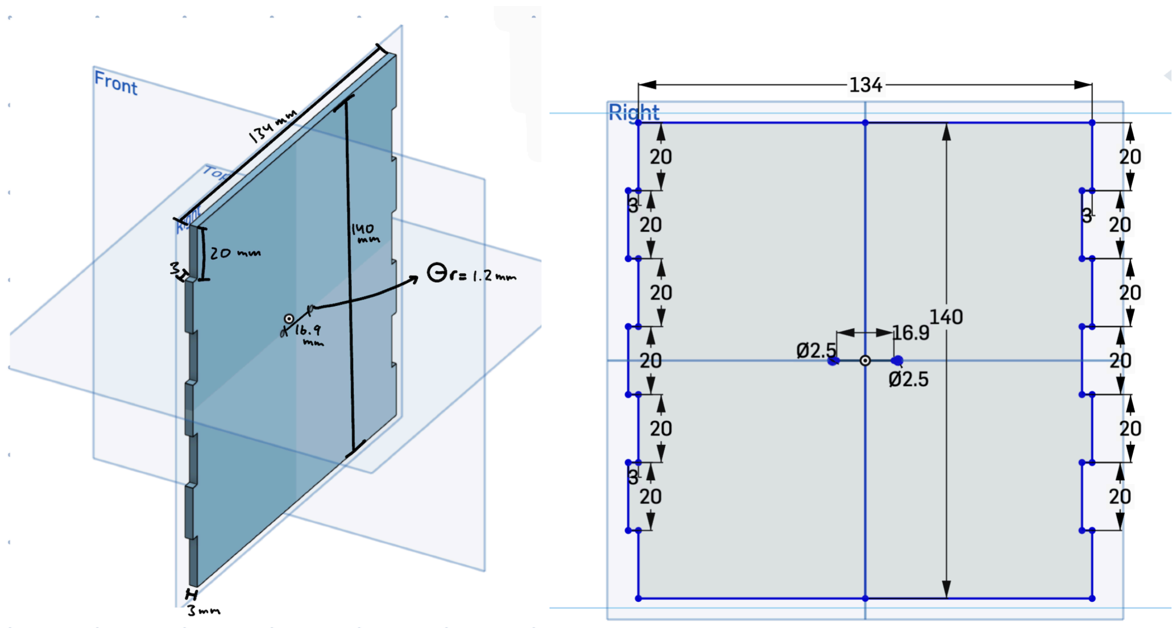


Figure 1.32 Wall, with support rod slots, no chord slot. We cut two of these. [*LINK*]

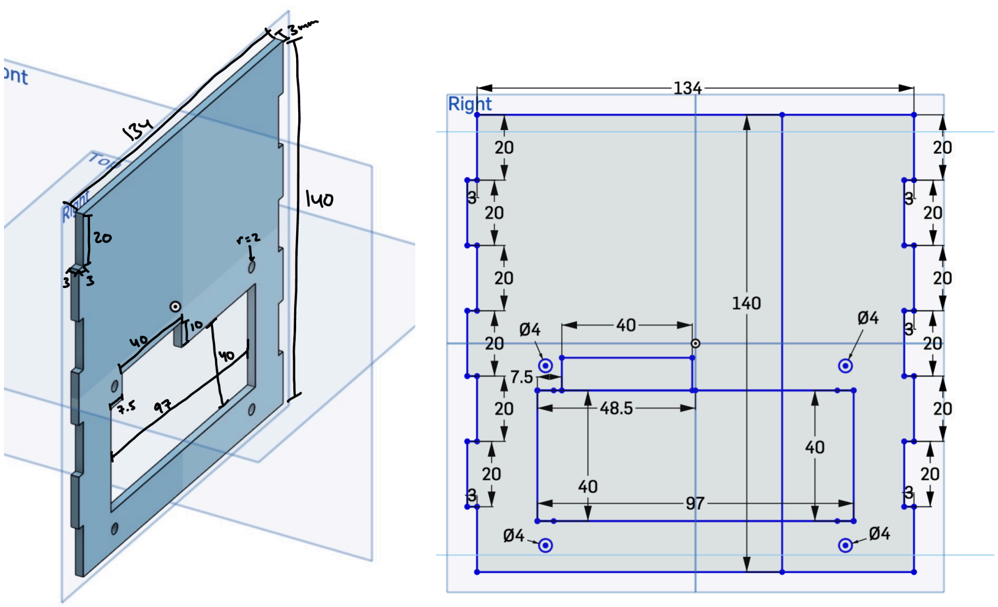


Figure 1.33 Wall with LCD Screen. [*LINK*]

Figure 1.4 Centrifuge Box Components (Physical)

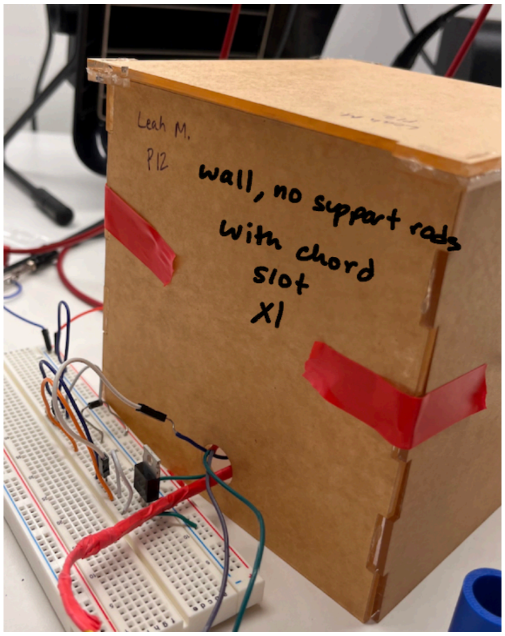


Figure 1.41 Wall, no support rods, with chord slot. We peeled off the film for V3, so it is transparent.

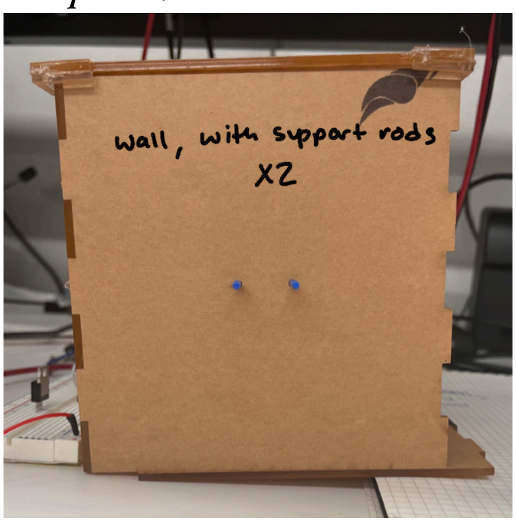


Figure 1.42 Wall, with support rod slots, no chord slot. We cut two of these. We peeled off the film for V3, so it is transparent.

