PosChair:
Posture Sensing and Correction Device

Final Report

24-441 Product Design

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Executive Summary

Poor posture has been proven to have adverse effects on health and wellbeing, and can be the direct cause of chronic pain. Posture research has especially proven that these adverse effects particularly impact office workers and students, who sit at a desk for more than 6 hours every day [11][12][19][10]. We decided to create a product that could detect posture, make users aware of their posture, and correct that behavior for people seated at a desk. To accomplish this goal, we decided to incorporate two sensor data streams, position of the user's back and force exerted on the seat of the chair, to inform vibration and visual feedback to the user. Having both distance and force data would enable the user to improve their back curvature and seat positioning. Designing this product could provide more insight in posture enhancement for the user, since existing products only target specific areas, such as the neck and shoulders. Our first prototype was a proof of concept of the distance sensing system and visual feedback using ultrasonic sensors mounted to a rail with adjustable mounts. The second prototype included infrared position sensing, load cell weight distribution sensing, vibration motor feedback, and further data visualization. In this prototype, the sensing, feedback, and user interface subsystems were each in separate electrical circuits that were not interconnected. The final design is a custom chair with adjustable infrared sensors implemented in the chair back and and load cells in the seat for weight distribution mapping. In order to implement these sensors, we designed mounting brackets as attachment points for the infrared sensors to be integrated within the structure of the chair back, and the force sensors were attached beneath the surface layer of the seat. This final product meets our design requirements of sensing accuracy, comfort, clarity of feedback, ease of setup, and height and weight requirements.

Opportunity and Design Problem

Customer Research

Good posture is necessary for a healthy lifestyle, and can be a preventative measure against other complications in any person's health [10][18]. Despite this fact, many people experience pain as a result of bad posture; this is especially true for people who sit regularly at a desk for long periods of time. In one population of office workers, 75 percent of the demographic "reported either chronic or acute back pain" [11]. With this ongoing problem in mind, we decided to come up with a solution for posture correction that targets people who work at a desk for several hours every day.

We will also keep in mind other stakeholder groups such as medical professionals such as chiropractors and physical therapists who advise patients on posture correction professionally. Our own customer research has also confirmed that the population surveyed, which was mostly made up of students, regularly sits at a desk for more than 6 hours and self-evaluates their posture as below average.

We also received information from stakeholders by interviewing physical therapists about the best way to correct issues with posture. The physical therapist stated that "good" posture is very subjective, because it's different for every body and treatment must be tailored to the individual. She also emphasized that the best way for her to correct her patient's posture is to make them more aware of what bad posture feels like, and what they can do to self-correct their position. This statement is in agreement with our own research, which states that the best form of posture correction which also leads to pain relief for those with posture-related pain is proprioception and posture awareness [17][11].

This type of posture correction creates a gap in the existing market for posture enhancement devices that our design project can fill. Existing devices are not able to be tailored to individual users, and they do not give adequate feedback for posture awareness and self-correction. Some existing devices can cause further pain and discomfort to the user by attempting to force correct posture.

There is already a market for posture correction devices which customers are willing to pay up to hundreds or thousands of dollars for. There is also evidence that external posture correction can lead to better self-control of posture in the long-term, meaning that an effective solution could compete with chiropractic and physical therapy options for long-term posture correction. A study on patients with lower back pain concluded that "facilitating proprioceptive integration and improving postural control in [lower back pain] patients could not only be potentially beneficial for their recovery but could also avoid patients from evolving towards more chronic painful states" [17]. From customer research and conversations with professionals who are also stakeholders in posture correction, we have determined that there is a market for a posture correction device which is able to be customized to the user and gives feedback for better posture awareness.

Benchmarking

The competitive existing products we found for posture correction fell into three separate categories: smart devices, posture braces, and ergonomic chairs (images in Appendix 3).

Smart Devices: Upright Go

There are a variety of smart, wearable products on the market for posture correction. We found the most popular and competitive device in this category to be manufactured by the Upright Go company. This company designs smart, wearable devices that detect posture of the user. Their most advanced product, the Upright Go 2 utilizes tilt and strain-gauge feedback sensors as well as a gyroscope to regulate changes in its user's spinal curvature and orientation [20]. For the device to function effectively, the user must set a baseline for upright posture. When deviations are detected, it utilizes an electric motor as an alert mechanism to deliver vibrations of varying intensities [20]. The Upright Go 2 caters to a slightly more niche market, costing $79.75 [9]. The device also incurs additional fees, as it needs to be attached to the user via a body-safe adhesive that requires regular replacement. Users have the additional option of forgoing adhesives and purchasing a magnetic lanyard for $19.95 to be worn around the neck instead [9].

Users have reported this device as ineffective in addressing posture consistently. This is due to the device's design, as its sensors are calibrated to detect only forward slouching. Side and back slouching are unable to be detected and thus corrected. Our group can confirm these findings, as we separately purchased our own Upright Go to assess its functionality in addressing posture in various different seated positions. Along with these issues, the device's location to be worn solely on the upper body, poses a problem with posture detection. In our group's conversation with a physical therapist, we learned that to properly correct posture, multiple areas of the back would need to be targeted. The Upright Go only focuses on the upper back at the base of the neck, thus neglecting other areas of the body necessary for adequate posture correction.

Posture braces

Posture correcting braces are designed for users to develop muscle memory of upright posture through tension to provide physical restriction of certain movements. These devices focus on targeting a specific area of the body (usually the upper or lower back), and use tension in order to restrict body movement. These braces are available to users at an economical price range from $30 to $50 [13].

Posture braces tend to be ineffective for long term posture correction [14]. This is because poor posture requires correction in multiple areas of the body. Targeting only one part of the body, wouldn't train the user to be able to holistically improve posture and likely result in regression to poor form once these braces aren't in use [14]. Additionally, users have also often reported these devices as being uncomfortable, bulky, and awkward to wear, with some even causing chafing and breath restriction [15][18]. Overall, posture braces are at best only a temporary fix to a bigger issue. Because these devices shift weight off of muscles when in use, over time this can actually cause muscle atrophy which further exacerbates poor posture and makes the user more prone to injury [4][8].

Ergonomic chairs

Ergonomic chairs are designed with more features to improve and support body posture. These features include adjustment in the height and tilt of a seat, reclining backrest, and adjustable headrests to allow the user to individually customize the chair's position to their body [1]. The device generally employs hydraulic, pneumatic, swivel, and tilt mechanisms to allow for this movement and locking in different chair components. Ergonomic chairs are catered towards a niche market. Price ranges of chairs with a full arrangement of features can range from $1000 to $2000 [16]. Though providing a full range of support and targeting multiple areas of the body, this device is limited to relying on user customization of features. The device relies on the user to understand what good posture looks and feels like, and adjust the seat accordingly. However, without feedback provided to the user, posture can't actually be corrected.

In assessment of the existing devices on the market, we see various gaps in the market that provide us with sufficient opportunity to create a product that can better address the needs of the consumer in posture correction. These gaps we've identified are listed in bullets below:

- Failure to address posture correction holistically (multiple areas of body neglected)
- Failure to provide user feedback to fix poor posture

Design Requirements

Our device's main requirements are the ability to accurately sense multiple areas of the body to address posture correction and provide feedback when the user has poor posture so that they are aware of their posture. It should also be non-intrusive to avoid making the user uncomfortable and intuitive so that the user can set and use it easily. Finally, our device should be usable for various body types. Table (1) compiles a list of the specific requirements.

Table (1): Design Requirements

Design Requirement	**Quantified Value**
Accurate posture sensing	Maximum 20% Error
Clear feedback to the user	User Rating 8-10 (Out of 10)
Increased awareness of posture	User Rating 8-10 (Out of 10)
Nonintrusive and Comfortable	User Rating 8-10 (Out of 10)
Ease of Setup	User Rating 8-10 (Out of 10)
Setup Time	< 10 Minutes
Weight Capacity	246 lb*
Max Height Accommodation	6 ft 2 in*
Min Height Accommodation	4 ft 11 in*

*Max/min requirements using 95th percentile male and 5th percentile female respectively [7].

Concept Generation and Evaluation

Concept Generation Methods and Outcomes

Through customer research and talking with physical therapists, we were better able to narrow down our brainstormed ideas to those that would perform best; we were also able to determine how to properly benchmark posture and what points on the body should be used for measurements. We then had a brainstorming session where we used the 6-3-5 method (see Appendix 4) to generate ideas that had large ranges in scope, like using a suite of expensive load cells all over the chair, to simple ultrasonic sensors to measure distance. From there, we had a discussion about what ideas could be feasible in the scope of the class and used Pugh Charts to identify the best ideas for different areas of posture sensing and correction.

Concept Evaluation

We divided our concept generation into 3 subsystems: the feedback subsystem, the sensing subsystem, and the device packaging subsystem. For each subsystem, we created a Pugh Chart and evaluated the scores to find the best concept for each system. We also took into consideration which concepts from each subsystem would function best together. For each subsystem, we used Upright Pose as a baseline, because we determined that it was the biggest competitor on the market to our product because of its use of both sensing and feedback for posture correction.

The first subsystem we created a Pugh Chart for was the feedback system. We determined our criteria to be, in order from highest to lowest priority, comfort, team capability, risk of injury, clarity of feedback, user preference, and cost. The points given to each feedback option were determined based on user studies, user testing, feedback from a physical therapist, and group discussion. Our feedback options were vibration, audible, tactile, tilt, and notification. It was determined based on the Pugh Chart, using Upright Pose as a baseline, that vibration feedback would be the method that best fit all of our criteria. Vibration feedback is not intrusive to the user, and so it was comfortable with a low risk of injury. It is also within the team's capabilities to implement and was highly preferred by the potential users we surveyed. While prototyping, we also continued to consider the option of other forms of feedback being used in tandem with vibration to provide more clear and useful feedback on the user's posture.

Table (2): Pugh Chart for Feedback Subsystem

Criteria	Weight	Feedback					Upright Pose
		Vibration	Audible	Tactile	Tilt	Notification	
		Method 1	Method 2	Method 3	Method 4	Method 5	Baseline
Cost	1	0	1	-1	-1	1	0
User Preference	2	1	-1	1	0	-1	0
Clarity of feedback	2	0	0	1	1	1	0
Risk of Injury	2	0	0	-1	-1	0	0
Comfort	3	0	0	-1	-1	1	0
Team Capability	3	1	1	1	0	-1	0
	Total	**5**	**2**	**1**	**-4**	**1**	**0**

The second subsystem evaluated was sensors. We determined that our criteria for sensors, in order from highest to lowest priority, was area covered, precision and accuracy, packaging and integration, cost, and the number of sensors. Our possible methods were pressure distribution sensors, distance sensors, contact sensors, and laser cage. The laser cage would be a sensor and laser beam array surrounding the user which detects whenever the laser beam is broken. Using the Upright Pose as a baseline, we found that distance sensor and contact sensors best met our criteria. We decided to implement distance sensors because they aligned better with the team's capabilities and did not require the user to be touching the back of the chair at all times. We also decided to use pressure distribution sensors on the seat of the chair to sense more areas that were identified as key to good posture by the physical therapist we spoke with.

Table (3): Pugh Chart for Sensing Subsystem

Criteria	Weight	Sensors				Upright Pose
		Pressure Distribution	Position	Contact (touch)	Laser Cage	
		Method 1	Method 2	Method 3	Method 4	Baseline
Cost	2	1	1	0	-1	0
Number of sensors	1	-1	-1	-1	-1	0
Area covered	3	-1	1	1	0	0
Precision / Accuracy	3	0	1	1	-1	0
Packaging / Integration	2	1	0	1	-1	0
	Total	**0**	**7**	**7**	**-8**	**0**

The final subsystem we evaluated was the device packaging. We determined the criteria to be, in order from highest to lowest priority: comfort, universality, cost, non-intrusiveness, and ease of setup. The possible packaging methods were a chair attachment, a chair modification, a custom chair, and a wearable device. With Upright Pose as the baseline, the method with the highest number of points was the custom chair. We chose this method because it allowed for a comfortable chair with easy setup for the user, and allowed us as a team to implement a more universal sensing and feedback system without having to design for the many different shapes and sizes of existing office chairs for which a chair attachment would have to be built.

Table (4): Pugh Chart for Device Packaging Subsystem

Criteria	Weight	Packaging Methods				Upright Pose
		Chair attachment	Chair modification	Custom Chair	Wearable	
		Method 1	Method 2	Method 3	Method 4	Baseline
Cost	2	1	1	-1	0	0
Non Intrusive	1	1	1	1	-1	0
Comfortable	3	-1	0	1	0	0
Ease of setup	1	0	-1	1	0	0
Universality	2	1	-1	0	0	0
	Total	**2**	**0**	**3**	**-1**	**0**

Product Functionality

Our product will consist of two main sensor groups, all integrated onto one chair (Figure 4 in Final Detailed Design). There is an IR array lining the back of the chair (Figure 7 in Final Detailed Design) that is able to detect the distance and angle of somebody's back. There is also an array of load cells in the seat bottom (Figure 5 in Final Detailed Design) which detect weight distribution and can detect leaning.

There will also be two forms of feedback, vibration and a user interface. The vibration motors are mounted inside of the chair (Figure 6 in Final Detailed Design) and vibrate when the user has had bad posture for a preset period of time. A user interface will also be used to visualize the data (see Figure 3 in Final Detailed Design) from the sensors and give the user a better sense of how to improve their posture. Below is a product functionality table which describes each component, what it is made out of, and how it functions within the broader system.

Table (5): Components and Product Functionality

Component (Count)	Material	Functionality
IR Sensor (3)	N/A	● Measures distance from chair back to user back ● All three sensors work together to create a full picture of back position and angle
Force Sensor (4)	N/A	● Measures pressure distribution across the chair bottom ● Array of sensors work together to create a pressure map that can corroborate IR sensors and indicate if the user is tilting/slouching
Cross Bar (3)	Plywood	● Connects the mounting bracket to the chair ● Allows for 2 inches of vertical adjustability of the mounting bracket
Mounting Bracket (3)	6061 Aluminum	● Interfaces between IR sensor and chair ● Uses dowel pins to slide up and down the cross bar
Thumb Screw (6)	8-18 Stainless	● Allows the user to tighten or loosen the mounting bracket to adjust the location of the IR sensor
Vibration Motors (4)	N/A	● Our primary form of feedback that alerts the user that they are out of their acceptable posture range
Motor Bracket (2)	3-D Printed PLA	● Attaches the vibration motor to the chair rigidly ● Transmits vibrations from the motor into the chair for maximum user feel
Force Sensor Sandwich (1)	3-D Printed PLA	● Allows for the force sensor to have a hard surface on both sides to get an accurate reading ● Also serves to mount the sensors to the chair bottom

System Functional Analysis

Functional Decomposition Diagram

Our device is composed of 4 primary systems: the power, sensor, feedback, and physical systems. The diagram below (Figure 1) and the corresponding table (Table 6) demonstrate the workflow of the product and the description of each system.

