Posture Sensing Smart Chair

Design Document

ECE 445 Spring 2020

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1 Introduction

1.1 Problem and Solution Overview:

Back problems due to slouching have become a huge cause for concern as people spend more and more time sitting in cubicles, hunched over a computer for hours upon hours every single day. In fact, according to a University of Washington study, Forty-five percent of Americans between the ages of 35 and 55 suffer acute back pain each year [1]. Moreover, other studies carried out by the Social Security Administration identified back pain as the top cause of disability under the age of 45 in the United States [1]. Not only is poor posture unsightly, but it also introduces stress on the neck and spine, causing further muscular tension as the body attempts to compensate for the lack of support.

While maintaining proper posture is something that needs to be taken seriously in perpetuity, we have decided to combat this problem by focusing on time spent sitting in front of a computer, like in a traditional office environment, for example. After all, many adults spend a significant portion of their lives in this position! In response to this, we have set out to create a chair that automatically senses a person's posture throughout the day, alerting users when they begin to slouch and tracking their positions over time. Our design will utilize both force and ultrasonic range sensors in order to ensure a healthy level of spine curvature. In particular, our chair will alert the user when their head is too forward or they have rounded shoulders, as shown in Figure 1.

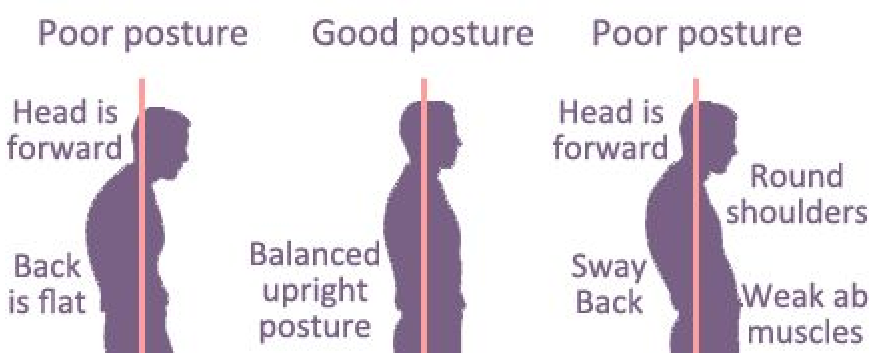

Figure 1: Good and Poor Posture

From our own experiences with posture-related back problems, we know the hardest part about changing our habits is accountability. While strengthening postural muscles is important in correcting kyphotic posture, it is useless if you are unable to *remember* to put those muscles to use. By using our product, we hope to make people more aware of the way they are sitting and allow them to monitor their progress as they try to break the habit.

Because poor posture is such a widespread problem there currently exist many solutions on the market. A large portion of these solutions fall under the umbrella of electronic wearables [3], like the Upright GO, shown in figure 3, which attaches to the user's back between the shoulder blades. While we did initially consider the idea of designing our own wearable, we ultimately decided against it because we suspect that many people would find them uncomfortable. Other solutions involve harnesses that physically pull the shoulder blades back, shown in figure 4. The problem with these lies in the fact that they don't support the development of stronger postural muscles and therefore won't actually fix the problem. The last major class of solutions to poor posture in the workplace are ergonomic workstations and include things like standing desks and using an inflatable ball instead of a chair. While these solutions have the right idea in mind, the average person does not want to stand or roll around on a ball for eight hours a day; it's exhausting and unsustainable for many! We believe a posture sensing chair would have many advantages over the existing products on the market.

Figure 3:

Figure 4:

1.2 High-level requirements list

1.Using Ultrasonic range sensors and force sensors, the system must be able to accurately classify the users posture as either good or poor with at least 70% accuracy.

2.The computer must be able to collectively analyze the data provided from the two subsystems (back and seat) and send feedback back to the chair's LEDs and vibrating system to notify the user's current posture.

3.The data analyzed must be shown visually through a graphical display -- available via web application -- showing the user's posture over time.

2 Design

2.1 Block Diagram

Our overall design will be split into multiple submodules which each have a functionality. Our power module will ensure that all of the devices in our design will receive power in order to operate. Our sensor subsystem will utilize ultrasonic ranger sensors and pressure sensors in order to gather data of a user's posture. These data will be then sent to our control system, in which the microcontroller will process the data and determine if the posture is good or poor. The analysis of this data will be then sent to our feedback subsystem in order to inform the user of his or her current posture. The software subsystem will also receive the data from the microcontroller in order to provide the user with a graphical analysis and gradual progression of his or her posture. The visual diagram of these interactions can be shown in Figure 5.