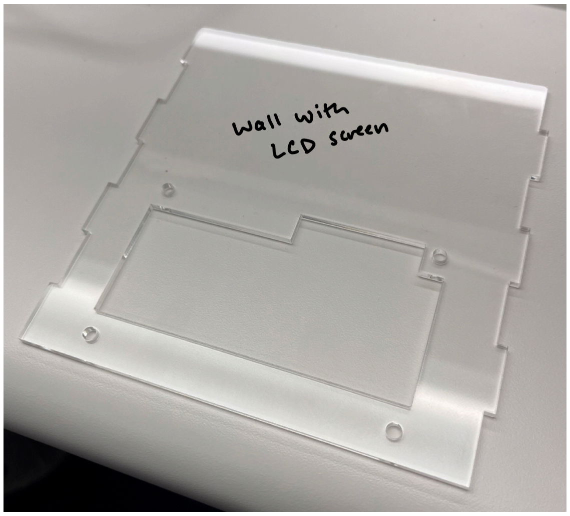
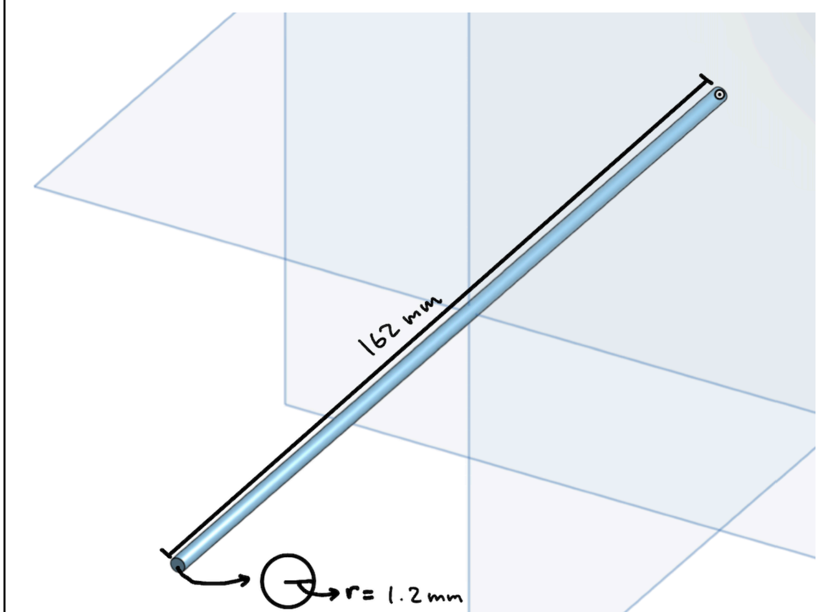


Figure 1.43 Wall with LCD screen insert..

Figure 1.5 Support Rods [LINK] - Two of these go through the holes in the motor into the holes in the walls to hold up the halefect sensor for the sensor subsystem. *(In V2 it was used to support motor, but it was not secure enough so now we are using a support apparatus from the bottom for that)*



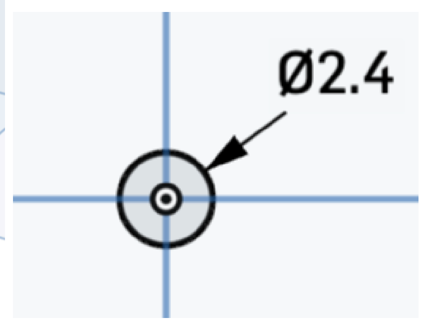


Figure 1.6 Tube Holders - The elongated bottom part serves no additional purpose in V3. *(V2: The elongated bottom part is used to block the light from the LED to the phototransistor every time it makes a rotation)*

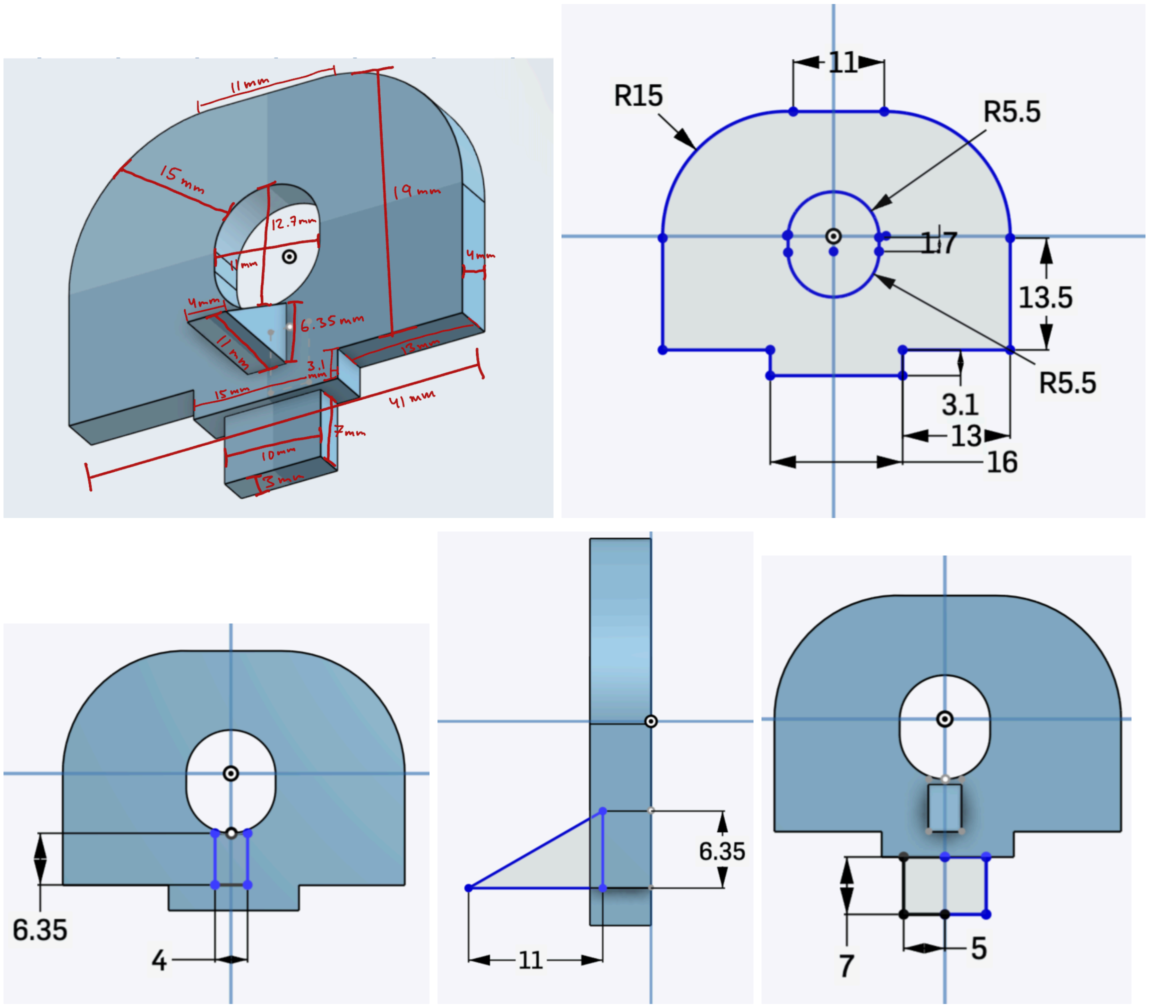


Figure 1.61 Onshape Tube Holder [LINK](#) We printed two of these.