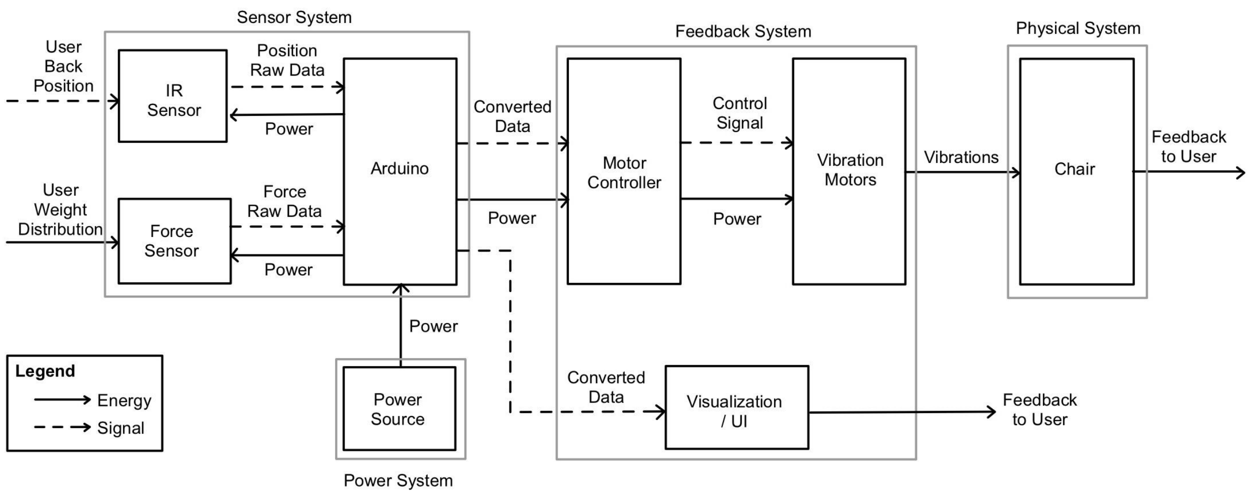

Figure (1): Functional Decomposition Diagram

Table (6): Functional Systems

Major System	Purpose	Example Components
Power System	Provide power to the electrical components of the chair	Rechargeable battery pack
Sensor System	Receive raw user data about their back position and weight distribution and converts it into data for analysis	IR sensors mounted via linear rails, force sensors mounted to a seat base, arduino
Feedback System	Determine if the user has poor posture and provide feedback to the user if their posture needs to be corrected	Motor controller, vibration motors, and motor mounts, visualization / UI
Physical System	Contain the other systems and interface point with the user	Chair with sensor system and feedback system that mount via bolting

Interface Specifications

The interface specifications show how a typical user is meant to interact with our product. The interface specifications are as follows:

1. The user sits down in the chair.
2. The user initiates a calibration sequence through the software.
3. They are instructed to assume good posture while the software takes a baseline reading of their good posture.
4. The user is then able to use the software to set key settings like acceptable posture limits and length of time before becoming alerted.
5. The user then assumes regular use of the chair, getting feedback vibration whenever they leave their acceptable posture limit.

Prototype Tests and Performance

Prototype Description

Our first prototype exhibits two iterations, where we experimented with ultrasonic sensors first mounted on the rail system. For our second iteration, we replaced the ultrasonic sensors with infrared. We also attempted to implement force-sensitive resistors but switched to load cells due to the reliability issues associated with the force-sensitive resistors. Finally, we also implemented a feedback system with vibration motors. These control systems are integrated together on one device and feed data to the UI system. Images of our prototype evolution can be found in Appendix 5.

Infrared Analysis

Our final prototype iteration features three infrared (IR) sensors mounted on adjustable aluminum blocks. To recap, our decision to implement these sensors were assessed from our tradeoff (Ultrasonic versus Infrared) comparisons. Infrared tended to demonstrate less noise variation, especially at farther distances. On average, the Sharp GP2Y0A21YK0F Analog sensor has an average detection range from 10 to 80 cm, with an measured error approximation of 1 to 2 cm for each sensor. Possible error can be attributed to electromagnetic interferences between the aluminum cross bar and infrared sensor. After reading values, noise was reduced by averaging five distance readings per second. Values unlikely to be read for a seated user's back, i.e. readings greater than 60 cm, were treated as Nulls and omitted. We witnessed a significant reduction in noise with our data. We computed the angle between the three detected points via Law of Cosines, where the angles detected between 150 and 180 degrees were deemed as appropriate posture. There is much improvement for calibrating the configuration towards maximizing good posture accuracy. Referencing the 3-Point Diagram (Figure 41, Appendix 6), we'd expect the user to adjust the top sensor (1) opposite their shoulder blade, middle (2) towards the middle of their back, and bottom (3) opposite their lower back. This would ensure that the angle reported represents even proportions and consistency.

Load Cells

In order to increase accuracy and range of posture sensing, our group decided to implement another sensor type into our chair to function in tandem with the IR sensors. The research and study we used to justify our decision to utilize load cells to measure weight distribution to detect slouching and leaning is detailed further in section A5 of the Appendix.
To accurately assess changes in weight distribution in our product, we needed a sensor to be able to detect and measure large forces when sandwiched between the foam and leather layers of our seat cushion. In our initial round of testing we found the force resistive sensors (FSR) we utilized in our prototype to be unable to function within our experimental constraints. Subsequently, we ended up utilizing load cells to assess human weight in our product. The load cells we utilized were half bridge load cells capable of measuring up to 50 kg (~110lbs) and had

to be paired with an amplifier, as the arduino's analog to digital converter isn't sensitive enough to register the small voltage changes occurring internally in the cells. In order to use the load cells, we needed to configure the sensors to form a full Wheatstone Bridge circuit (depicted in figure 43 in Appendix 7) to read changes in voltage and resistance and subsequently calculate applied force [29]. We tested several different electrical configurations (further detailed in Appendix 7) and found that soldering two half wheatstone bridge cells together (meaning two load cells would work in tandem to measure weight) to form a full circuit, produced the most stable and least erratic data readings.

We ran into several issues when attempting to calibrate our cells. We found we had trouble getting the load cells to consistently produce similar output values for the same applied force. The cells would detect changes in applied force, but these values wouldn't change on the same scale between each other. Generally, load cells form a full Wheatstone bridge internally with three fixed resistors and only one resistor being variable. This resistor is meant to be adjusted for the calibration process. Our load cells however, function as half wheatstone bridges, containing two variable resistors. This complicates the calibration process, as the resistor values change relative to each other to produce an average value. When troubleshooting this problem, we found that solving this problem would require the manual creation of a calibration curve; factoring in non-linearity, hysteresis (maximum values outputted between load cells for the same force applied), and error, which is beyond the scope of our project [31]. To try and account for this issue, we manually adjusted calibration values through constant experimentation and analysis of the data. However, because of the scope of this issue, for our final prototype we decided to provide feedback on these sensors solely via our user interface (further detailed in Appendix 7). To account for drift, we reset the cells every so often to allow the output values to restabilize and produce proper values. To eliminate these calibration issues, we would utilize load cells with only one variable resistor.

Vibration System

The objective of our first round of feedback system testing was to make a proof of concept to show that we could provide haptic feedback—vibrations— to the user. To do this, we mounted a motor system to the seat bottom using 3D printed mounts to determine whether the vibrations could be felt and whether changes would have to be made to the mount design. In our initial prototype, we had only 2 motors hooked up to the Arduino system and we ran the motors at full speed. Users noted that they could feel the feedback and it felt like a massage chair, which indicated that it was comfortable to use without being intrusive. This met our user comfort design requirement. However, the target correction area was unclear, so having visualization feedback as a supplement would be useful. Additionally, users wanted more customization options. On the assembly end, we found that the mount was difficult to assemble on the chair. However, overall we were able to prove that the concept works as vibrations could be felt with just two motors.

For our final prototype, we updated the system to make it easier to assemble and introduced customization with different vibration levels. The lower level has the motors running at a lower speed and the higher level has the motors running at a high speed. More detail can be found in Appendix 8.

Engineering Analysis

Battery Life Analysis

Assumptions:

- Parallel arrangements of sensors assuming common connection to arduino 5V source
- Amplifier increases voltage/current or power of signal for load cell
- Arduino provides maximum 200 mA of current [28].
- Individuals on average work for 8 hours per day at their desk

Table (7): Relevant Variables

Variable	**Definition**
V	Voltage in Volts
I	Current in Amperes
P	Power in Watts
I $\times$ Hour	Current in Amperes over one hour
P $\times$ Hour	Power in Watts over one hour
Time	Total Battery Operation Hours / Single Charge

Table (8): Power Breakdown

	Quantity	**I (Amp)**	**V (Volts)**	**Power (W) = Quantity $\times$ I $\times$ V**
Infrared Sensor	3	0.03	5	0.45
Load Cell	4	0.0015	5	0.03
Vibration Motors	4	0.0018	5	0.036

$P_{Total\ Drawn}$: 0.516 Watts

Table (9): Battery Life Analysis

	V	**I $\times$ Hour**	**P $\times$ Hour**	**Time =** P $\times$ Hour / $P_{Total\ Drawn}$	**Work Days** = Time / 8 hours / day
5 Volt Port	5	12	60	108.7	13.59

Piston Mount FEA

The purpose of this analysis is to determine material selection for the mass manufactured seat piston mount assembly. We want to be able to accommodate up to the 95th percentile male in height and weight, which makes our load case 250 pounds (1110 N). For simplicity, we decided to use the current geometry from CAD we recreated off of the current chair, and optimize for material strength. Our assumptions are as follows:

- Piston assembly treated as one solid body
- Distributed 250 lbf force across the top face, where it interfaces with the chair bottom
- Fixed support at the bottom of the assembly containing al 6 degrees of freedom
- Mesh convergence study conducted to within 10% change of peak stress
- Piston assembly analyzed in the most retracted position
- A static load of 250 lbf was used, with the expectation that dynamic loads would be acceptable with a factor of safety of 3

The analysis yielded results of 140 MPa peak stress at the smallest part of the piston. This result is corroborated with hand calculations, which give a result of 130.5 MPa, which is within 10% of the FEA value. Hand calculations can be found in Section 9 in the appendix. Using this result we can find a proper material for our purposes.

Table (10): Piston Mount FEA Results

Material	**Yield Strength (Mpa)**	**Factor of Safety**	**Cost**
Stainless Steel	275	1.94	$$$
6061 Aluminum	275	1.94	$
1018 Steel	370	2.64	$
4130 Steel	435	3.10	$$

4130 steel is a good balance between cost, maintaining a high enough factory of safety for dynamic loads, and manufacturability.

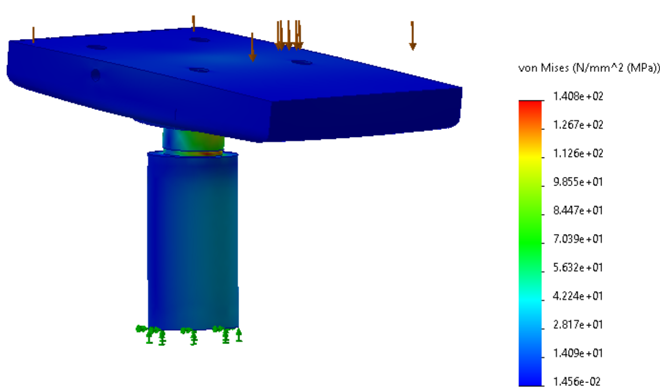

Figure (2): FEA Results

Motor Mount Material Selection via Thermal Analysis

The purpose of this analysis is to determine what material should be used for the motor mount based on the thermal properties of the material. We want to ensure that the mount can withstand the maximum temperature of the motor and it can dissipate heat enough that the motor does not burn out. This was done through hand calculations using Fourier's Law and thermal resistance. Here are the assumptions made:

- The system is in a steady state.
- The thermal properties are constant.
- The heat input is constant.
- The system undergoes 1D radial heat conduction.
- The system is modeled as a series of concentric cylinders with the output at the minimum distance between the seat fabric and the motor.
- The temperature of the fabric starts at 20°C, which is the room temperature.
- Motor efficiency is 80% [21].

The thermal model of the system is shown in Figure 50 of Appendix 9. In the diagram, the components are labeled with the subscript that will be used in parentheses. The power is Q (W), and it is the product of the voltage V (V), current I (A), and 1 minus the efficiency η. Other properties of the system include the radius r (m) of each component, the thermal conductivity k (W/mK) of each component, and the character length L (m) of the system. The thermal resistance R (K/W) of each material can be calculated using:

$$R = \frac{ln(r_2/r_1)}{2\pi Lk}$$

where r_2 is the larger radius. Using the thermal resistance, the temperature difference can be calculated with:

$$Q = \frac{T_2 - T_1}{R}$$

This can be rearranged to determine the higher temperature:

$$T_2 = T_1 + QR$$

The constant properties of the system are in Table 11.

Table (11): Constant Properties of the System

Property	Variable	Units	Value
Voltage	V	V	5
Current	I	A	0.5
Efficiency	η	N/A	0.8
Heat Transfer Rate	Q	W	0.5
Motor Length	L	m	0.025
Motor Radius	r_M	m	0.0105
Casing Radius	r_C	m	0.0169
Padding Radius	r_P	m	0.0255
Fabric Radius	r_F	m	0.0265
Padding Thermal Conductivity[1]	K_P	W/mK	0.035
Fabric Thermal Conductivity[2]	K_F	W/mK	0.09
Padding Thermal Resistance	R_P	K/W	74.82
Fabric Thermal Resistance	R_F	K/W	2.72

1. The thermal conductivity for the padding is that of foam [22].
2. The thermal conductivity for the fabric is that of synthetic leather [23].

Given the initial condition of the fabric starting at the initial temperature of 20 ºC, the temperature of the system at each component interface can be found in Table 12 below.

Table (12): Temperature Distribution of the System of Component Interfaces

Property	Variable	Units	Value
Fabric-Air Interface Temperature	T_F	ºC	20.0
Padding-Fabric Interface Temperature	T_P	ºC	21.4
Casing-Padding Interface Temperature	T_C	ºC	58.8

To determine which injection molded material would be most ideal, we looked at the thermal properties of various common injection molding materials and determined which would result in the lowest motor-casing interface temperature [24][25]. The results are outlined in Table 13 below.

Table (13): Temperature Results for Varying Casing Material

Material	**Thermal Conductivity K_C (W/mK)**	**Thermal Resistance R_C (K/W)**	**Motor-Casing Interface Temperature T_M (ºC)**
Acrylonitrile Butadiene Styrene (ABS)	0.21	14.43	66.0
Polyamide (Nylon)	0.3	10.10	63.8
Polycarbonate (PC)	0.22	13.77	65.7
Low Density Polyethylene (LDPE)	0.33	9.18	63.4
High Density Polyethylene (HDPE)	**0.52**	**5.83**	**61.7**
Polypropylene (PP)	0.22	13.77	65.7
Polystyrene (PS)	0.13	23.31	70.4

Given these results, the most ideal material for reducing the temperature of the motor to prevent burnout would be HDPE. Although there is not a datasheet for this exact motor, the datasheet for a motor with similar specifications indicates that the highest operating temperature is 60 ºC [26]. Under the assumption that the motor used has a similar maximum operating temperature, we can see that 61.7 ºC is a close enough number that it should be reasonable. Furthermore, under real loading conditions the motor would not be run continuously. Given the low heat transfer rate, the motor would likely not be operating long enough to heat up to that temperature.

Component and Material Selection

The following table details the material/component used, the part it's used in, as well as the justification for its use in the manufactured version of our chair. The materials and components mentioned in the table cover materials not mentioned in the Engineering Analysis section of this report.

Table (14): *Material Selection*

Material	**Part**	**Justification**
Plywood	Cross Bar	- Increased stability - High impact resistance - High strength to weight ratio
HDPE	Mounting Bracket, Force Sensor Mount, Motor Mount	- UV Resistant - Relatively stiff material - Can withstand temperatures from -148 to 176 degrees Fahrenheit - Cost-effective - Resistant to most chemical solvents
Foam	Cushioning Layer for load cells and seat bottom	- Lightweight material - High elasticity and resilience - Excellent thermal insulator - Good shock absorber/damper

Component: Infrared vs Ultrasonic Justification

We compared the infrared and ultrasonic readings by placing both sensors 6 inches apart, and 30 cm away from the edge of the table. The sensors' transmitter and receivers were flush such that light/sound waves could be transmitted from the same distance. A 2x1 foot board was shifted by hand with consistent speed (approximately 2 cm per second) close and far from the sensors, with controlled theoretical distances ranging from 2 to 30 cm. Our setup was tested in the first floor open techspark lecture room, with little light influence and noise disturbance. The graph (referenced in the Appendix 6) demonstrates the distance readings for one infrared and ultrasonic sensor. Arduino data was collected every 200 milliseconds. The blue stars highlight where ultrasonic grossly overestimated the distances, and where infrared was able to discern readings more accurately. The magenta stars represent where infrared wasn't able to pick up distances less than 4 cm. As seen in the 'Conclusions' section in Appendix 6, our mean & standard deviation values for both readings displayed 14% & 5.8% differences. Based on our graph and calculated statistics in Appendix 6, it seems reasonable that both sensors are able to detect surfaces with fair precision. Ideally, we would aim to reduce the yellow area as much as possible. A spike in ultrasonic reading could be attributed to spikes in speed of the surface movement, since faster movement away from the ultrasonic sensor could cause noise. Since we don't expect our user to move beyond 20-30 cm away from the chair back, and also don't want them to move too close to the back, it seems that the infrared sensor would be the suitable choice given its overall precision at distances within 5-30 cm.