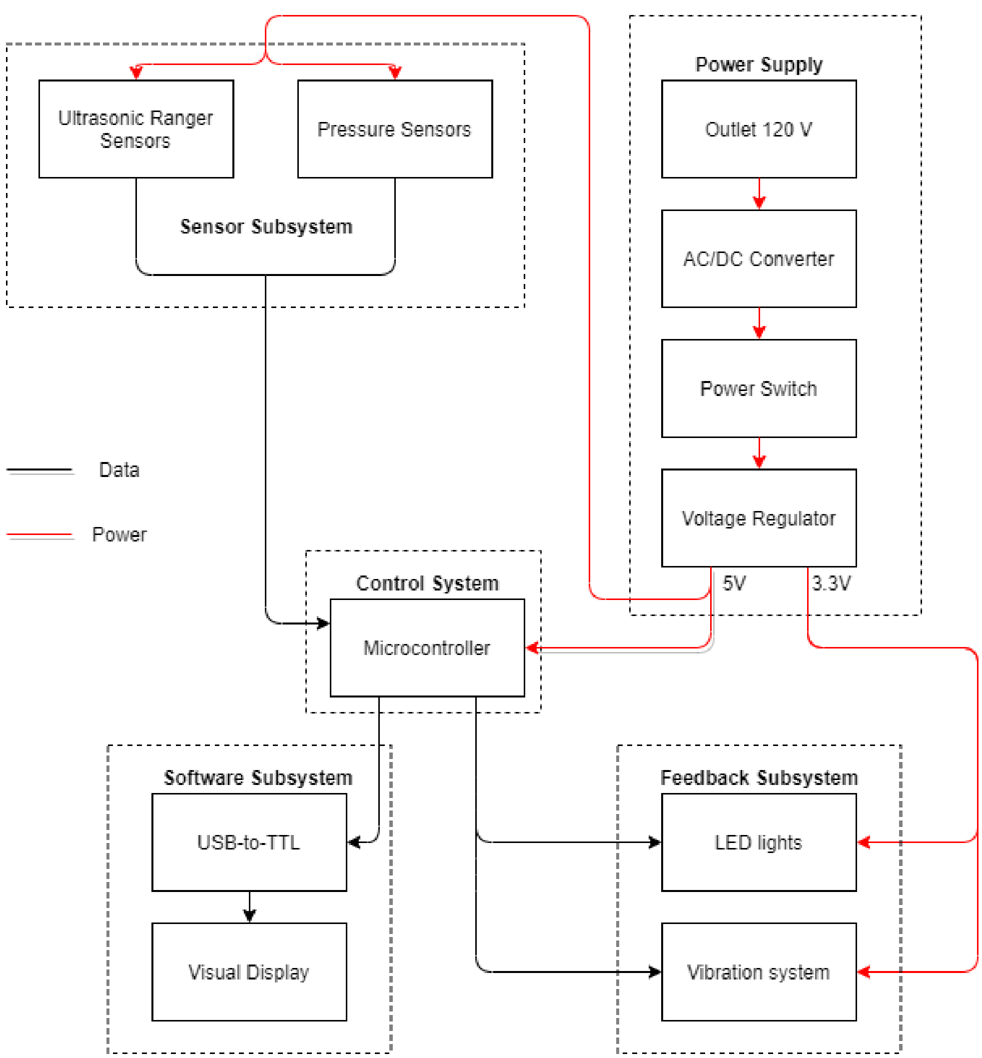

Figure 5: Block Diagram

2.2 Physical Design

Figure above displays the rough version of how our design is going to look. PCB and power are going to be placed underneath the chair, and they will be insulated so that the circuits will not endanger the user. There will be numerous sensors placed throughout the chair and all these sensors will also be isolated or insulated with foam covers in order to protect the user from the electrical circuits. For the pressure sensors, twelve pressure sensors will be placed in the seat while eight pressure sensors will be placed in the backrest. For the ultrasonic sensors, there will be two near the shoulder blades, and two on the top of the chair in order to measure the distances for the head and neck. The LEDs will be placed near the armrests in order to notify the user if the posture is poor. The location of the sensors and LEDs may change after testing in order to provide the most accurate and useful feedback. The physical design with layout and dimensions can be visually shown in Figure 6.