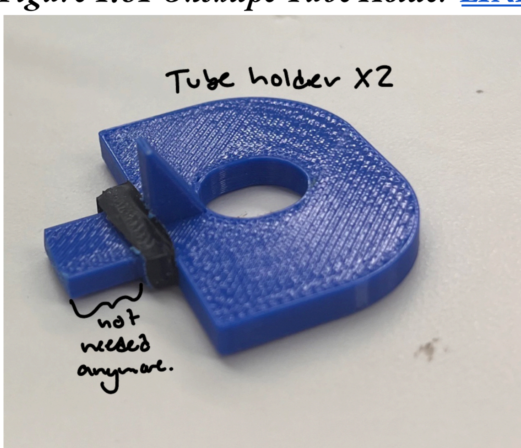


Figure 1.62 Physical Tube holder

Figure 1.7 Rotor Board [LINK](#)

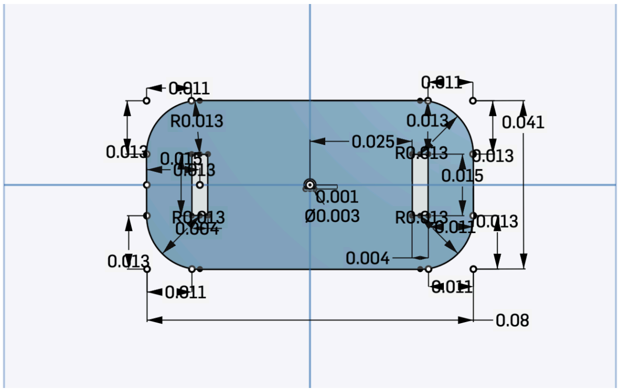


Figure 1.71 Onshape Rotor Board


Figure 1.72 Physical Rotor Board

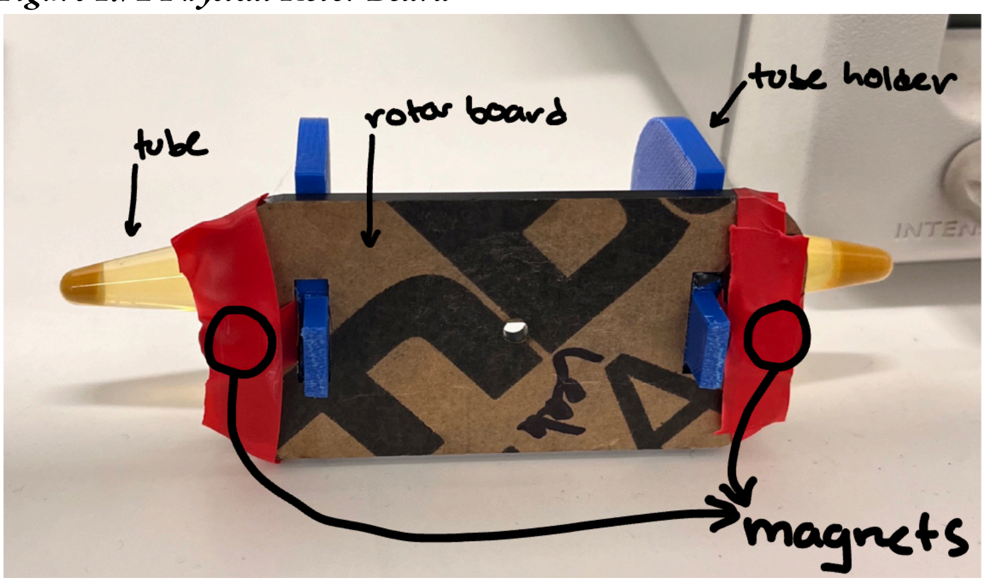


Figure 1.73 Rotor Board, Tube holders, Tubes, and Magnets

Figure 1.8 Support Apparatus/Bottom of Box [LINK]()

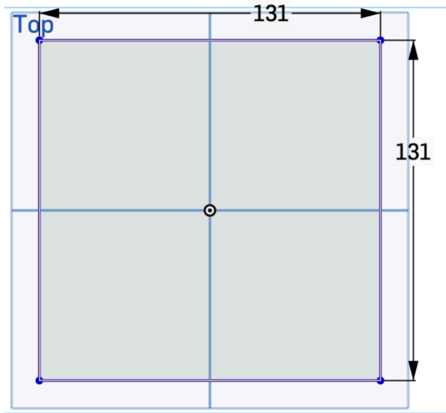


Figure 1.81 Base of box, connected to support apparatus.