Component: Load Cells vs FSR Justification

Initially, we utilized small, thin force resistive sensors (FSR) capable of measuring up to 30 kg (~66lbs). We configured sensor wiring to model a voltage divider circuit depicted in Figure 52 in order to read changes in voltage and subsequently calculate forces. We ran into several problems when utilizing these sensors to collect data. One of the issues we had was in calibration of these sensors for accuracy. Force resistive sensors function by applying a point force directly to its spacer opening, with resistance decreasing as more force is applied. However, the relationship between force and resistance isn't linear. To calibrate these sensors to produce accurate readings, the manufacturer's best fit curve establishing the relationship between mass applied and resistance must be utilized to interpret these results linearly within particular force ranges. The manufacturer's curve we utilized for this is depicted in Figure 51 and is referenced in Appendix 10 [3].

Even with utilizing a curve for our sensor, we found that our force measurements when checked with a scale were producing large values of error. In conducting further research to produce more accurate results, we found that varying the resistor value in our voltage divider circuit could vary our equipment sensitivity to forces within certain ranges. In accordance with Figure 53 (located in Appendix 10) which showcases the relationship between output voltage, force, and varying resistor values, we found that choosing a lower fixed resistor value would yield better sensitivity at higher forces [5]. Thus, to better be able to detect the higher forces necessary to measure human weight distribution, we utilized the lowest fixed resistor value we had in our possession, at 10Ω. However, despite our efforts to make our sensor more sensitive to higher force values, we found that our sensor was still unable to accurately detect high forces. We also tested the FSR's capability of registering forces on various surfaces and sandwiched between various materials. We found that FSR's were only able to properly detect point forces applied on solely hard surfaces. Thus, we found these sensors to be better suited for human touch, but completely unsuitable for measuring weight distribution within the constraints necessary for our product.

Subsequently, we switched our sensor component from FSRs to small loads capable of measuring up to 50 kg (~110lbs) each. We configured the sensor wiring to model a Wheatstone Bridge circuit in order to read changes in electrical resistance and subsequently calculate force. We subjected the load cells to larger forces, in order to test their ability to detect human weight distribution. We also tested the cells on various surfaces and sandwiched between various materials; including the foam and leather components of our chair. We found that these cells were able to effectively detect changes in human weight distribution under all of our material and surface constraints. Thus we found these sensors to be better suited to be utilized for measuring human weight under our experimental constraints. The table below summarizes our justification for utilizing these load cells over our initial FSR sensor component.

Table (15): Force Sensor Justification

Component	Part	Justification
Load Cells	Sensor System integrated in seat cushion	- Ability to detect changes in human weight distribution - Ability to detect forces sandwiched between material - Ability to detect forces on various surfaces

Final Detailed Design

Detailed Design Description

Our product consists of four main systems, each with their own subsystems. The first main system is the sensing system which gathers data from infrared distance sensors embedded into the chair back, as well as force sensors embedded in the chair bottom. These two sensor arrays allow us to understand the user's back position and angle, as well as their weight distribution. The user will be able to set a personalized benchmark when they first use the product and then the sensors will work in tandem to detect back angle, slouch, and weight distribution. The acceptable range of positions will be able to be customized by the user.

Once the user has been outside of the acceptable posture range for an amount of time set by the user, they will receive feedback from our feedback system to correct their posture. This will come in the form of vibrations in the chair and two graphics from our user interface system that will help the user visualize their posture. Figure 3 depicts the graphics the UI will output to the user, with two separate images showing a map of the users back and back angle, as well a seat map showing changes in the users weight distribution. These feedback mechanisms will alert the user that their posture is not in their acceptable range and they will be compelled to correct their posture. These two systems are integrated in the physical system of the chair which all sensors and motors mount to. Additionally, they are run by our power system which provides power where needed.

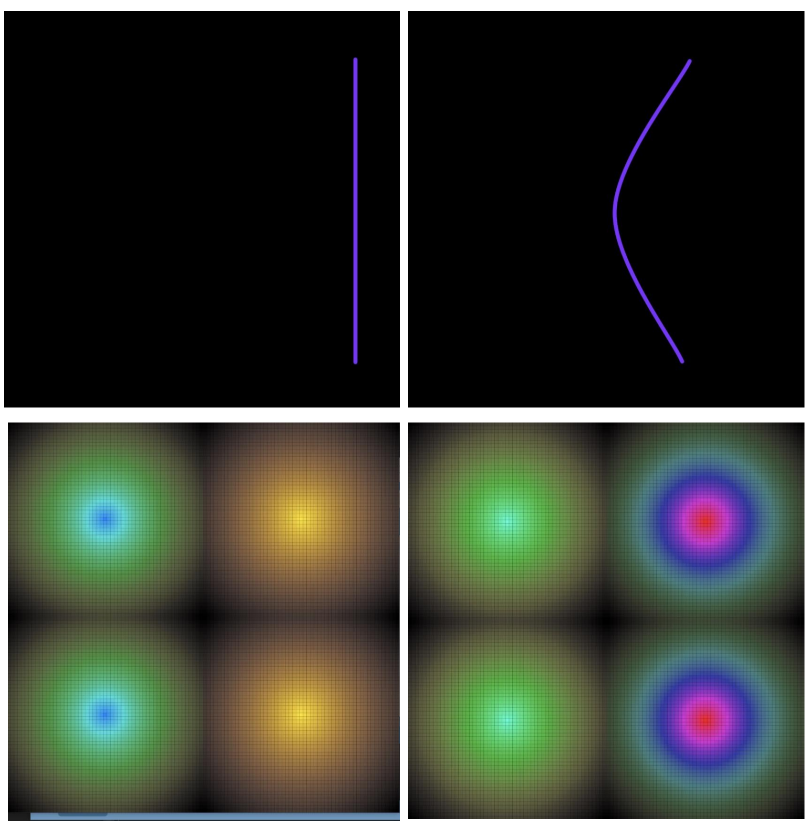

Figure (3): UI Visualization

Complete CAD Model

Figure 4: Final CAD render of the entire product

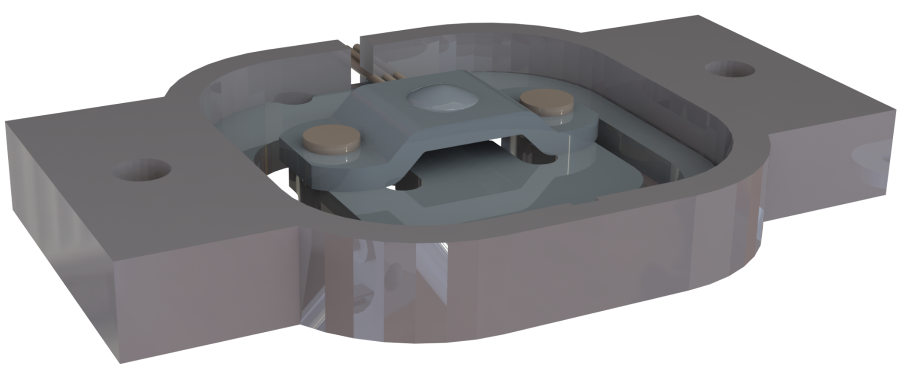

Figure 5: Load Cell case

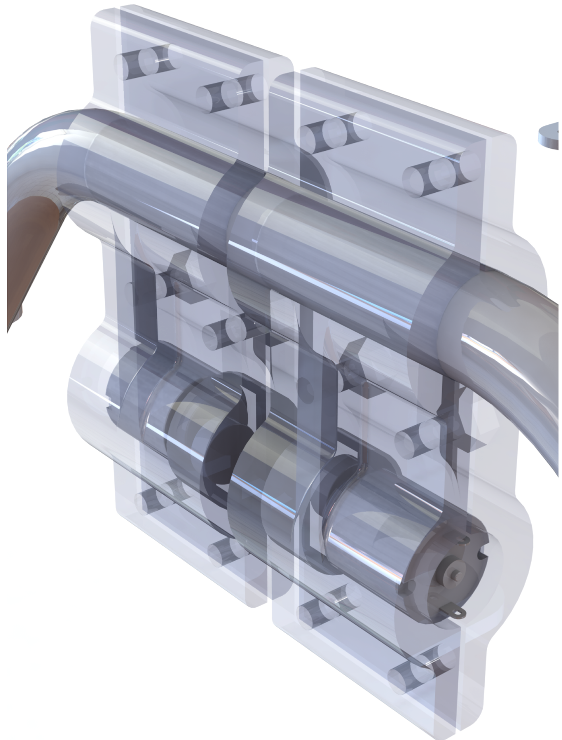

Figure 6: Motor Mount and motors

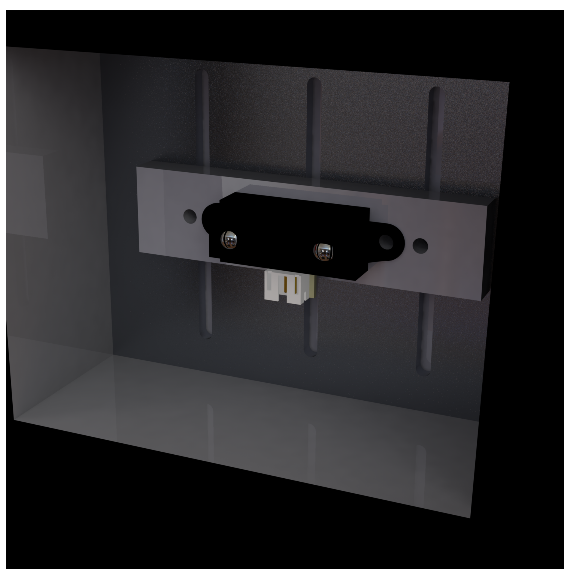

Figure 7: IR Sensor and mount

Bill of Materials

The following table details the parts and materials needed to build the chair. Because our product is a modified version of a pre-existing chair, we assume any parts that already existed from our original chair are standard. Any manufacturing or assembly-related modification that has to be made to a component or parts that do not already exist are considered custom.

Table (16): Bill of Materials

Item No.	Part Name	Description	Material	QTY	Part Type
1	IR Sensor	Sensor for determining back position	Copper	3	Standard
2	Force Sensor	Sensor for determining weight distribution	Steel	4	Standard
3	Vibration Motor	Eccentric motor for providing haptic feedback	Steel	4	Standard
4	Printed Circuit Board (PCB)	Circuit board for controlling the sensor and feedback systems and connecting to the UI	Copper	1	Custom
5	Battery Pack	Rechargeable battery to power the device	Lithium-Ion	1	Standard
6	Wiring Cables	Cables to connect the electronic systems	Copper	13	Custom
7	IR Sensor Bracket	Mounting bracket for the IR sensor to the back base	HDPE	3	Custom
8	Force Sensor Bracket	Mounting bracket for the Force sensor to the seat base	HDPE	4	Custom
9	Vibration Motor Mount	Mounting bracket for the vibration motor to the seat frame	HDPE	4	Custom
10	Seat Base	Seat base plate	Plywood	1	Standard
11	Seat Frame	Seat shape metal frame	1018 Steel	1	Standard
12	Seat Springs	Springs to maintain chair shape	Music Wire Steel	1	Standard
13	Arm Rest	Arm Rest	HDPE	2	Standard

14	Padding	Padding for user comfort	High Density Polyure-thane Foam	2	Standard
15	Back Base	Chair back wood base	Plywood	1	Standard
16	Back Frame	Chair back shape metal frame	1018 Steel	1	Standard
17	Back Crossbar	Interface between IR mounting bracket and chair that allows for adjustability of the sensor position	Plywood	3	Custom
18	Thumb Screws	Screws to tighten or loosen IR mounting bracket for position changes	8-18 Stainless Steel	6	Standard
19	Outer Fabric	Casing fabric for the chair	Synthetic Leather	1	Custom
20	Mesh	IR transparent mesh to cover casing	Mesh Polyester Fabric	1	Standard
21	Electronics Box	Enclosure for the PCB and battery pack for compact packaging	HDPE	1	Custom
22	Screws	Screws for holding together the frame and chair	8-18 Stainless Steel	20	Standard
23	Chair Piston	Piston for raising and lowering chair height	4130 Steel	1	Standard
24	Chair Wheels	Wheels for rolling the chair around	Nylon	6	Standard
25	Chair Base/Legs	Base and legs for chair structure	HDPE	1	Standard

Manufacturing and Assembly Techniques

The following describes the primary manufacturing and assembly techniques needed for our product under mass production conditions. We assume that all tools and materials are available. Because this is a modification of an existing chair, we assume that the parts that were pre-existing in the chair can be purchased from a chair mass manufacturer and other standard parts can be purchased from a supplier such as McMaster (hardware) or DigiKey (electronics).

The first table describes the manufacturing techniques needed for custom parts. The second table describes the assembly techniques needed for the device.

Table (17): Manufacturing Techniques

Component	**Manufacturing Method**
Printed Circuit Board	Printing
Wiring Cables	Soldering, Crimping, and Sheathing
Back Crossbar	Routing
IR Sensor Bracket	Injection Molding
Force Sensor Bracket	
Vibration Motor Mount	
Electronics Box	

Printing a Circuit Board

Rather than using an arduino in our mass-manufactured design, we want to have a PCB so that we can make a custom circuit board for the system's electronics and upload our firmware directly to that board rather than being attached to an arduino. Printing PCBs is cheaper than other wiring methods and can be done easily on a mass scale. It would be cheaper than implementing multiple arduino boards and breadboards onto each chair as they would all be integrated into the PCB instead.

Soldering, Crimping, and Sheathing Cables

For interfacing with the PCB, we can directly solder stranded wire to the board. This is a common method and can be incorporated into the PCB manufacturing process directly. On the other end of each wire, crimping and attaching pin heads or soldering directly to the electrical components would make the most sense as the motors and sensors each have their own method of wiring. By using a combination of soldering and crimping, we can easily assemble the wires. Sheathing the cables with some insulating material would be the final step of the manufacturing process. This is needed to protect the cables and keep them contained.

Routing

The wood crossbar is a simple component with slots and drill holes. Three are needed for each chair. These can be easily mass manufactured on a large plank of wood with multiple pieces routed out of it. That way, the cross beam can be produced quickly and the routing setup can be left to run multiple times.

Injection Molding

Injection molding is a common technique for manufacturing of plastic parts that is inexpensive at large scales and can meet geometric tolerances as needed. These parts all require custom geometry. They are not load bearing, so they can be made of plastic. These parts all have basic tolerances to ensure that the standard parts they are interfacing with can fit the injection molded part. Each chair requires multiple brackets and mounts, and one of the electronics boxes. Therefore it makes sense to use injection molding as there are many components that would be repeated.

Table (18): Assembly Techniques

Steps	**Description**
Injection Molding	All injection molded components are made and prepared for assembly.
PCB, Cable, and Electronics Assemblies	The PCB, cables, and electronics are made and assembled together and mounted to their corresponding enclosures and brackets.
Fabric Assembly	The existing outer fabric purchased from mass manufacturers would be modified to have slots cut out and the mesh material would be sewn in instead.
Metal Frame	The metal frame is made of steel to make it easy to weld and cheap in mass manufacturing. It needs to be welded together and then assembled onto the wood backing pieces.
Seat Bottom Assembly	The seat bottom components are bolted together. The foam is attached with adhesive and the force sensor mounts are adhered to the foam. The motor mount is bolted onto the side frame.
Chair Back Assembly	The chair back components are bolted together. The IR sensor mount is attached to each cross bar.
Electronics Box Assembly	The PCB and battery are mounted to the electronics box.

Once these individual assemblies are made, they are all assembled together. The seat bottom and back go together. The electronics box is mounted to the underside of the chair. The fabric assembly is then put over the entire system.

Cost Estimate

Given our cost analysis, we expect that a fair price for our product is $275. This value reflects the unique gap in the market this product fills as well as leaving enough room for a healthy profit margin and fixed cost such as factory bring up, engineering costs and logistics. The following table is a cost breakdown of what we estimate the first 10,000 units would cost, on a per unit basis.