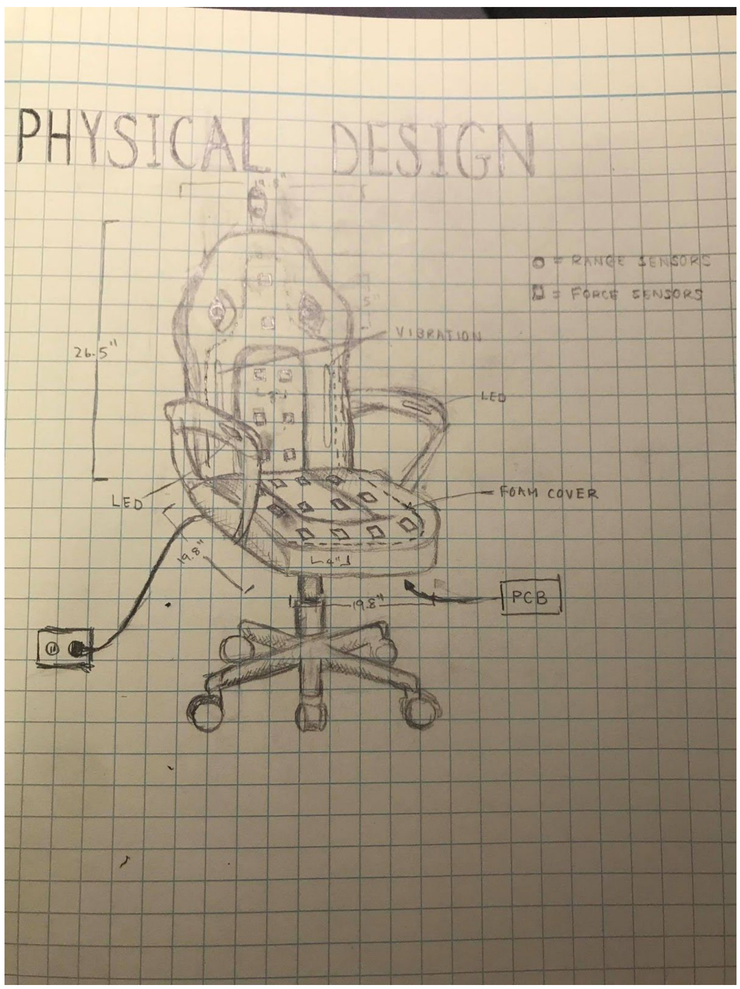

Figure 6: Physical Design

2.3 Power Supply

2.3.1 Outlet 120 V

AC Power originates from the standard wall outlet - 120 V.

2.3.2 AC/DC Converter

The power converter will convert the AC power from the wall to DC power in order to be used by the devices in our design.

Requirement	Verification
1. Convert the 120V AC to 12V ± 5% DC.	1. Attach input leads to voltmeter 2. Observe and ensure that the value does not leave the range of 12 V ± 5%

2.3.3 Voltage Regulator

The voltage regulator will regulate the voltage from the AC/DC converter at the specific voltages required for the various devices in our design.

Requirement	Verification
1. Regulate the voltage to 5 V ± 5% for the microcontroller, pressure sensors, ultrasonic sensors, and vibration motors.	1. Probe using Oscilloscope 2. Observe and ensure that the value does not leave the range of 5 V ± 5%
2. Regulate the voltage to 3.3 V ± 5% for the feedback LEDs.	1. Probe using Oscilloscope 2. Observe and ensure that the value does not leave the range of 3.3 V ± 5%

2.3.4 Power Switch

The power switch will turn the chair entirely on or off. The switch is intended to turn off the vibration motors and flashing LEDs when the user has to move around a lot or is not using the chair.

Requirement	Verification
1. The power switch should turn off the entire chair system	1. When the switch is turned off, ensure that all devices no longer have power.