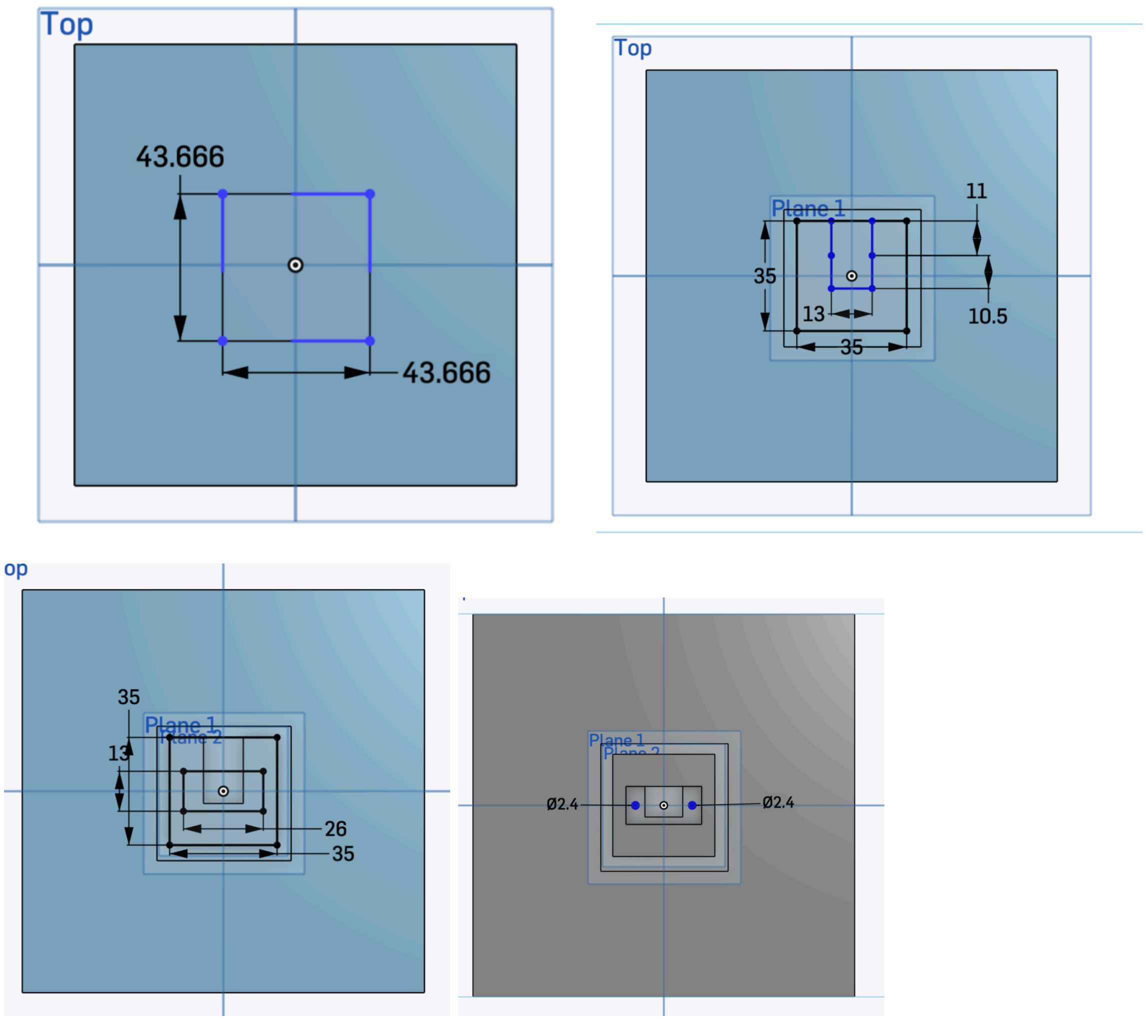


Figure 1.82 Onshape measurements for support apparatus. It has one larger prism as the base of the apparatus, then a smaller prism on top of it with a hole like structure to the piece that the motor sits in so that wire could still be connected to the base of the motor

while it was secured. Click on the link to see full design clearly.

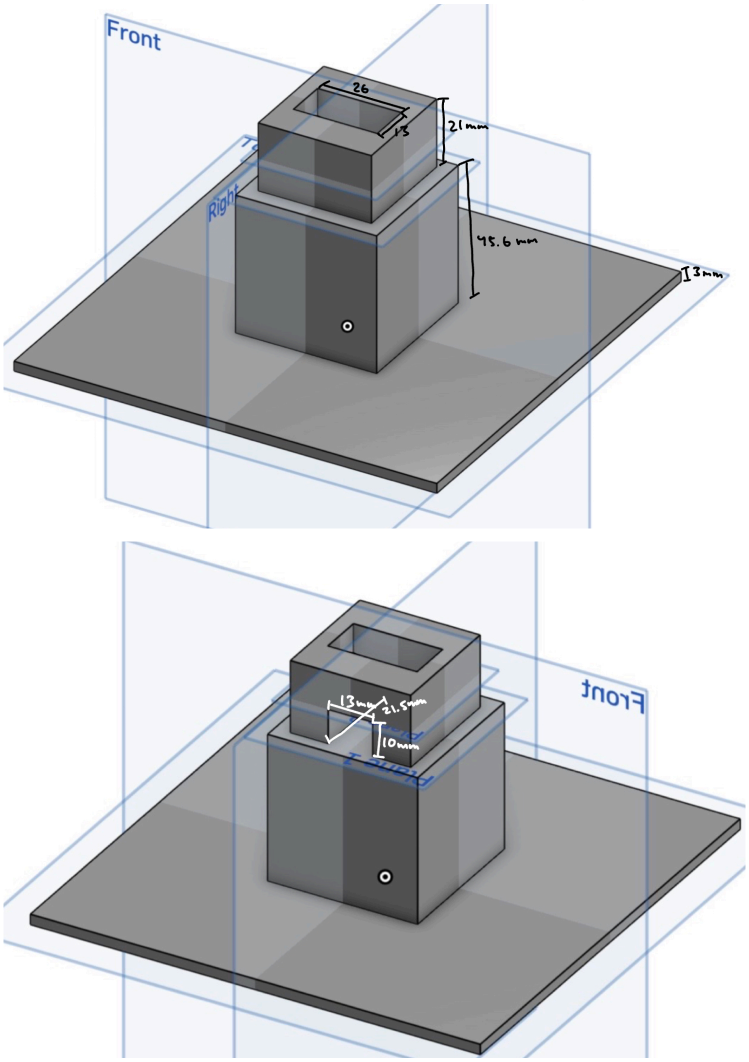


Figure 1.83 Full onshape design for support apparatus and bottom.

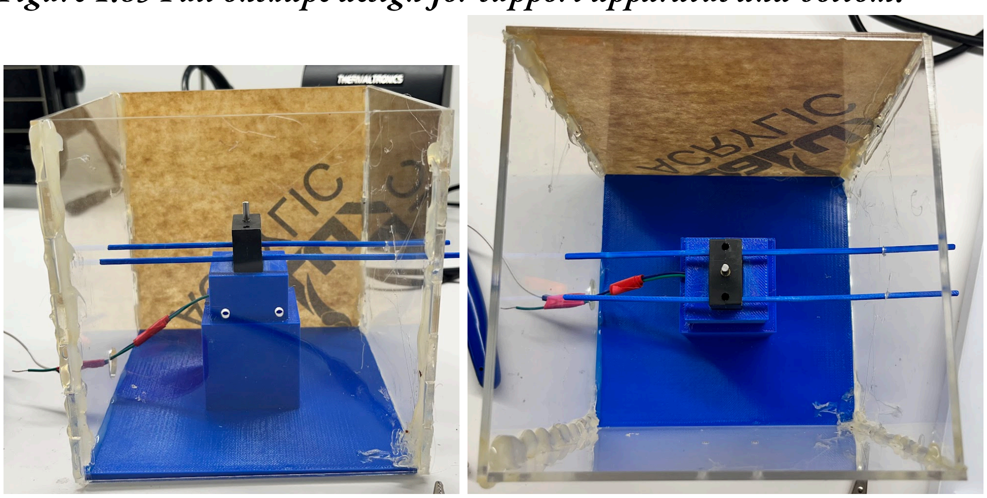


Figure 1.84 Physical bottom of box/support apparatus.