Table (19): Cost Estimate

Part Name	Quantity	Cost Per Unit	Source	Total Cost
IR Sensor	3	$5.17	Digikey.com	$15.51
Force Sensor	4	$4.86	Digikey.com	$19.44
Vibration Motor	4	$2.89	Digikey.com	$11.56
Printed Circuit Board (PCB)	1	$12.86	PCBWay.com	$12.86
Battery Pack	1	$19.77	Amazon.com	$19.77
Wiring Cables	12	$0.05	Digikey.com	$0.60
IR Sensor Bracket	3	$2.57	icomold.com	$7.71
Force Sensor Bracket	4	$1.25	icomold.com	$5.00
Vibration Motor Mount	4	$1.56	icomold.com	$6.24
Seat Base	1	$7.52	Industrial suppliers	$7.52
Seat Frame	1	$7.43	Industrial suppliers	$7.43
Seat Springs	1	$6.85	Industrial suppliers	$6.85
Arm Rest	2	$5.48	Industrial suppliers	$10.96
Padding	2	$5.12	Industrial suppliers	$10.24
Back Base	1	$7.56	Industrial suppliers	$7.56
Back Frame	1	$6.89	Industrial suppliers	$6.89
Back Crossbar	3	$3.51	McMaster-Carr	$10.62
Thumb Screws	6	$0.56	McMaster-Carr	$3.36
Outer Fabric	1	$0.30	McMaster-Carr	$0.30
Mesh	1	$0.25	McMaster-Carr	$0.25

Electronics Box	1	$5.92	icomold.com	$5.92
Screws	20	$0.05	McMaster-Carr	$1.00
Chair Piston	1	$5.12	Industrial suppliers	$5.12
Chair Wheels	6	$2.96	Industrial suppliers	$17.76
Chair Base/Legs	1	$7.25	Industrial suppliers	$7.25
Labor Costs	.25 hrs	$1.53	Assume $6.15 China minimum wage	$1.53
Factory Overhead	-	$10	$100,000/10,000 units	$10
Materials and logistics overhead	-	$5	$50,000/10,000 units	$5
Engineering costs	-	$15	$150,000/10,000 units	$15
			Total Cost:	$239.25

Failure Mode and Effects Analysis

The following table includes the four components most at risk of failure in our product and their severity, occurrence, and detection numbers which are each decided on a scale of 1-10 and used to calculate the Risk Priority Number for the failure mode. The highest risk failure is circuit failure, with an RPN of 225, and the lowest risk of failure is the swivel base buckling, which has an RPN of 40.

Table (20): Failure Mode Analysis Risk Priority Number Calculation

Item	**Failure Mode**	**Severity**	**Occurrence**	**Detection**	**Risk Priority Number**
Battery	Discharged	**7**	**8**	**4**	**224**
Motor	Stall	**6**	**2**	**5**	**60**
Swivel base	Buckling	**10**	**4**	**1**	**40**
Circuit	No current flow	**5**	**5**	**9**	**225**

Table (21) includes each failure mode with its effects, causes, existing design controls, recommended further actions, and who is responsible for those actions.

Table (21): Failure Mode Analysis

Item	**Failure Mode**	**Effects of Failure**	**Cause of Failure**	**Design Controls**	**Recommended Actions**	**Responsibility**
Battery	Discharged	No power to electronics	Extended use	Rechargeable battery	Make battery charging easily accessible	Design Engineer
Motor	Stall	No vibration feedback	Extended periods of use at high speeds	Motor is only programmed to spin for a few seconds at a time	Program hardware to prevent constant motor use	Software Engineer
Swivel base	Buckling	User falls out of chair	Weight limit exceeded	Weight limits; stress analysis	Additional stress testing	Design Engineer
Circuit	No current flow	Electrical components (motors, load cells, or IR sensors) lose connection to system	Broken wire connection	Soldering	Prevent exposed wires and solder all connections	Electrical Engineer

The four most prominent failure modes for our product are battery discharge, motor stall, the chair buckling, and no current flow in the circuit. Our design addresses battery failure by implementing a rechargeable battery that is easily accessible by the user. Motor stall is prevented by programming, because the vibration motors are only run for 5 seconds at a time. The swivel base buckling was accounted for by stress analysis on the chair, and is prevented by user weight limits. Circuit failure cannot be completely eliminated, but soldering all connections and preventing exposed wires in the mass produced product will greatly reduce the risk of that failure.

Life Cycle Analysis

The following table details items making up the manufactured version of our chair and the subsequent parameters used to calculate Carbon dioxide emissions associated with our products life.

Table (22): Life Cycle Analysis

	Production			
	Sensor System		**Feedback System**	**Physical System**
	Item 1	**Item 2**	**Item 3**	**Item 4**
Item	**IR Sensors**	**Load Cell**	**Vibration Motor**	**Chair**
Best match economic Sector # and name	#334: Computer and Electronic Products	#334: Computer and Electronic Products	#33399B: Hydraulic pumps, motors, cylinders and actuators	#33721A: Office furniture and custom architectural woodwork and millwork
Confidence	Medium	Medium	High	High
Reference unit	kg	kg	kg	kg
Units consumed per product life	0.014	0.64	0.40	18
Cost per unit	$3084.27	$10.21	$20	$16.67
Lifetime cost	$43.18	$6.53	$8.00	$300.06
Economy-wide kgCO2e released per $1 Output of industry	$0.073	$0.073	$0.217	$0.222
Implied kgCO2e per product life	$\$3.15 \cdot 10^{-6}$	$\$0.477 \cdot 10^{-6}$	$\$1.74 \cdot 10^{-6}$	$\$66.61 \cdot 10^{-6}$

We used data from the United States Environmental Protection Agency (EPA) to perform a lifecycle analysis on our product in order to assess its impact on the environment. Our analysis focuses on carbon dioxide (CO2) emissions, which are associated with both air pollution and global warming.The table above depicts the parameters used to calculate CO2 emissions associated with the life of our mass produced product. In our life cycle analysis, we performed calculations on the items making up the majority of our sensor, feedback, and physical systems. (update pie chart in response to changes on the table)

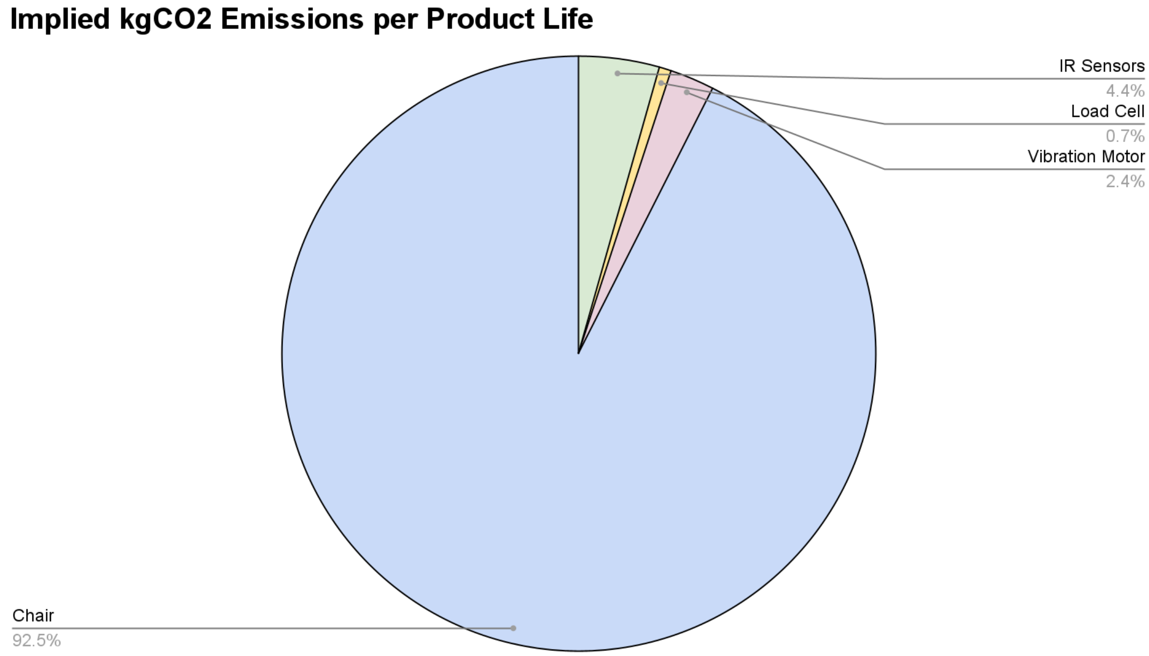

Figure (8): Pie chart of Implied kgCO_2 Emissions per Product Life

The pie chart above compares the implied emissions of CO2 per product life of each item. The metrics above show that the chair component of our product contributes the most to carbon dioxide emissions, making up 92.5% of the chart. If we were to make any design decisions around minimizing our carbon footprint, it would likely be to reduce the amount of material utilized in the creation of the chair. However, the actual metric values we calculated were exceedingly low (at $66.61x10^{-6} kg CO2) , indicating that our carbon footprint is already minimal. Because our design in itself contributes minimally to environmental impact, we chose to optimize the design of our chair around sensor integration and functionality. However, the life cycle analysis we conducted made us more conscientious on picking less variety of materials and minimizing the amount of materials to utilize for our physical system. These design decisions would further optimize the physical components of our system for our product's end of life stage.

Conclusions

Our research and analysis on popular competitive posture aids and correctors indicated several gaps in the market. Most competitive products on the market are unable to address posture correction holistically. Often these devices solely target one area of the body, neglecting the fact that to improve posture, multiple areas of the body need to be assessed and corrected. We also found that many competitive products fail to provide user feedback necessary for the individual to be aware of and fix poor posture. Our product meets our design specifications to fulfill these two functions, which allows our product to assess and correct posture more effectively than our competitors. Along with our product's functional capacity, our device is also able to accommodate various body types, is able to be easily set up, and is comfortable and nonintrusive to the user.

The sensor and feedback systems of our product provide a competitive advantage over other existing solutions on the market. Our sensor system is composed of infrared sensors and load cells. The infrared sensors detect distance points from three different areas of the back (upper, middle, and lower sections). Abnormalities are sensed when these data points drift too far from an initial baseline set by the user. The load cells pick up weight distribution changes associated with poor seated posture. These cells work in tandem with the IR sensors to confirm slouching results from the IR sensors. These cells also pick up posture deviations in locations the IR sensors wouldn't detect through shifts in weight distribution from the baseline pressure distribution of the user. The utilization of both sensors simultaneously to detect posture abnormalities, allow for the assessment of posture correction holistically. Our feedback system is composed of motors and software comprising a user interface system. Once the sensors detect posture abnormalities, the motors run to provide feedback to the user in the form of vibrations of varying intensities through the chair. This vibration serves as an alert to the user to correct their form. Along with the vibration feedback, the software produces a user interface that visually depicts data collected from both sensors as a form of visual feedback. A display of the users posture as well as a seat map is presented, so the user can visually monitor and correct abnormalities in their posture. Both methods of feedback serve to provide clear methods of feedback necessary for recognition of bad posture and correction to be initiated. The systems highlighted above fill the gaps we've identified in the market, which further set apart our product from other existing posture aids.

When conducting research on competitors, we found the market for posture aids and correction devices to showcase that consumers are willing to pay hundreds to thousands of dollars for an effective product. Our Pos-Chair, which costs $275, is much cheaper than other ergonomic chairs on the market. Ergonomic chairs generally cost thousands of dollars (generally ranging from $1000 to $2000) and have far less functionality than our product. Other competitors encompassing the wearable and smart device categories may be cheaper, but the market gap that we address gives our product more market value and justifies our devices' higher cost. We anticipate that our device will be profitable, and would expect to make a profit margin of about 14.94% per product. This margin is likely to increase as the parts required to create our product would decrease when ordering in bulk for mass production. Because of the value our product adds to the market and our predicted profit margin value, we would recommend commercializing our product.

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Appendices

Appendix 1: Notes for Future Teams

We have completed the ideation, design, prototyping, and iteration of a product that can be mass produced. Throughout this process, we have learned valuable lessons in design and prototyping. In terms of design, we learned more about the considerations that come from manufacturing methods, material selection, and life cycle analysis. We also learned about how to design for a specific user target and rapid prototyping. When coming up with design problems, we learned to do market research and find a design problem to solve based on gaps in existing markets. We ran into challenges with the electrical complexity of the system, so we learned a lot about using sensors, motors, motor controllers, and arduino. Over this time, we found that the Techspark staff was very helpful for troubleshooting technical issues such as wiring problems and sensor issues. Making use of online tutorials and libraries for Arduino code was helpful in figuring out how to approach code-related problems with the system and integrating it. Finally, we found it useful to just sit down as a group and talk through the problem and have people work on it together even if the problem was not one team member’s expertise because in walking through the problem, it was easier to find the correct solution.

In retrospect, there are parts of the process we would have done differently. One major lesson we learned was to be aware of scope. This falls in both ideation and throughout the design and iteration process. In ideation, we should have focused more on what our team’s realistic capabilities are and focused on what we know how to do rather than what we think we can learn in the amount of time we were given. In the design and iteration process, we should have focused more on tackling one aspect of the project at time and descoped earlier in the design process so that we can focus more of our energy on the parts that were not working. We also should have started earlier, especially when it came to ordering parts. There was potential for us to do more preliminary testing with different components, such as different load cells or different vibration motors. However, since we did not order early enough, by the time we realized the issues with our existing components, it was too late to adjust and start again. To keep on track, we should have set small achievable goals and focus on working towards a baseline proof of concept before adding on features.

For future teams, we recommend discussing with each team member’s goals and capabilities prior to team formation. Additionally, when coming up with initial ideation and potential project proposals, we suggest keeping in mind those team capabilities since the selected project will be much harder if there is a steep learning curve to the skills needed for those projects. Throughout the design process, focus on working together as a team rather than operating independently and checking in each meeting. Clear communication is key throughout the project so keep each other updated, and take group meeting notes to ensure that everyone is on the same page. It is also useful for tracking progress. When doing proof of concept prototypes, don’t hesitate to try different components (eg: different motors). The budget for this course is quite high so trying out more components is feasible. If future teams were to attempt to continue upon our project, we recommend getting in contact with a physical therapist to follow up throughout the design process and perform more user testing throughout the process.