2.4 Control System

2.4.1 Microcontroller

We will be using high-performance, low-power ATmega328P 8-bit microcontroller for this design. We chose this microcontroller for its affordability and abundance of documentation. We are also most familiar with this microcontroller as it was used in Arduino Uno. Atmega328P has a full suite of programs and system developing tools, such as C compilers, in-circuit emulators, and evaluation kits, which could be used in testing our sensors and feedback subsystem [6].

Its operating voltage is 2.7 V to 5.5 V and will take analog inputs from the pressure sensors and ultrasonic distance sensors. Since we do not have enough pins to include all of the sensors, we intend to use a mux so that we can grab data from the sensors one at a time. The microcontroller will analyze the data, as explained in Tolerance Analysis below, and output voltages to the LEDs and the vibration motors.

Requirement	**Verification**
1. Pull data from Sensors every .5 second.	1. Ensure that the data is being loaded 2. Measure the time in real-time
2. Analyzes the posture with > 70% accuracy.	1. Sit on the chair and attempt many different postures, including good and bad 2. Count the number of good postures and the attempted postures 3. Ensure the percentage of good posture is over 70%
3. Does not take longer than 700ms to analyze the posture.	1. Sit on the chair and attempt a good posture 2. Once you have a good posture, attempt a bad posture 3. Code in microcontroller program so that it captures the time when the posture goes bad. 4. Attempt in real-time with own stopwatch to estimate that the latency is less than 700ms and compare with computer-captured value.
4. Can indicate good/bad posture and communicate its judgment towards the software and feedback subsystem.	1. Time the latency to check what data it is currently making a judgment out of. 2. Compare common poor posture with the data analyzed to see if they resemble an accurate decision.

2.5 Sensor Subsystem

2.5.1 Ultrasonic Range Sensors

The main function of the ultrasonic range sensors is to detect the rounded shoulder posture or forward head. We will be using HC-SR04 ultra ranging module in order to measure distances of body parts, such as shoulders, head, and neck. We decided on HC-SR04 for its availability and low cost. However, it can also easily detect background noise. These ultrasonic sensors have four pins that are VCC, Trig, ECHO, and GND and have a working voltage of 5V and current of 15 mA [7]. Using the equation,

$$P = IV$$

We can estimate that the power used by an ultrasonic range sensor is 75mW.

Requirement	**Verification**
1. Must be able to detect discrepancies between distance to head and distance to neck.	1. Mount sensors to top of chair, one pointing toward head, the other toward neck 2. Take 15 measurements in both of the positions above - find mean and variance of measurements. Ensure Probability of Error is < 30% 3. Repeat with other people sitting in chair
2. Must use >60ms measurement cycle to prevent trigger signals to the echo signal.	1. Use a range of different cycles to see whether or not the two analog signals are conflicting with each other.
3. Requires 5 V $\pm 1\%$ power	1. Attach input pin to voltmeter 2. Ensure the value does not go out of the range

2.5.2 Pressure Sensors

We decided to use a mix of SEN-09376 and SEN-0375 Force Sensitive Resistors (FSR). SEN-09376 FSRs are square and have dimensions of 1.75” x 1.75” [9]. SEN-09375 FSRs are round sensor 18.28 mm in diameter [8]. Both FSRs can sense applied force anywhere in the range of 100g - 10kg. We decided to include both in our design for different purposes. The SEN 09375 will be placed as a 4x3 grid on the seat. These sensors are more cost-effective and ideal for the purpose of determining the weight distribution and positioning. We use the SEN 09376 resistors on the back because of the area coverage. Ideally, it would be best to use 09376 model for all the resistors, but decided that 09375 made our budget a little more cost-effective with minimal to no loss of efficiency towards the product.