Figure 1.9 Full Assembly

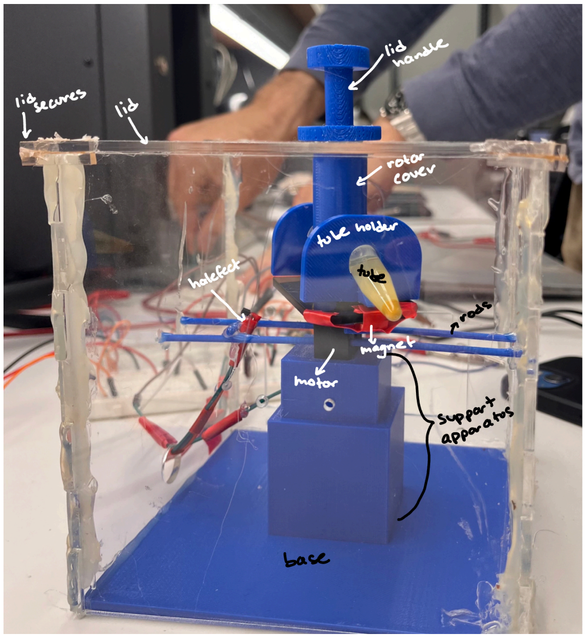


Figure 1.91 Side view of full centrifuge assembled.

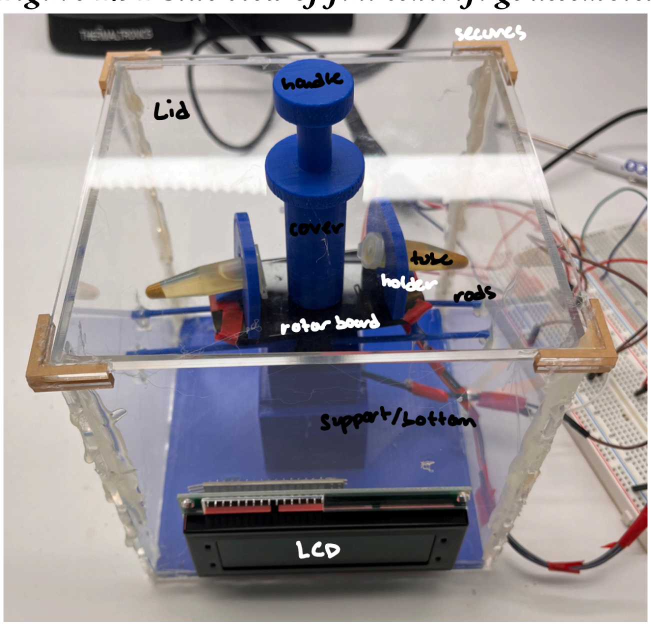


Figure 1.92 Top View of full centrifuge assembled.

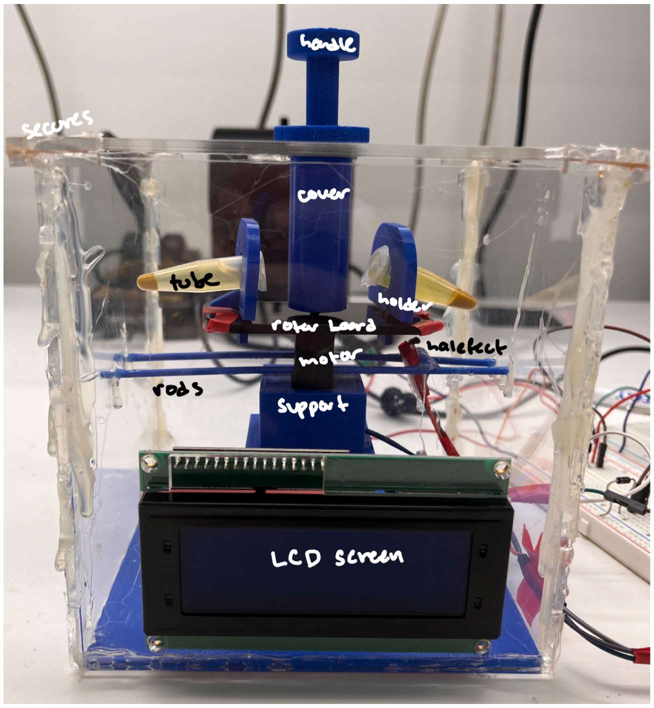


Figure 1.93 Full centrifuge assembled from front.

b. Electrical Build Parts

Brief Reflection:

- Initially, our circuit diagram was cluttered, inefficient and contained a redundant comparator. Throughout our build process we changed the system quite a bit, and you can view our first iteration of the circuit here.

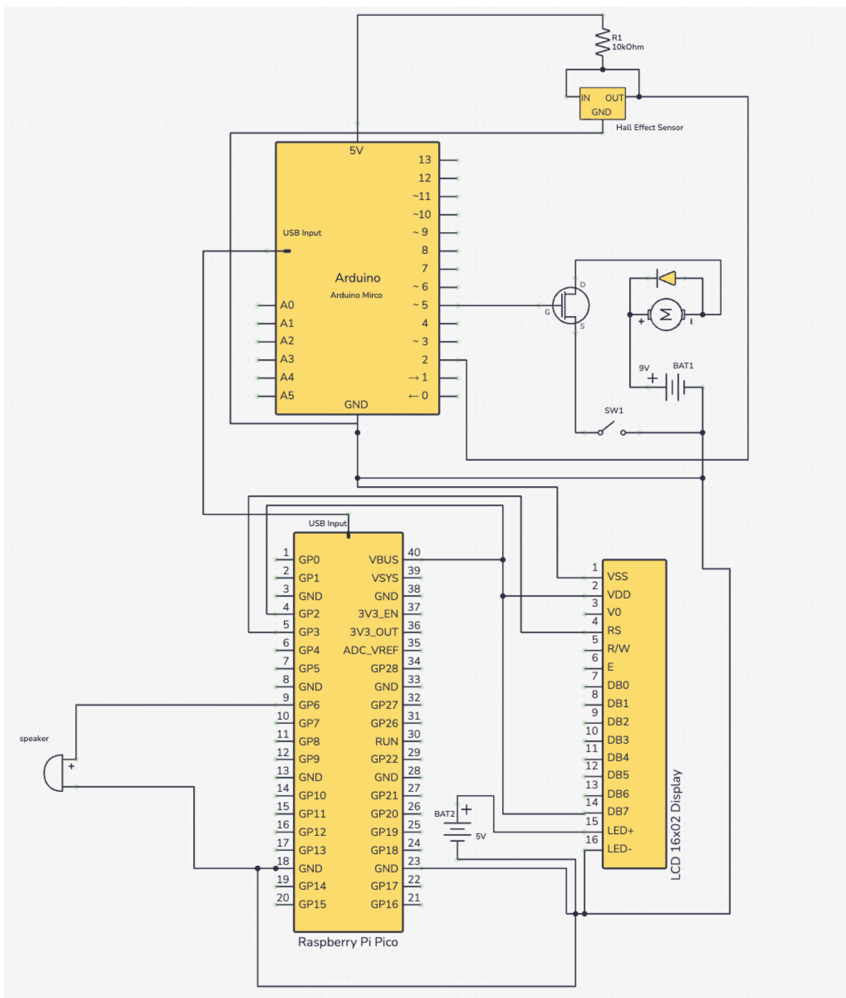


Figure 2.11: Circuit Diagram for the V3 Centrifuge (see below)