Appendix 2: Full CAD Diagrams

Chair Back

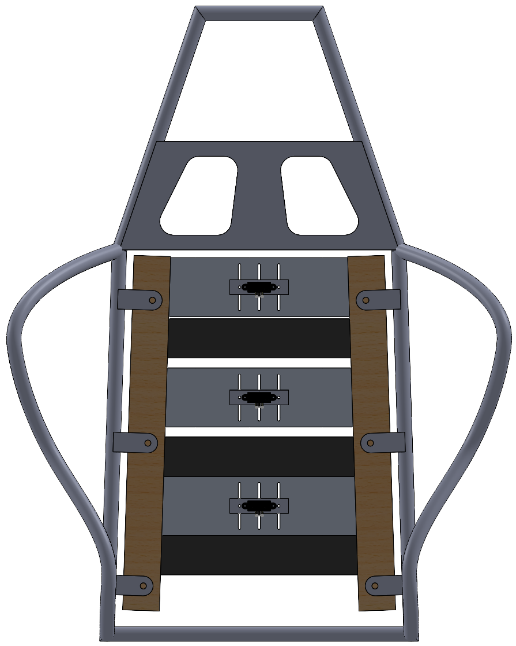


Figure (9): Front

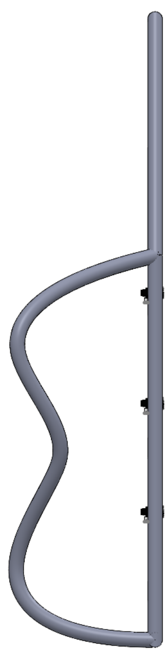


Figure (10): Right

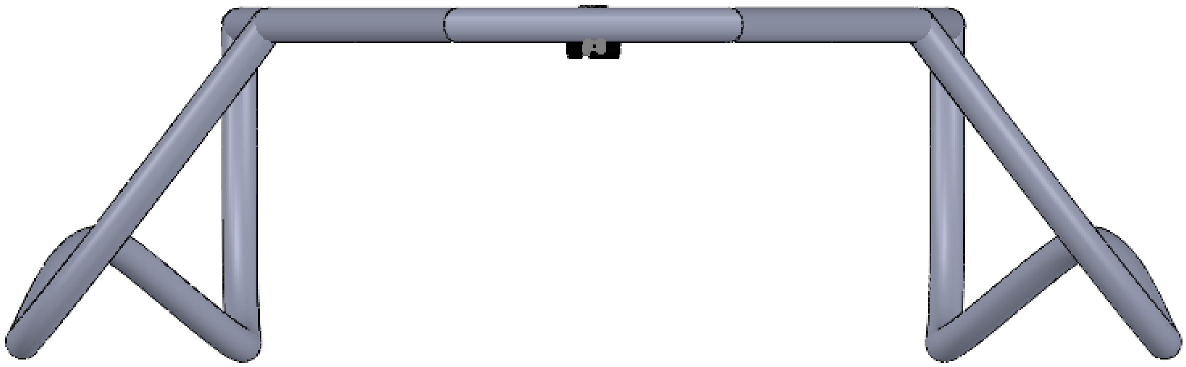


Figure (11): Top

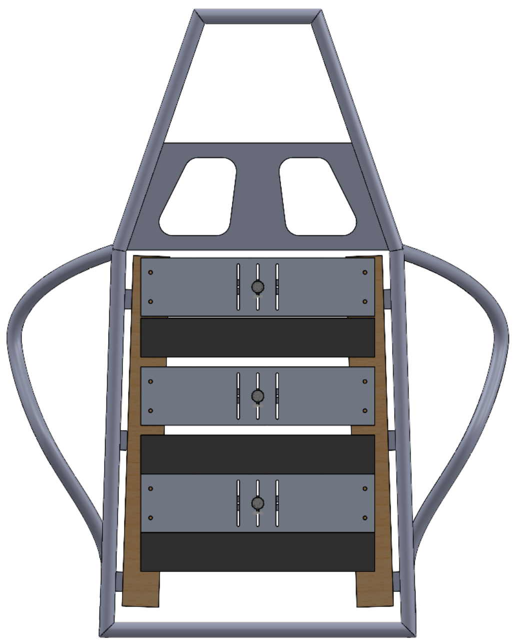


Figure (12): Back

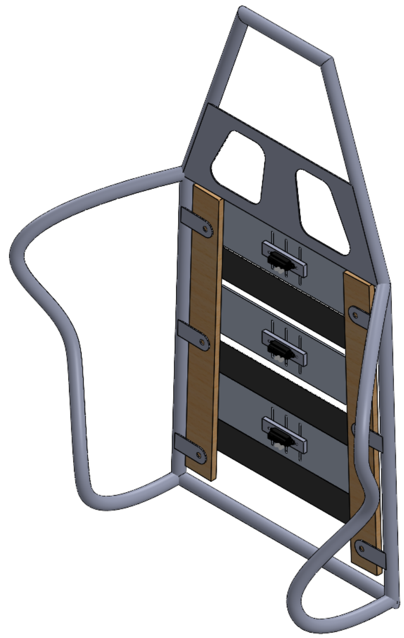


Figure (13): Isometric

IR Sensor and Mount

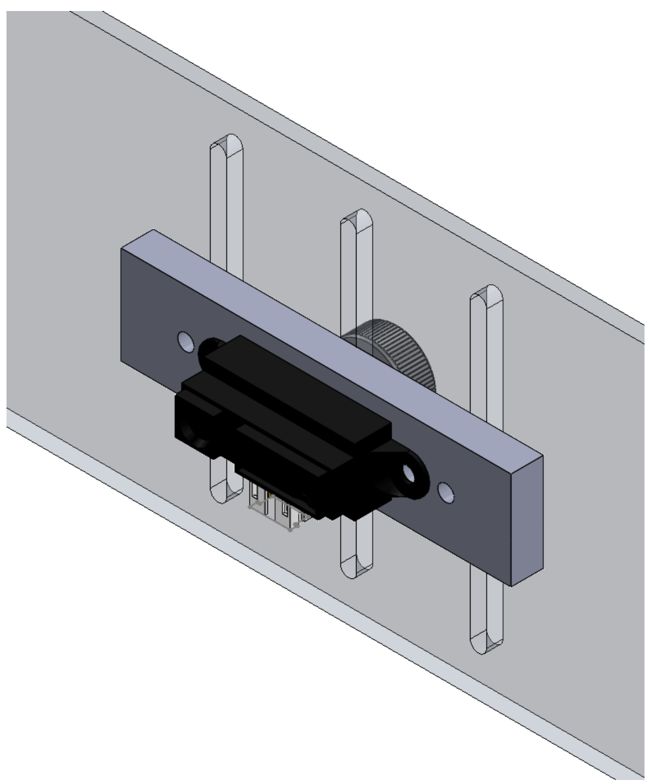


Figure (14): IR sensor and mount

Seat

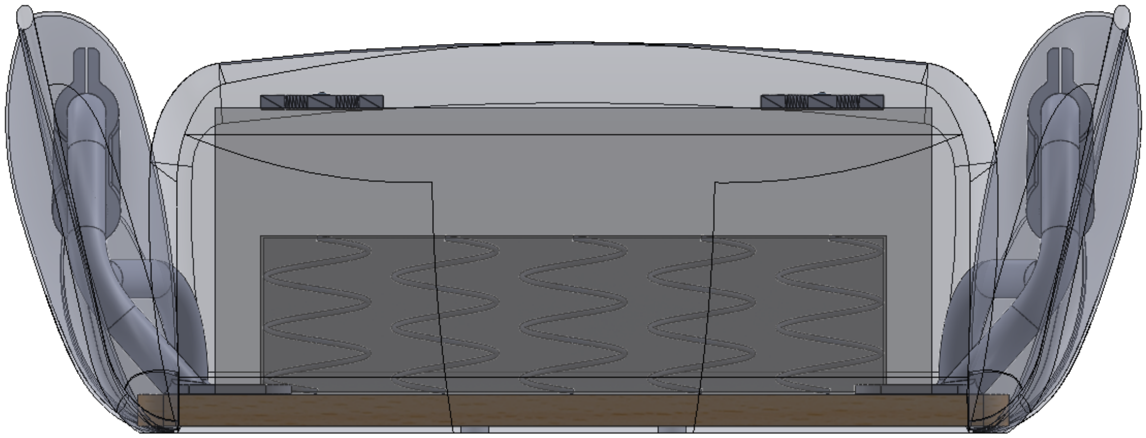


Figure (15): Front

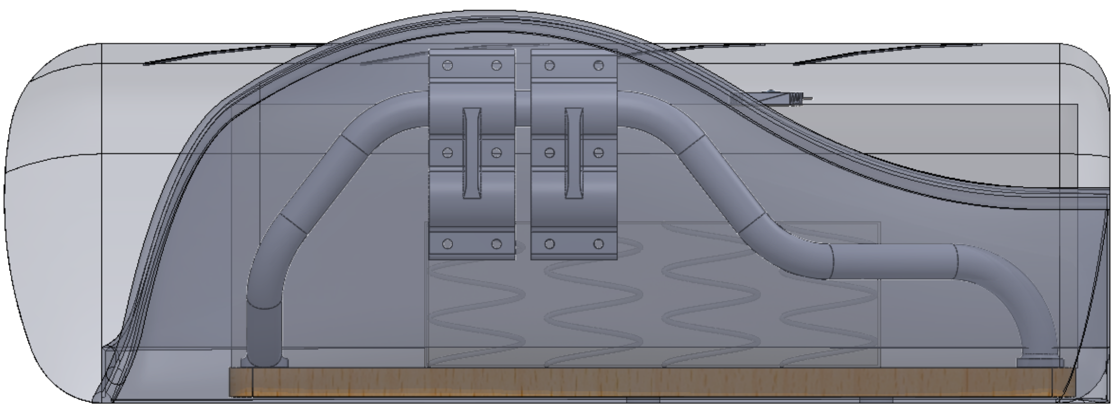


Figure (16): Right

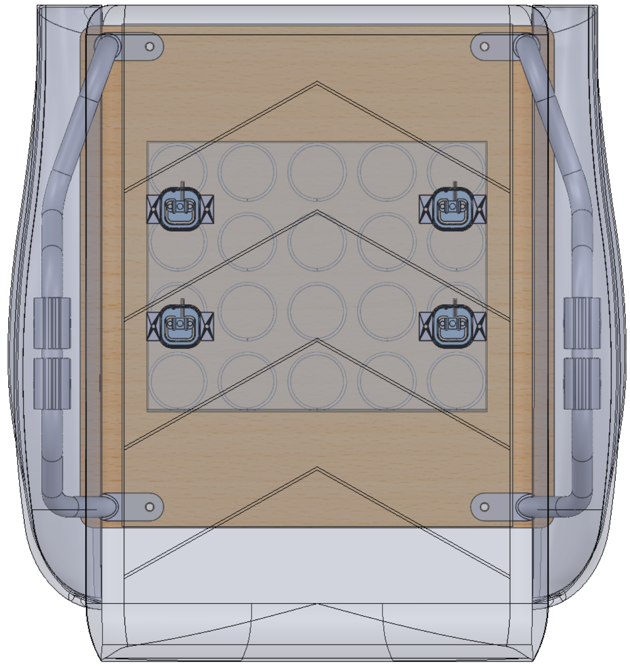


Figure (17): Top

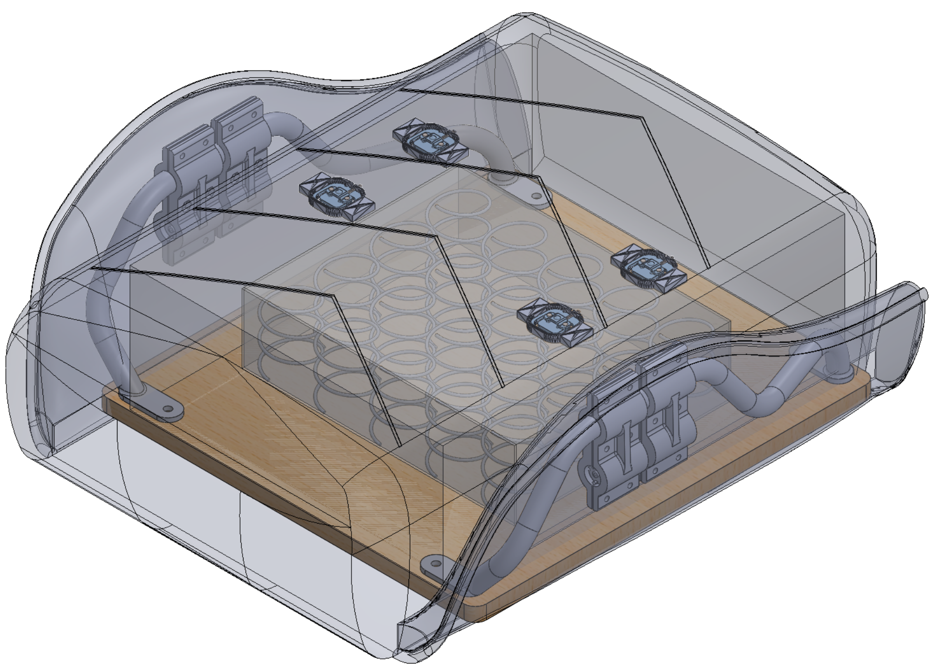


Figure (18): Isometric

Feedback System

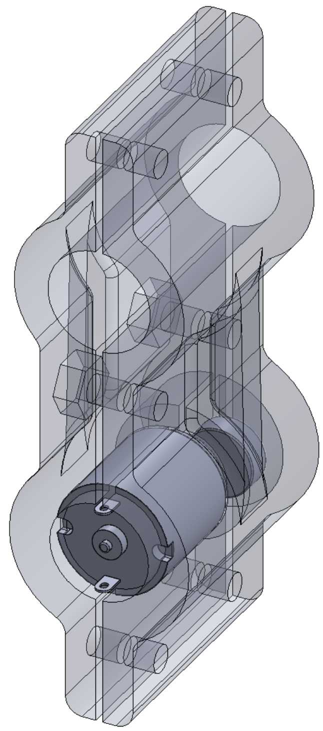


Figure (19): Vibration Feedback system

Force Sensor System

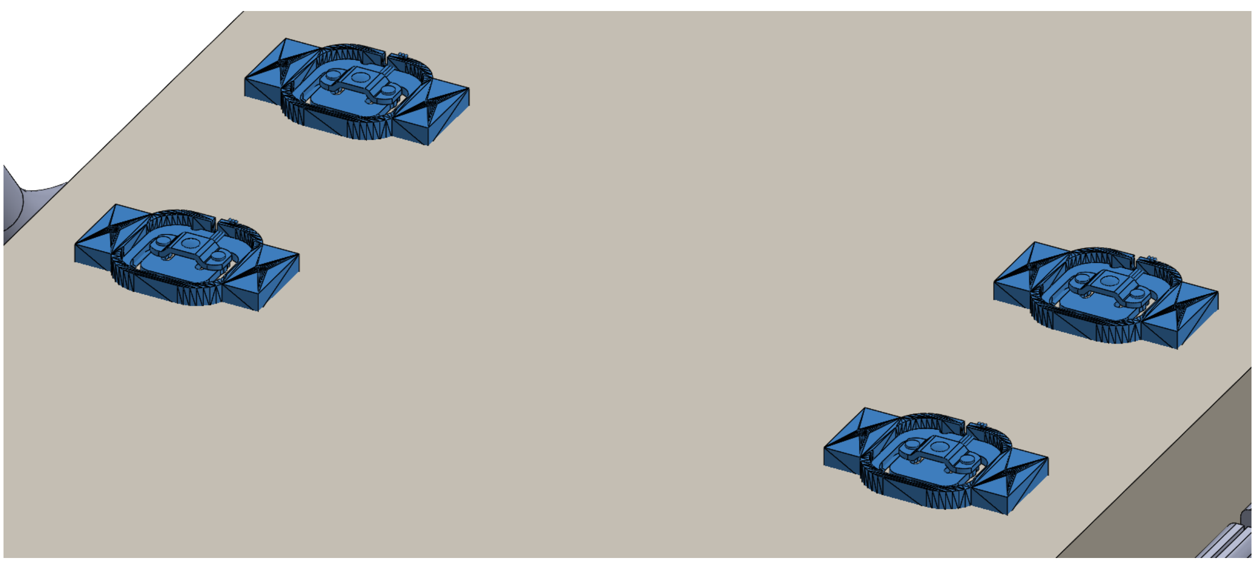


Figure (20): Force sensor system

Appendix 3: Competitor Products

Figure (21): The Upright GO2 device

Figure (22): An example of a posture brace

Figure (23): An example of an ergonomic chair

Appendix 4: Initial brainstorming notes

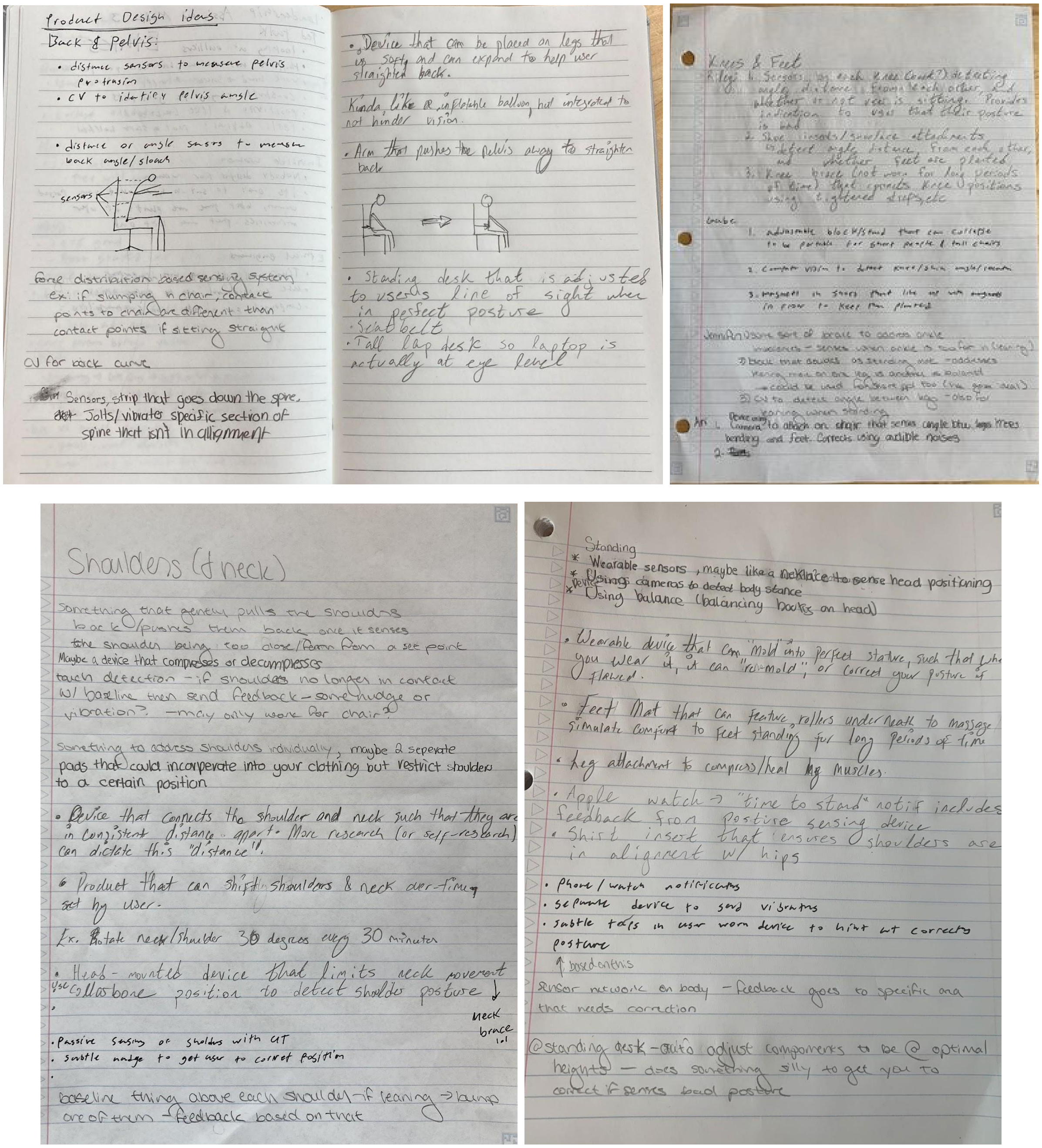


Figure (24): Initial brainstorming notes

Appendix 5: Prototype Description

Final Prototype

Figure (25): Full Prototype

Figure (26): Full Prototype with chair partially open

Figure (27): IR Sensors on Chair

Figure (28): IR Sensor Adjustability on Chair

Figure (29): Load Cells Implemented

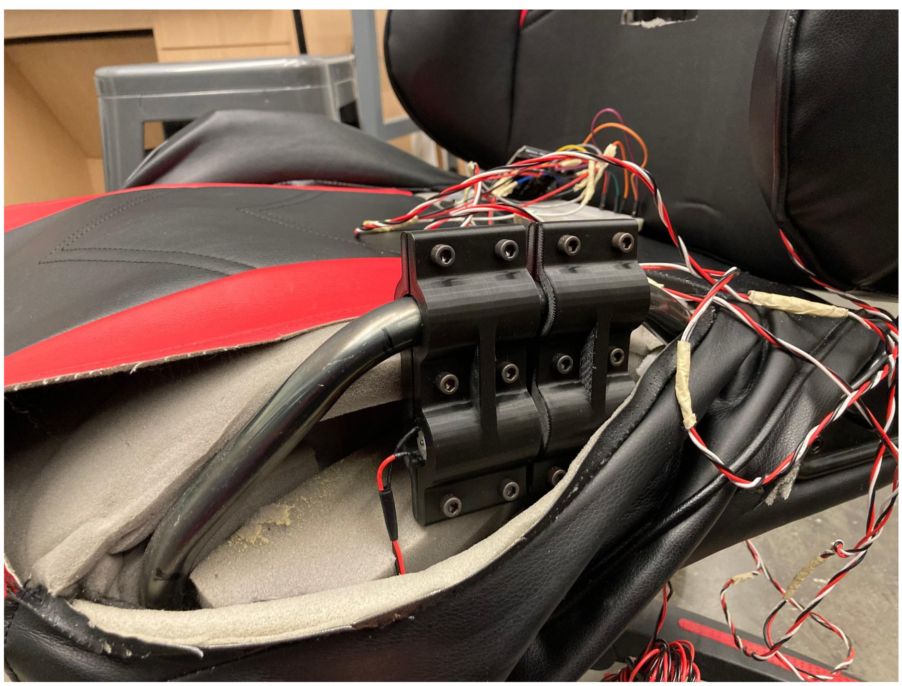


Figure (30): Vibration Motors

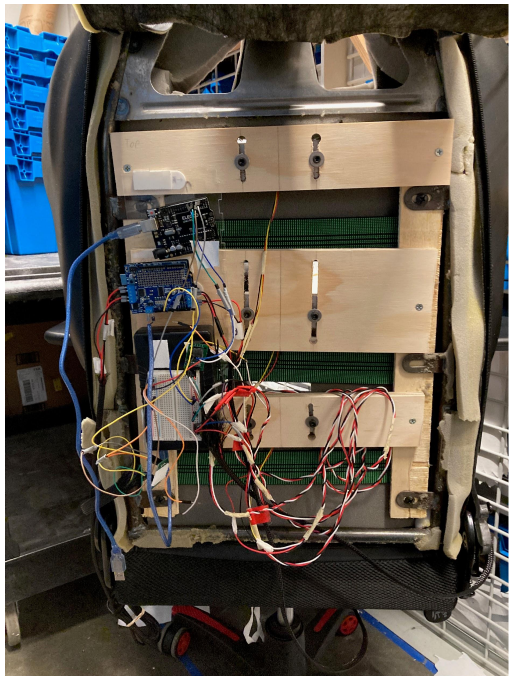


Figure (31): Full Prototype Electronics System

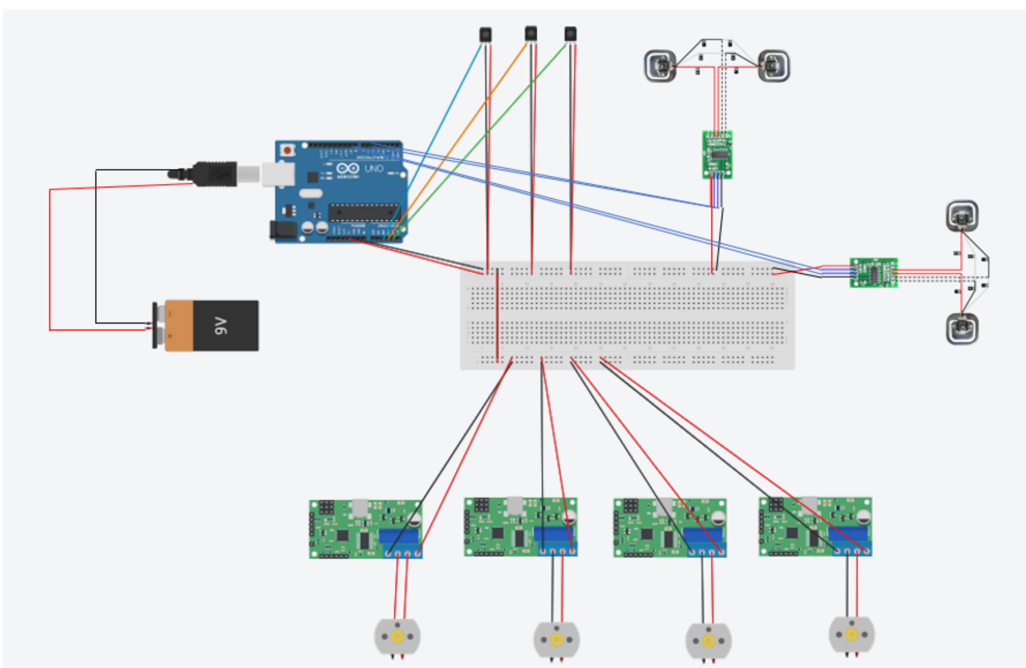


Figure (32): Electrical Diagram

Prototype Evolution

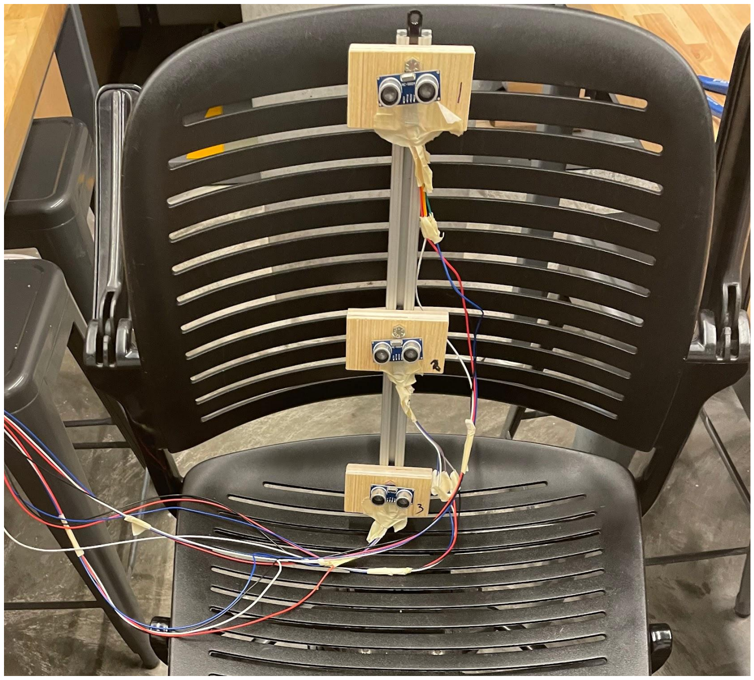


Figure (33): Ultrasonic Prototype Setup

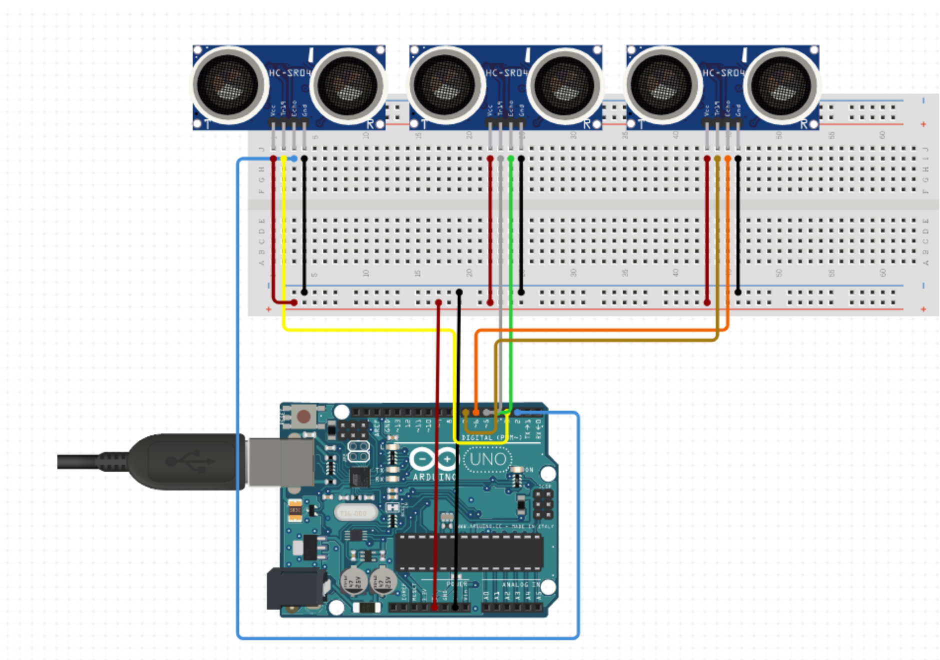


Figure (34): Ultrasonic Prototype Electrical Diagram

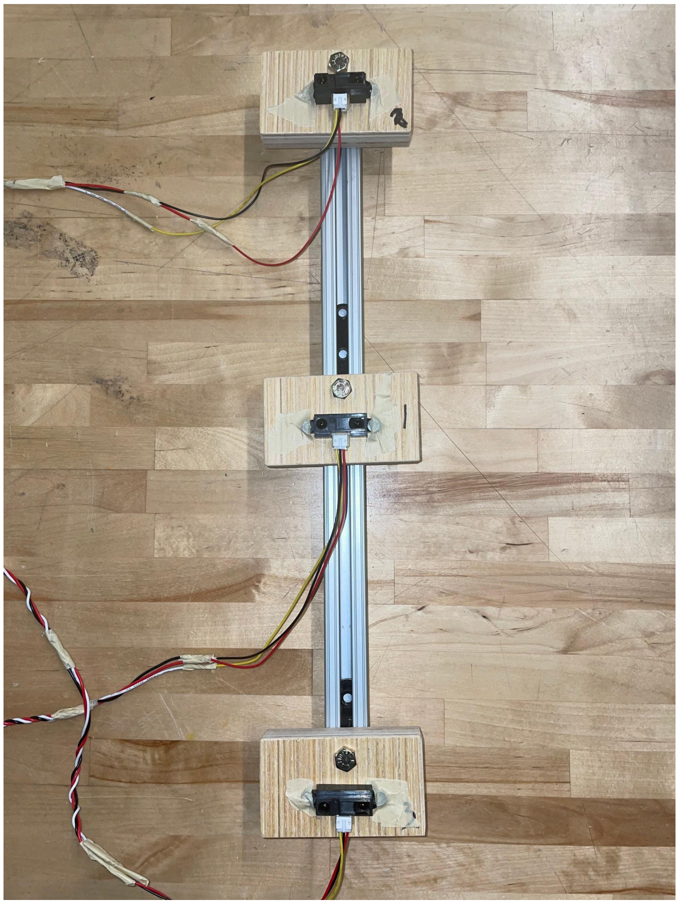


Figure (35): IR Initial Prototype Setup

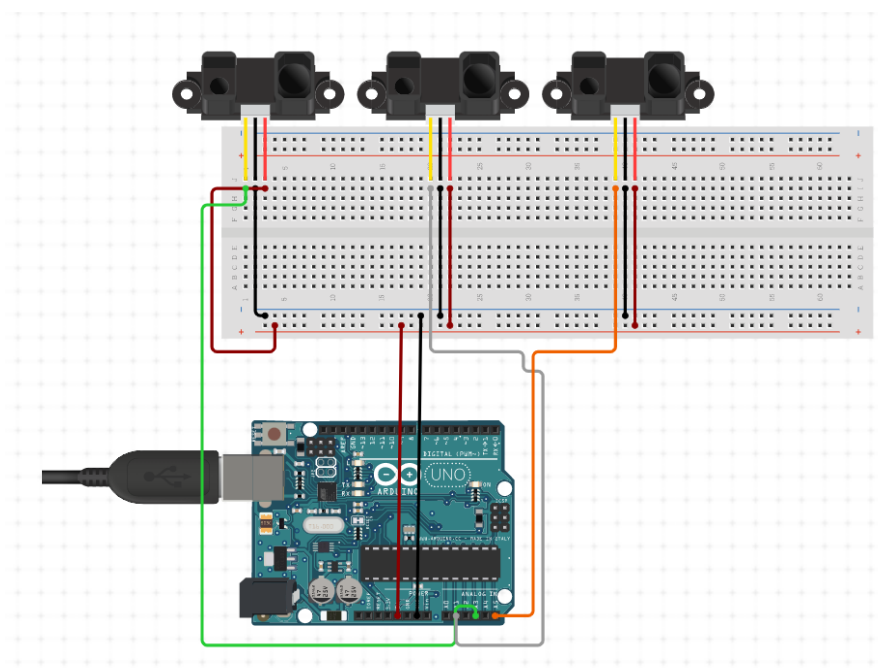


Figure (36): IR Initial Prototype Electrical Diagram

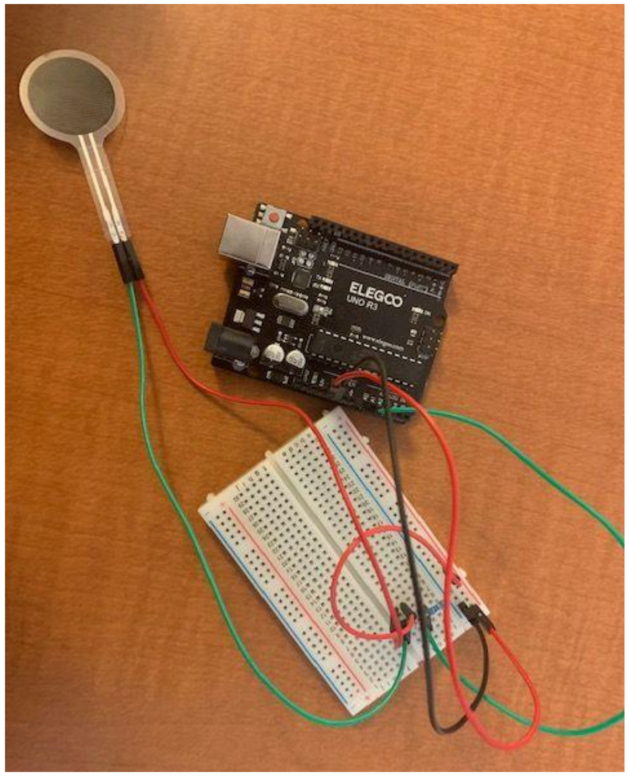


Figure (37): FSR Prototype Setup

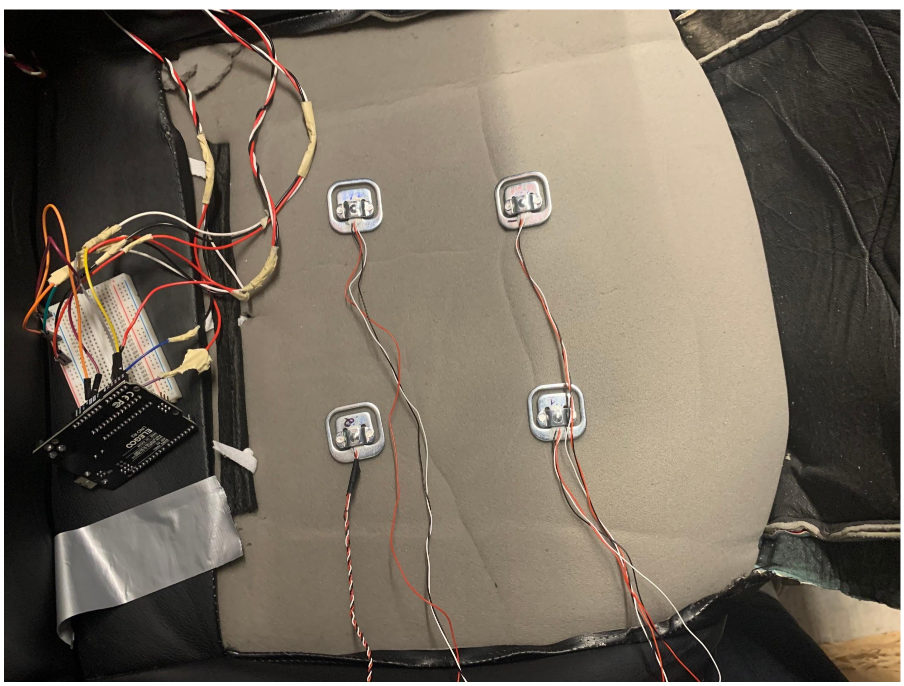


Figure (38): Load Cells Prototype

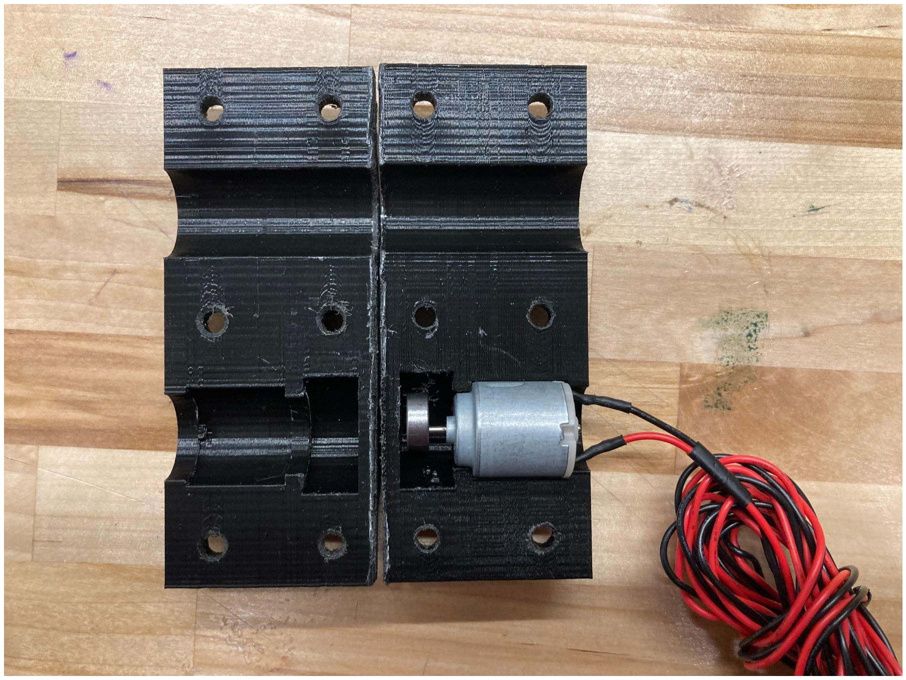


Figure (39): Unassembled Motor Mount

Appendix 6: Prototype Testing for IR Sensors