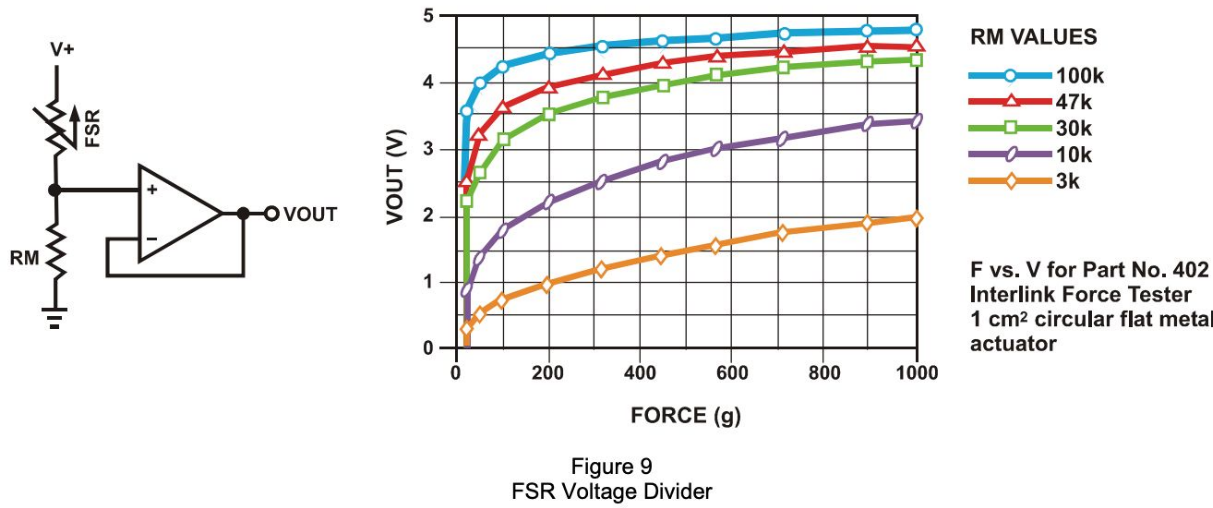

Figure 7: Circuit for FSR

As a simple force-to-voltage conversion, the FSR is tied to a measuring resistor in a voltage divider configuration. The output is as follows:

$$V_{out} = \frac{R_M V+}{(R_M + R_{FSR})}$$

As shown in the above equation, the output voltage increases as the force increases. When there is no force applied, the FSR has extremely high resistance but this resistance decreases as force is applied causing the current to 'turn on', thus leading to a larger voltage drop across Rm. When no force is applied vout will be almost zero.

Requirement	**Verification**
1. Requires 5 V ± 1% power	1. Attach input pin to voltmeter 2. Ensure the value does not go out of the range
2. Requires sensor readings to be consistent if the user is not moving	1. Sit on the pressure sensor 2. Measure with a voltmeter 3. Make a measurement every 10 seconds for a minute and ensure the values don't change by more than 0.5 V
3. Requires sensor readings to have < 0.5 V is no user is sitting on the pressure sensors	1. Put a cushion on and ensure nothing else is on top of the pressure sensor 2. Supply 5V voltage and ensure that the sensor readings don't exceed 0.5V

2.6 Software Subsystem

2.6.1 USB-to-TTL

We will be using FT232RL USB to TTL Adapter in order to handle all the USB signalling and protocols. It handles TTL level of 5V and 3.3V adjustable design

2.6.2 Visual Display

Our software subsystem is mainly responsible for displaying data to the user in a way that describes their seating posture over time. We will be using Ruby on Rails as the framework to build our web application. This project heavily depends on the data measurements from the sensors, thus we'd figured this development tool would be ideal because of its simplicity and efficiency to abstract these measurements. Using the collection of data, we will implement features on the web application such as frequency of maintaining good posture throughout the day and identifying weak points from the sitting posture.

Requirement	**Verification**
1. Data can be displayed on the web server within 1s of the data being collected.	1. Data will be gathered from the pressure sensors and ultrasonic sensors. 1. Check the data is in the web server in real-time
2. Data must be collected and stored in timed intervals to show gradual progression of the user seating posture.	1. Have the user sit casually on the chair for an extended period of time (minimum 4 hours). 2. Using a timer to let the user know the system is taking a snapshot of the current posture, read the data and see if there are any outliers. 3. Observe the web application to see if there are snapshots being updated/added on schedule every timed interval.

2.7 Feedback Subsystem

2.7.1 LED

In our feedback system, we use LEDs to indicate the status of different areas for users to improve their posture. The chair design will use the simple red and green LED lights as provided from the ECE store. These LEDs will be strapped to the sidearm of the chair and in place where each will represent a different section of the user (head, upper back/neck, mid back, and lower back). If LEDs are all green, that represents good posture. If one or a couple of the LEDs are red, those will help the users understand which area of their back they need to adjust.