- *Full Link to Online Software*
- *Full Link to Clearer Images*

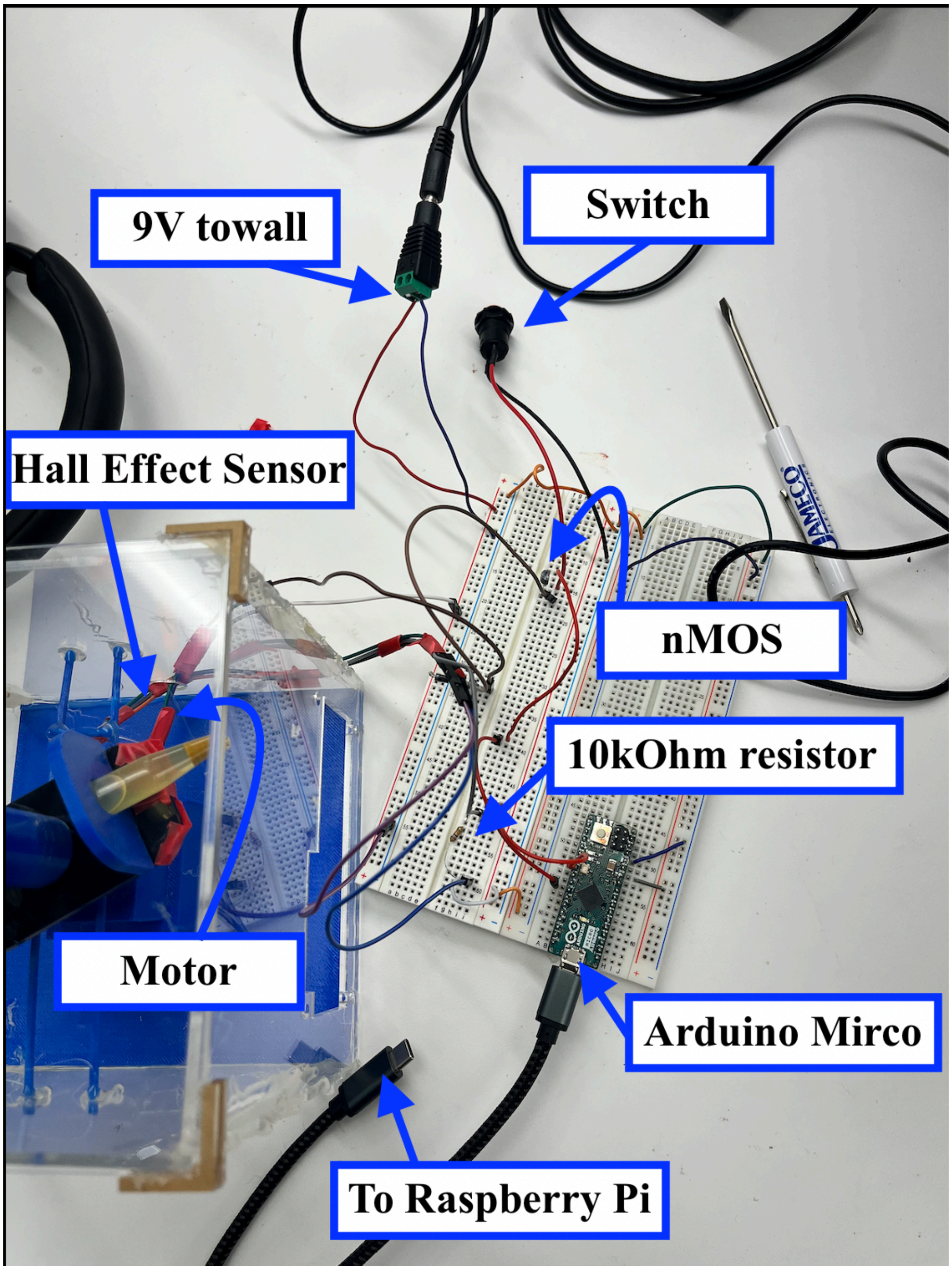


Figure 2.12: Built Circuit Without Raspberry Pi Connection (LINK)

c. Programming Build Parts

[GITHUB REPO LINK]

[User Flow PowerPoint Manual]

Section 4: Testing

a. Trace Matrix Sample ([full document])

- Please note for our trace matrix, all the updated tests are in **RED,** as we built on the already functioning V2 system.

Type of Test	Specification #	Specification Description	Test to Perform	Relevant Requirement	Specification Value [Units]
Resistors, Capacitors, and Potentiometers isolation measurements	1.11	Hall effect pull-up resistor resistance value test	Using a multimeter test the resistance of the resistor in the hall effect series circuit subcomponent. Required value is 10kOhm	All 2.1 Rotational Speed Requirements are relevant for these subsystem specification tests	10kOhm
	1.12	V_logic resistor value test	Using a multimeter test the resistance of the comparator's V_logic resistor in the series circuit subcomponent. Required value is 5kOhm		5kOhm
	1.13	Comparator V_Ref	The input V_ref must be = 4V ± 10%, to ensure cleaned up signal from the V_logic and GND		4V ± 10%
Magnet System isolated, and through comparator oscilloscope tests	2.11	Measure input hall effect voltage using oscilloscope	Input voltage should be 5V in the hall effect sensor to power supply subcircuit	All 2.2 Duration of centrifugation & 4.1 Completion of centrifugation are relevant requirements for these subsystem specification tests	5V
	2.12	Magnet and Hall Effect (4cm)	Connect the Hall Effect to our pull-up resistor and to a 5V power supply. By moving the magnet away from the sesnor expect in the no magnet case for V_o = 5V and when magnet is present, V_o = LOW.		5V when no magnet, 0V when magnet present
	2.13	Oscilloscope HALL EFFECT output from collector of hall effect, alters between 5V and 0V	Connect the oscilloscope to the hall effect output. Expect in the absence of the magnet, for the output to be 5V		5V
		Oscilloscope HALL EFFECT output from collector of hall	Connect the oscilloscope to the hall effect output. Expect in the presence of the magnet, for the		

Figure 4.11: Sample Trace Matrix

b. Testing Matrix Sample ([full document])

Measured Value [Units]	Pass/Fail	Proof – Link to Artifact	Assessment
9.94kOhm	**Pass**	**NA**	**Hall effect resistor is correctly set!**
5K	**Pass**	**NA**	**Throughout our build, we decided to only use the output from the hall effect sensor to function as the square wave**
4.15V	**Pass**	**LINK**	
5V	**Pass**	**LINK to Folder**	**These tests gave us confidence that we were ready to test the sensor against a square wave function generator. The magnet connection was wired correctly to start next part of the test**
5V when no magnet, 0V when magnet present	**Pass**		