IR VS Ultrasonic Testing

The objective of this prototype testing was to determine whether Ultrasonic Sensors or IR sensors would be better suited for our prototype.

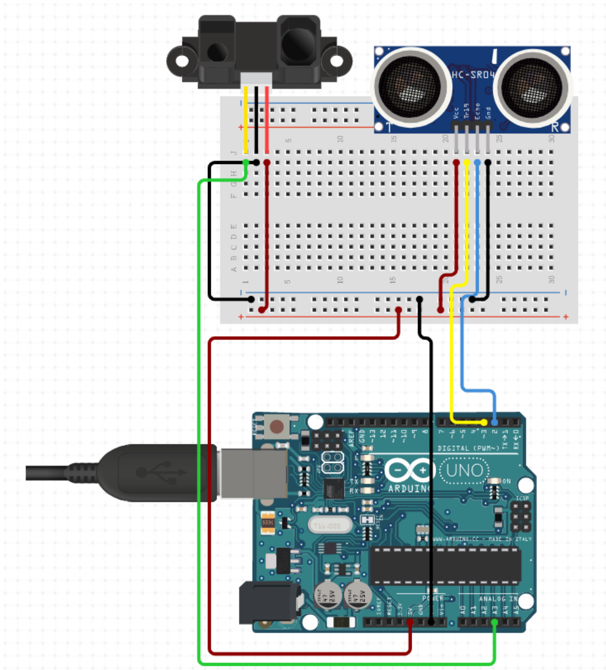


Figure (40): Arduino Configuration Schematic

Infrared uses the following code formula [30]:

- Volts = analogRead(sensor) X 0.0048828125; // value from sensor * (5/1024)
- Distance (cm) = 29.988 X POW(Volt , -1.173)

Ultrasonic computes via the following steps [32]:

- Turn off trigger pin
- Wait 2 microseconds
- Turn on trigger pin
- Wait 10 microseconds
- Turn off trigger pin
- Reads a pulse (either HIGH or LOW) on a pin
- Waits for the pin to go from LOW to HIGH , starts timing, then waits for the pin to go LOW and stops timing
- ultrasonic_distance = (duration/2) / 29.1;}

Table (23): IR VS Ultrasonic Testing Conclusions

		Sources of Error	Statistics
Ultrasonic Sensor Pro:	Good for closer readings, where it could detect objects up to 2 cm away.	Ultrasonic sensors can feature distortions when subjected to influence from	**Mean:** 17.5767 cm **Standard Deviation:** 9.0267 **Median:** 14.5000 **Variance:** 91.1949
Ultrasonic Sensor Con:	Starts to demonstrate noise distortion when around 20 cm away. These readings exceeded our maximum experimental distance of 30 cm.		
Infrared Sensor Pro:	Good for long distance readings greater than 5 cm	Possible external light sources can interfere with light transmitting/receiving since infrared reflects light signals	**Mean:** 15.3742 cm **Standard Deviation:** 9.5496 **Median:** 16 **Variance:** 81.4818
Infrared Sensor Con:	Bad for short proximity readings less than 5 cm		

Sensor Placement

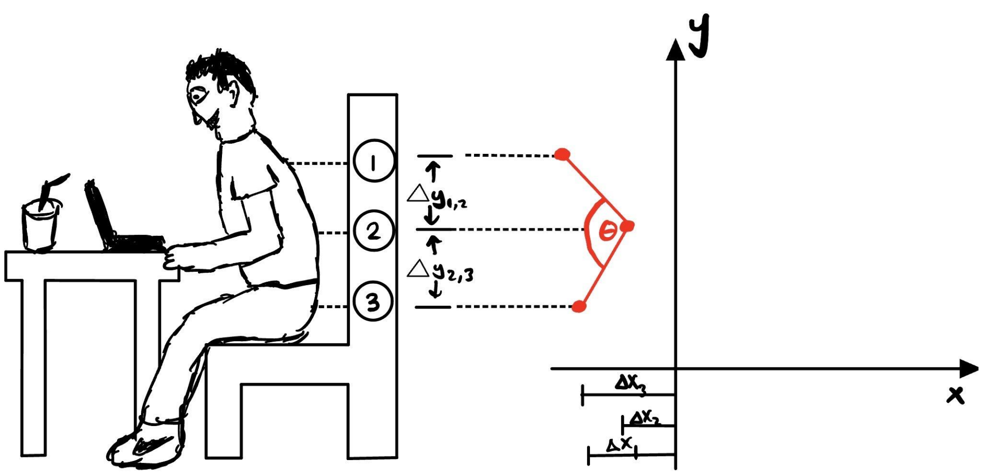


Figure (41): 3 Point Diagram

Appendix 7: Prototype Testing for Weight Distribution

Weight Distribution Research

In order to increase accuracy and range of posture sensing, our group decided to implement another sensor type into our chair to function in tandem with the ultrasonic sensors. In preliminary research to assess another quantity best suited for posture sensing, we found a trend between user upright posture and weight distribution in a chair. In a study focused on developing a seat to provide users with posture support, thin pressure sensitive maps were used to sense and develop a pressure distribution map of the