Figure 4.12: Sample Test Matrix

c. Hazard Testing Sample

Hazard Testing

Requirement #	Requirement Description	Coverage Assessment	Proposed Mitigation (If Insufficient)	Proof of Mitigation	Assessment
6.1 Single fault condition for centrifuge	The centrifuge must be designed to remain safe if a single failure occurs.	Partially Covered - Some failure scenarios (motor bracket instability, comparator failure) have mitigations in place, but additional redundancy is needed for critical components.	Implement a second layer of redundancy for speed control (secondary fail-safe circuit that shuts down the motor if RPM exhibits uncontrolled behavior).	Lid of the box has a protrusion that goes almost onto th emiddle of the rotor base so that in case of base failrue the base will be block by the protruison. There is also a kill switch in case of unctrontollable behavior such use uncontrolled RPM, high current, strange noises, etc.	The switch used for V2 is a small SPDT swtich that heats up a lot because all of the current running through th emotor alos runs through the switch. This does not pose an immediate danger for the system however to optimize this for V3 we can use a rocker switch with an amperage rating of 10A.
6.2 Specific hazardous situations	The centrifuge should not emit flames, toxic gases, or hazardous substances.	Partially Covered - Fire and toxic emissions risks have been addressed, but some risks (overheating components leading to ignition) need further mitigation.	Introduce temperature sensors to monitor heat generation and trigger an automatic shutdown if a threshold is exceeded.	The box provides an enclosure that should not allow toxic fumes out, the material of the box has a melting point of 320F which will not be reached in our system with the components used. The switch overheats but not to the level of causing ciruit meltdown.	Same as above^ using a rocker switch with higher amperage rating to properly handle the current
6.3.1 Leakage of liquid	The centrifuge must prevent liquid leakage from causing safety risks.	Covered - Biohazard containment measures and material choices prevent spills.	No action needed.	Acrylic (material used for contrifuge box) keeps all liquids out. https://drive.google.com/file/d/1xRcKMMJOiSRjyprd2dfwX1B2lU1isNlv/view?usp=drive_link	Same box may be used for V3, the material properly mitigates possibility of spillage
6.3.2 Locking of moving parts	The centrifuge should remain safe if parts jam or lock unexpectedly.	Insufficiently Covered - No clear mitigation for a jammed rotor or locked bearings.	Introduce an automatic shutoff if the system detects a sudden drop in RPM or excessive vibration, indicating a jam.	When rotor base is blocked, motor isn't strong enough to force it to continue spinning.	The motor used already stops spinning when there is a block. It is possible to include code in the future iteration that detects a block and ramps down the system to a halt