individual's pressure distribution on the chair [6]. Though pressure intensity would vary in tandem with an individual's body weight, location of pressure intensity peaks remained consistent when users were in proper upright posture.In our group's conversation with a physical therapist, we learned that proper upright seating posture is demonstrated when the ischial tuberosities ("sitting bones") are engaged. The findings in this study confirms this. When users demonstrated proper upright posture, peak pressure points were most intense at the ischial tuberosities relative to other areas of the body [6]. Figure 42 demonstrates this, with peak pressure located at this point and indicated by the color red. The pressure is mapped by the colors of the visible light spectrum, with the most intense peaks indicated by the color red and decreasing down to purple [6]. Thus our group deduced that we could measure weight distribution in a seat cushion and gear this data towards detecting slouching and leaning associated with improper seated posture.

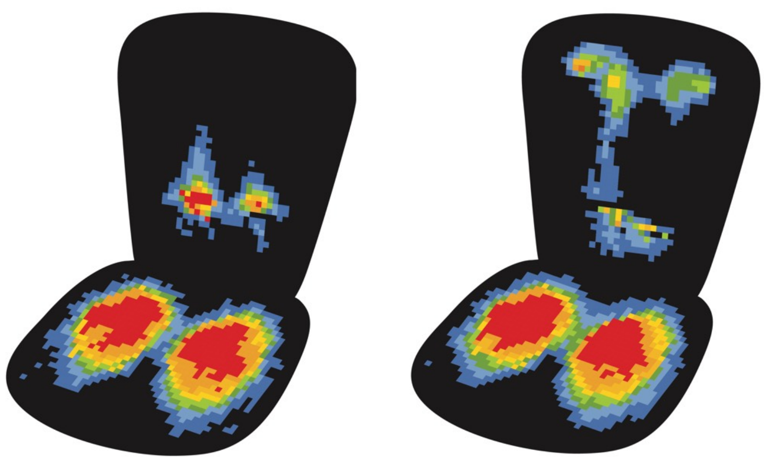


Figure (42): Pressure distribution map of individual's sitting in upright posture

Load Cell Testing

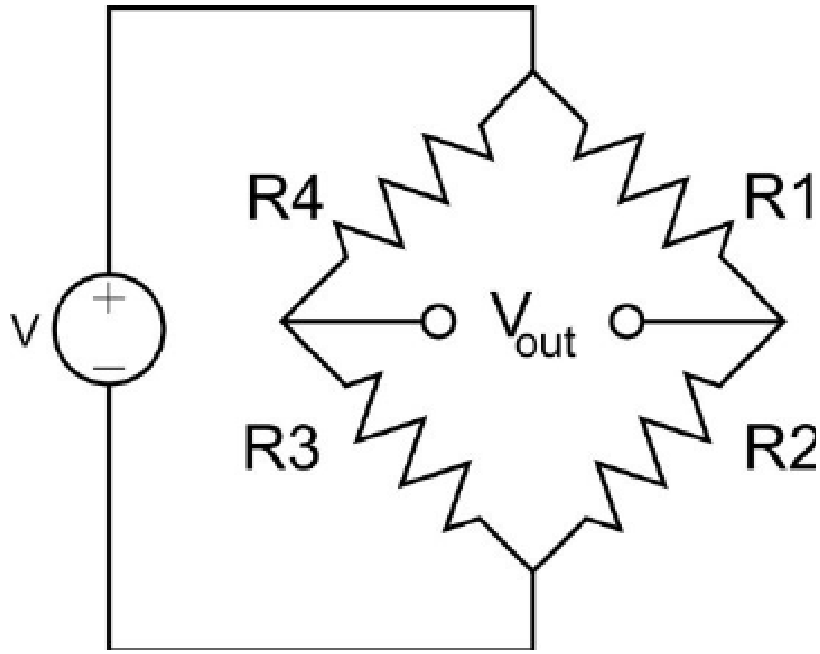


Figure (43): Model of a Full Wheatstone Bridge Circuit

Initially, we utilized the load cells independently to create a single circuit, which required connecting the load cells to two 1 kΩ external resistors (to match the internal resistors inside the cell) and an amplifier. We initially utilized a breadboard to make these connections (demonstrated in Figure 43), but found that this caused some of the signal to be lost and resulted in unstable data readings. Subsequently, we ended up directly soldering the load cells to the resistors and connecting them directly to the amplifiers (demonstrated in figure 45) [29]. However, we noticed that this electrical configuration of the sensors was still producing erratic, unstable values. To combat this issue, we ended up soldering two half wheatstone bridge cells together to form a full wheatstone bridge, and connected these cells directly to the amplifiers (demonstrated in figure 46) [29]. Due to this configuration, two load cells would work in tandem to measure weight, which we found produced data readings that were less erratic and stabilized quicker.