Figure 4.13: Sample Hazard Testing Table

Section 5: Assessing

a. **Testing Speed Control (full link)**

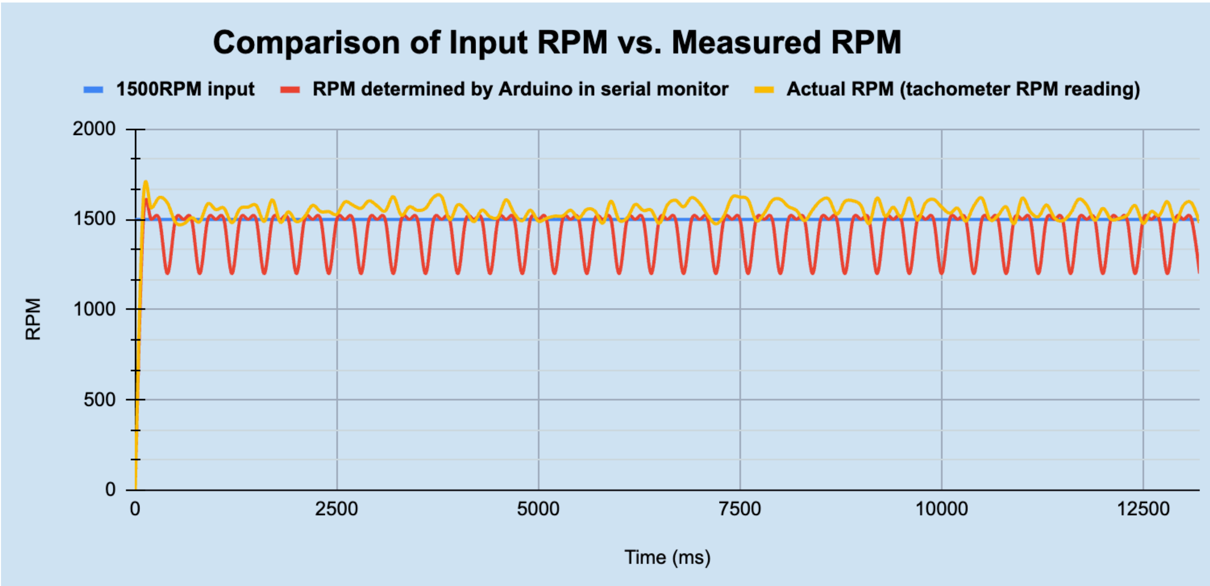


Figure 5.11: Stability of PID System at 1500 RPM

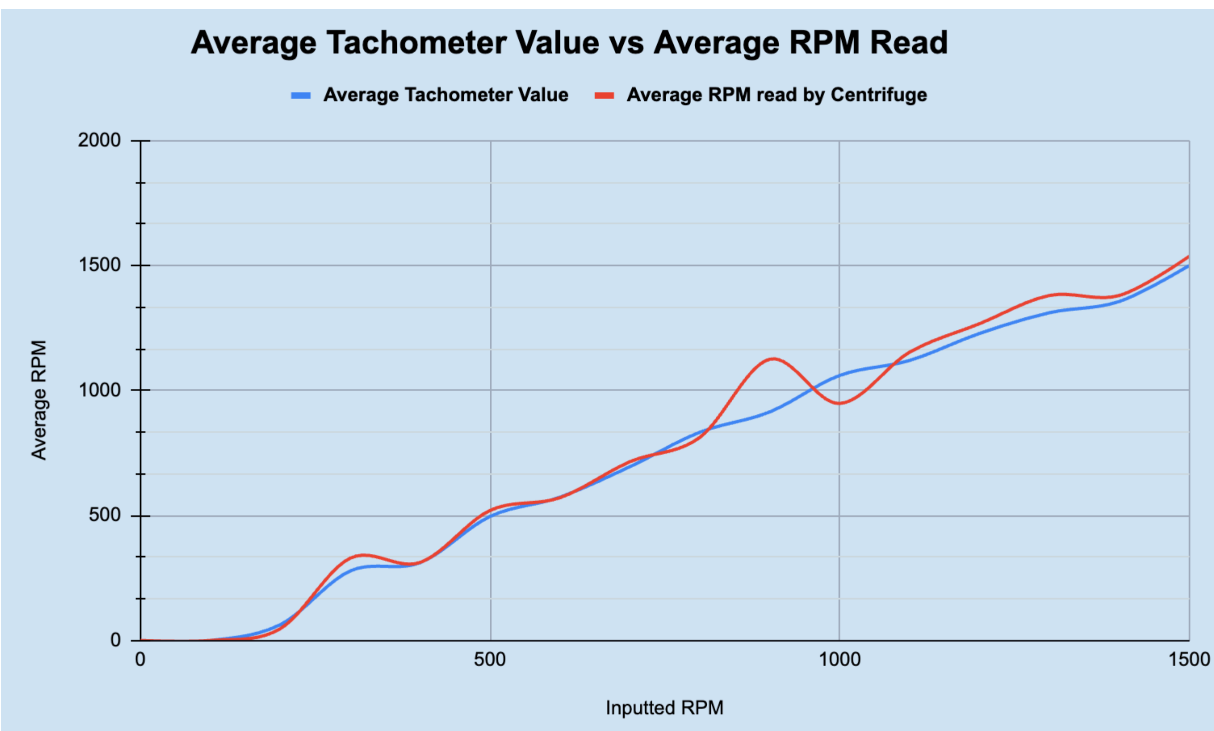


Figure 5.12: Stability of PID System and Error Across all 0-1500 RPM

b. Requirement Analysis

The V3 centrifuge was tested against the necessary requirements to ensure functionality, safety, and performance. The following table assesses whether each requirement is fully, partially, or insufficiently covered, and if any further work is needed.

Requirement Type	Requirement Name	Assessment	Future Changes/Improvements
1. Sample Containers	1.1 Container volumes 1.2 Number of containers	The system holds and spins the sample containers required, full and empty. The same base and holders from V1 were used for V2 and were used throughout testing. In V3, we improved the stability of the rotor base by ensuring the motor fits securely into the support.	A future version could include making a new rotor base with more tube holders.
2. Centrifugation Parameters	2.1.1 Rotational speed range 2.1.2 Speed setting increments 2.1.3 Speed setting accuracy 2.1.4 Rotational speed ramp-up 2.1.5 Rotational speed ramp-down 2.1.6 Stability of rotational speed 2.2.1 Duration range 2.2.2 Duration setting increments 2.2.3 Duration setting accuracy	The centrifuge met the requirements for ramp up/down, speed increment setting, speed accuracy, and duration setting/range through the Arduino code. For V3, we improved mechanical stability with a secured base and motor mount to minimize vibrations affecting speed readings which was successful.	No significant changes needed

3. Operating Commands	3.1 Initiation command 3.2 Cancellation command	Both commands work for the centrifuge. Ramp up and Ramp down happen within the 30 sec initiation time.	No major changes planned, as the command system is functioning correctly.
4. Indicators	4.1 Completion of centrifugation	The completion of centrifugation is indicated in the serial monitor with a message "Centrifugation complete. System waiting." On the Lcd "Time's up! Ramping down... Motor OFF"	A future version can implement the originally proposed speaker system with a termination sound.
5. Test Samples	5.1 Anticoagulated blood 5.1a Tomato juice with oil and Vaseline 5.2 Water with turmeric	The centrifuge performed well with turmeric samples but struggled with fully pelleting the blood samples. In V3, we optimized speed settings, but blood separation still takes longer than expected.	Future testing should explore different speed/time settings for samples of varying viscosities. A faster motor may be implemented in a future version.

6. General Safety	6.1 Single fault condition for centrifuge 6.2 Specific hazardous situations 6.3.1 Leakage of liquid 6.3.2 Locking of moving parts	The centrifuge has various safety features. The V3 design maintains the emergency kill-switch and separation of electrical and motor/sample systems. The system also continues to meet safety requirements by having an enclosed box. The switch from rods to a fixed motor base allowed for further 6.3.2 success..	Future models may include a separate enclosed compartment for the electrical subsystem to prevent electrical safety concerns.
7. Protection Against Mechanical Hazards	7.1 Mechanical hazards associated with moving parts 7.2.1 General 7.2.2 Instability - overbalance 7.3.1 General 7.3.2 Spillage on centrifuge	The box enclosure for the centrifuge continues to provide protection against moving parts. The lid attachment helps prevent rotor detachment. V3 changes included securing the base to improve overall stability. The system remains stable when tilted at ~5 degrees without breakdown.	Again, a future version may explore an enclosure that contains all subsystems.
8. New V3 Requirements	8.1 Standalone operation 8.2 Indication of termination (sound) 8.3 Indication of termination (ping)	V3 proposed new features including auditory alerts for cycle completion, bluetooth control, and an LCD display. The LCD display was successfully implemented, displaying a welcome message,e ramping up and rpm monitoring screen, and a ramping down/completion screen. The speaker system was not	A future version would explore the addition of a speaker that will play sounds throughout the centrifugation process indicating start, spin, and termination. It would also include a function app, perhaps instead using a web

		implemented due to lack of time and the app had some bugs that could not be resolved by the time of the final presentation.	server instead of a bluetooth connection to reduce Network connectivity issues.

Evidence of improvement in speed efficiency and error mitigation

V2

V3

c. Conclusion

As shown in the diagrams above, we were able to significantly improve the accuracy of our sensor system compared to V2. From Figure 5.11, there is an average sensor error of 8.14% and an average speed error of 3.63%. This marks a substantial improvement over V2, as it now allows the Arduino to accurately determine how fast the motor is spinning. The process we followed was quite unique, because our V2 system relied on an LED-phototransistor to generate a square wave signal that had to be cleaned using a comparator. As demonstrated in this presentation (link), the V2 system experienced numerous issues with sensor stability, likely stemming from both mechanical and electronic errors. By implementing a new mechanical design and a new sensor system, we were able to correct these issues. Our initial plan for the new sensor system involved using a Hall-effect sensor feeding into a comparator. However, we soon discovered the comparator introduced more noise than it filtered out. As a result, we increased the pull-up resistor on the Hall-effect sensor and removed the comparator entirely. This was a good demonstration of engineering because it eliminated a redundant component while improving performance. Furthermore, what was initially a mechanical flaw in V2—the skewers—proved to be advantageous as a means of positioning the Hall-effect sensor. Placing the sensor less than 1 cm from the rotor base provided a clean signal, minimizing errors in the RPM readings through the Arduino's interrupt protocol.

During our efforts to create a user interface that operated without a computer in the loop, we encountered several issues that prevented us from achieving all of our goals. While Raspberry Pis are versatile, they are still relatively simple computers and, combined with our limited time frame, we found ourselves repeatedly facing connectivity problems. As we learned from other groups, a Raspberry Pi's Bluetooth functionality relies on a stable Wi-Fi connection associated with a consistent IP address. Stanford's highly secured and robust network required us to connect the Raspberry Pi to a separate, dedicated router. Unfortunately, we discovered this requirement too late, leaving insufficient time to reroute our system accordingly. Consequently, we continued to experience the same connectivity errors when trying to deploy our JSX (React Native) app. Similarly, we had problems with the speaker, which we later learned was to do with a wiring issue, and yet again another Raspberry Pi–connectivity error because we wanted to store sounds on our 4Gb SD card. Ultimately, we focused our energy on a higher accuracy sensor system. If we had the time to improve on a V4, we would focus primarily on insuring the computer out of the loop design.