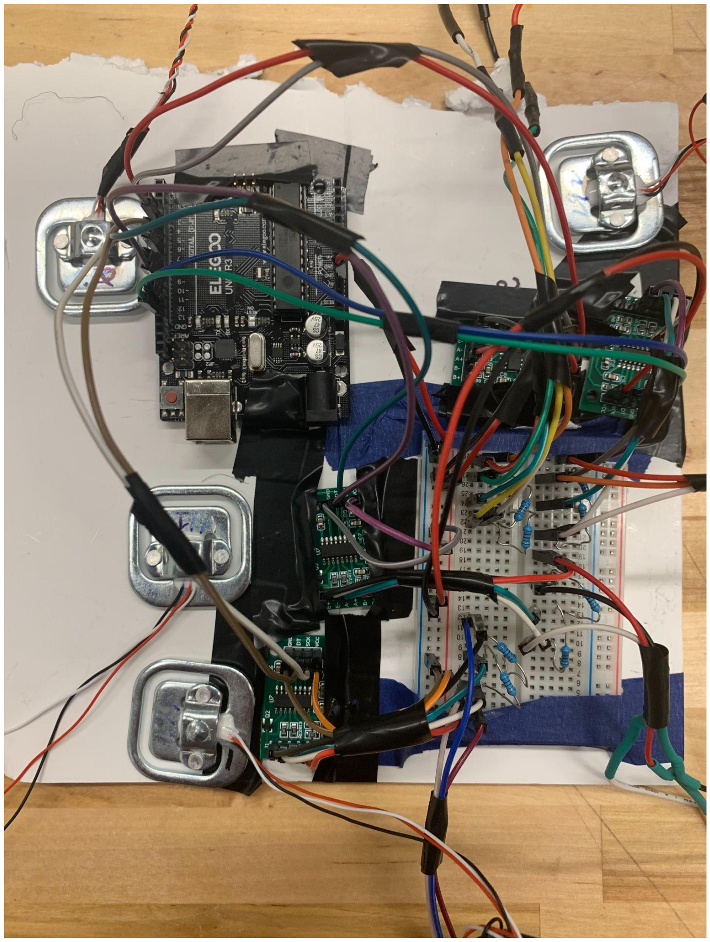


Figure (44): Load Cells, External Resistors, and Amplifiers Connected Via Circuit Board

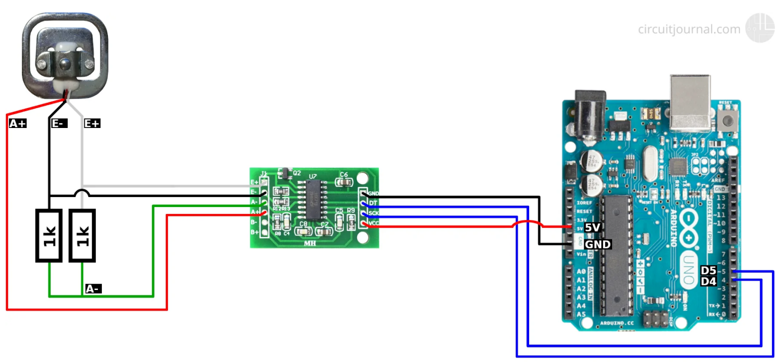


Figure (45): External Wheatstone Bridge Electrical Configuration

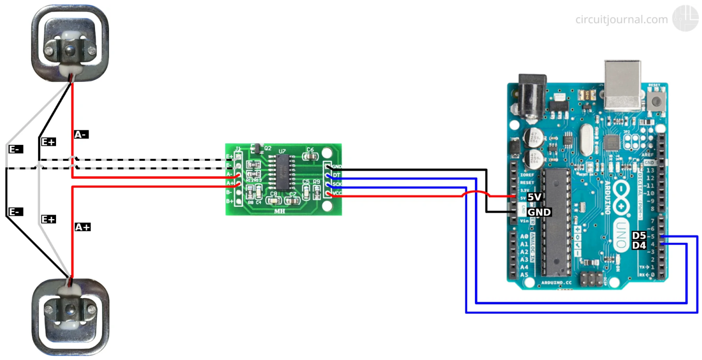


Figure (46): Two Load Cell Wheatstone Bridge Electrical Configuration

User Interface

To properly map out weight distribution differences, we studied the values the cells were outputting independently, and created maximum and minimum values to scale the changes of the load cells relative to each other.The user interface therefore showcased weight distribution changing relative to the cells located on left and right sides of the seat cushion. Weight changes are indicated by change in color with an increase in weight indicated by the color red decreasing down to purple. Figure 47 demonstrates an instance of a user leaning to the right, where the user has shifted their weight from an equilibrium position to apply more weight on the cells located on the right side of the seat cushion. Accordingly, we see on the right side the seat map changing to the more intense color red and to a less intense color green on the left side. Figure 48 demonstrates the opposite, where the user is now leaning to the left, and more weight is applied to the cells on the left. Accordingly, we see on the left side the seat map changing to the more intense color of light red and to a less intense color of blue on the right side.

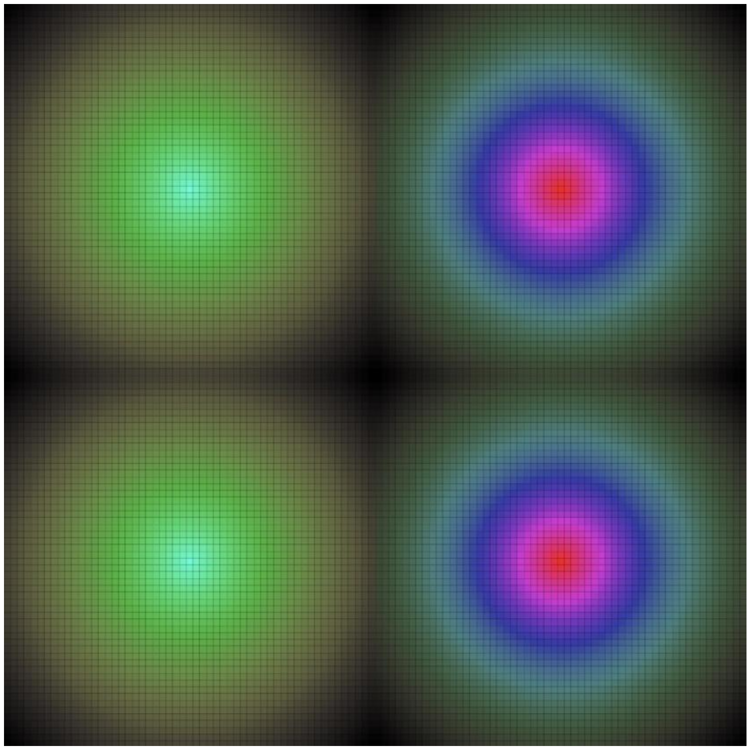


Figure (47): UI Seat map demonstrating deviancy in posture (right side lean)

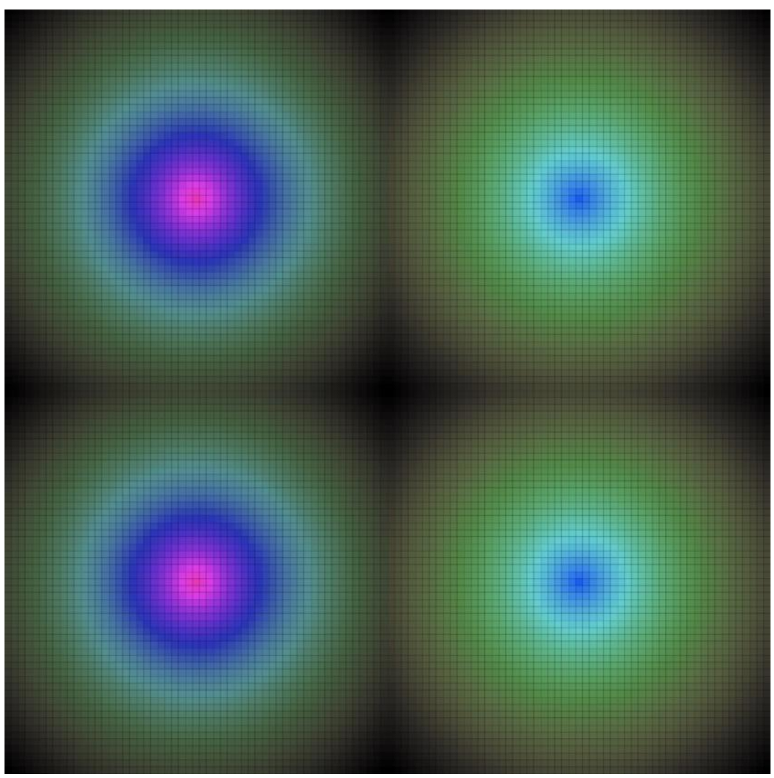


Figure (48): UI Seat map demonstrating deviancy in posture (left side lean)

Appendix 8: Prototype Testing for Motor Mount Design

Motor Mount Design and Iteration

The mount was a two piece design that would be bolted around the metal frame tube in the seat bottom and around the motor (Uxcell Mini Vibration DC Motor). The motor shaft and eccentric weight was enclosed to reduce any risk of the motor getting caught in the foam of the chair when running. The final design can be found in Figure 6.

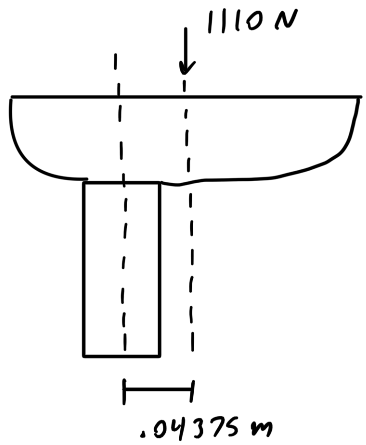
The initial design was challenging to assemble. The chair geometry made it difficult to get tools into the places where they were needed, so it was impossible to fully tighten the mount using standard tools. To address this issue, we added slots specifically for the nuts. This way, the nuts would be retained without requiring a wrench to hold them and the person assembling the product can focus on tightening the bolt. This eliminates the tightening issue.

Motor Power Issue

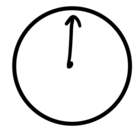
Initially, we wanted the system to use 4 motors, two on each side as depicted in Figure 30. However, the motor controller (Adafruit Motor Shield V2) we used limited the current that each motor could consume. One possible solution to this would have been to incorporate an additional motor shield as they are stackable to increase the current limit. However, this would require us to purchase another motor shield and solder and rewire it to the system. Additionally, new code to be implemented/ Due to time constraints, we decided to not move forward with trying to run 4 motors. Since our overall goal was to introduce customization and we can achieve that with different motor speeds as well, we decided that was sufficient for prototype purposes and the mass manufactured version would incorporate more customization through using all 4 motors. The aforementioned power issue would not be a concern as we would have custom PCBs for our product.

Appendix 9: Engineering Analysis

Stress Analysis Hand Calculations



$R = .02625\,m$



$$I = \frac{1}{4}\pi R^4$$

$$\sigma_b = \frac{My}{I} = \frac{1110(.04375)}{1/4 \cdot \pi \cdot .02625^4}$$

$$\sigma_b = 130\ \text{MPa}$$

$$\sigma_a = \frac{P}{A} = \frac{1110}{2.164} = .512\ \text{MPa}$$

Figure (49): Bending and axial stress calculations using given geometry and measurements from CAD

Thermal Analysis Diagram

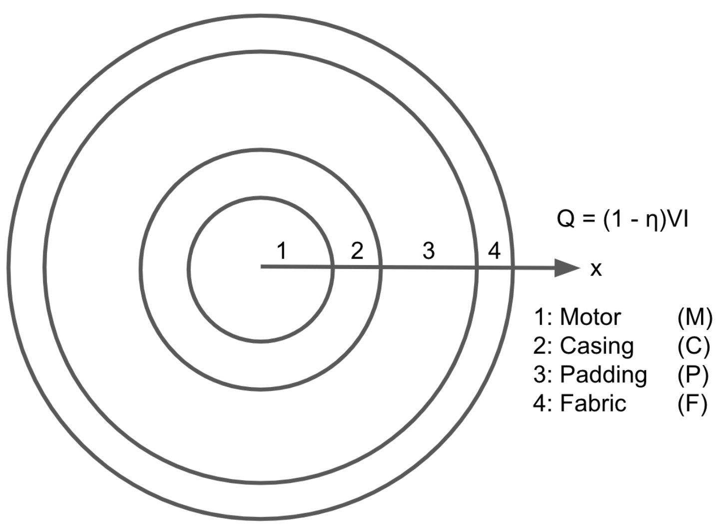


Figure (50): Thermal Model of Motor Mount Heat Transfer System

Appendix 10: Load Cells vs FSR Justification

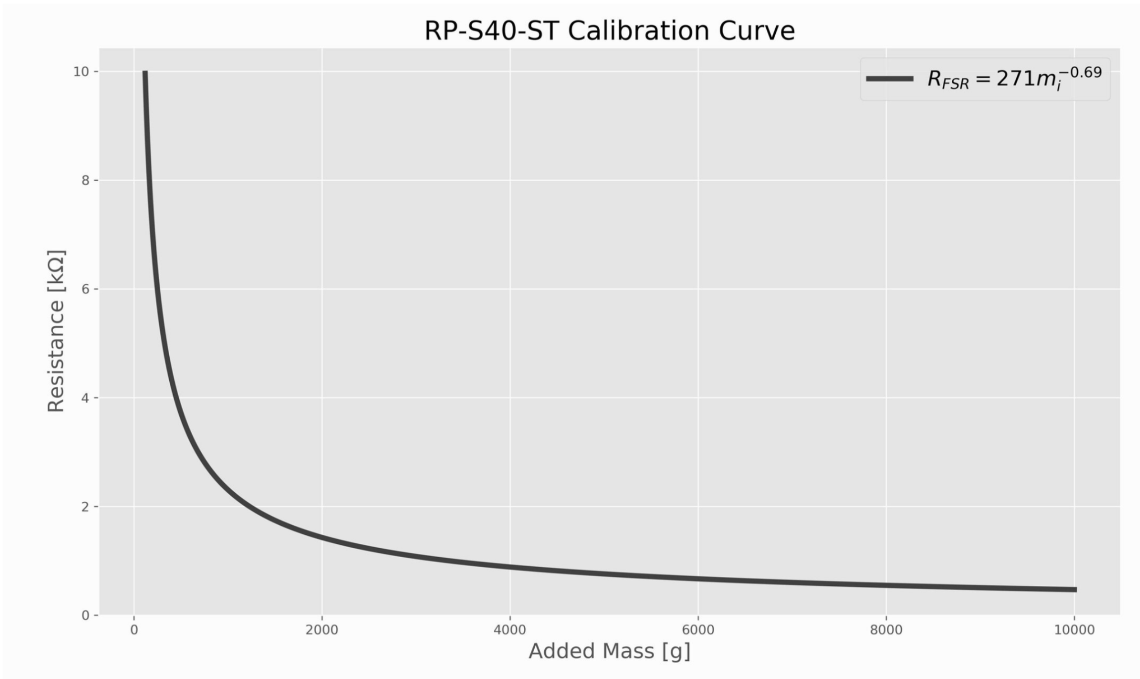


Figure (51): The manufacturer's best fit curve establishing the relationship between mass applied and resistance

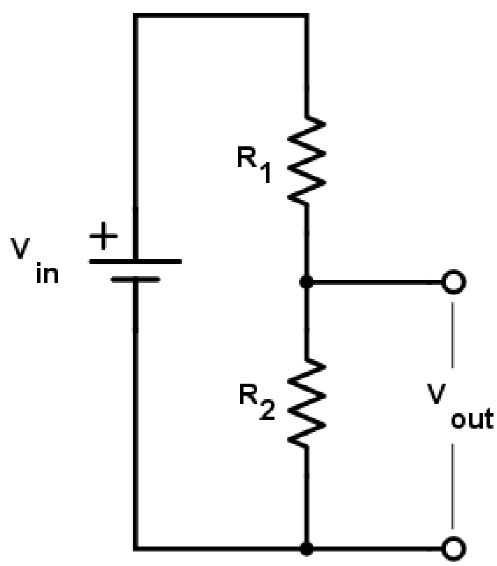


Figure (52): Model of the voltage divider circuit used to calculate output voltage

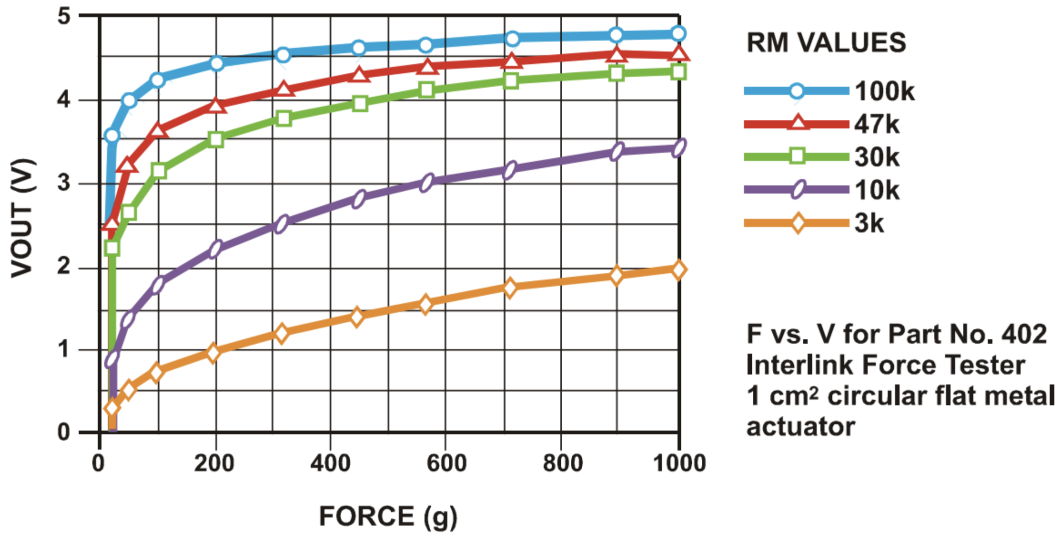


Figure (53): Plot of output voltage and force demonstrating the relationship between output voltage, force, and varying resistor values