Requirement	Verification
1. Ensure that LED indicators are visible to the user	1. Sit on the chair and see if the LEDs can be noticed at different heights
2. Ensure that LEDs produce at least 8 lumens of light energy when they are fully powered	1. Turn the LEDs on 2. Use a Lux meter to verify the light energy.
3. The subsystem must provide the appropriate signals over 90% of the time.	1. Run a series of test trials with obvious faults and check the feedback from vibrations/LED. 2. Note any faulty signals and double check the connections of the devices.

2.7.2 Vibration Motors

We decided to use ROB-08449 vibration motors for its low cost. It has a mechanical noise of 50 dB max and operates at 2.3 - 3.6 V DC. They will work as a reminder to the user when the posture is poor and they don't notice the red LEDs.

Requirement	Verification
1. The vibration should be minimal (< 45 dB) but noticeable under the foam pads.	1. Place the vibration motors on the chair and put foam pads on top of them. 2. Sit on the chair and determine if the vibration is noticeable. 3. Use a decibel meter to observe how loud vibrations are. Add/remove insulation as needed to modify the noise production.
2. The subsystem must provide the appropriate signals over 90% of the time.	1. Run a series of test trials with obvious faults and check the feedback from vibrations/LED. 2. Note any faulty signals and double check the connections of the devices.

2.8 Tolerance Analysis

The most essential part of determining whether our product is applicable to the real world is the accurate readings of the sensors and inference of the data. The numbers provided from the force onto the pressure sensors and range of the various back sections to the ultrasonic sensors will be analyzed through our computer software by having various test cases to check proper alignment. Since our product accounts for natural movements on the chair, we've carefully implemented thresholds of up to a few centimeters apart for every measurement the product performs.

We use this chair design to tackle an important real world problem — how can we quantitatively measure good posture? Although easy to demonstrate, good posture must be described in numbers so that the product's software subsystem can compare the current seating posture with its ideal model. Some cases to check posture includes:

- Parallel distance of the shoulder blades
- Weight balanced between right/left sides
- Placement of the sacrum (lower back)
- Curvature of the middle back
- Cervical spine and head alignment

It is important to note that the feedback system is entirely dependent on the readings of the sensor. We aim to perform quality control testing frequently to ensure all sensors are functioning perfectly so that none of the systems get compromised.

Calibration

In order to account for unique body physiques, the chair is implemented with a calibration system that performs initial measurements of a user's good posture. We will use the data measured from the sensors to develop a standardized model of a user's good posture to detect any poor posture over time. In the process of calibration, the user will run through a certain number of trials sitting down on the chair with initial good posture, which the measurements will be sent to the microcontroller to create a standardized model of a good posture.

Using the set amount of trials, the chair will calculate a mean

$$\mu = \frac{\Sigma measurements\ from\ n\ trials}{n}$$

We will develop a standard deviation for the measurements with the following equation:

$$\sigma = \sqrt{\frac{\Sigma(r_i - r_{calib})^2}{n-1}}$$

Accounting for natural movements, we expect all the measurements to be considered good posture if they are within the first standard deviation of the calibration.

SEN-09376 Ultrasonic Sensor

In our design, we use 4 HC-SR04 Ultrasonic distance sensors to determine the alignment of sections within the back. The manufacturer specifies that the unit can provide 2cm - 400cm of non contact measurements with an accuracy threshold of +/- 3mm [5]. Our sensor placement allows for the 2cm of the required space and any distances past 40 cm is negligible (assuming user is sitting on the chair).

Our first alignment case checks the parallel distance of the shoulder blades. We place 2 of the 4 sensors onto the holes along the upper-mid part of the chair facing perpendicular towards the user's back. Refer to Figure 8 and 9.

Figure 8: Placement of the Sensors

Figure 9: Sensors' Direction

We expect the ideal models for this case to be:

$$D_{Acceptable\ posture\ of\ Left\ shoulder} \in D_{\mu,\ Left\ Shoulder} \pm \sigma_{Left\ Shoulder}$$
$$D_{Acceptable\ posture\ of\ Left\ shoulder} \in D_{\mu,\ Right\ Shoulder} \pm \sigma_{Right\ Shoulder}$$

Where D_0 is the standardized distance between a user's good posture of the shoulders upon calibration and the range sensors. This case is used to detect whether a user is slouching or leaning too much on the chair thus indicating a bad posture due to weight imbalances on the body. Example cases are shown below in Figure 10.

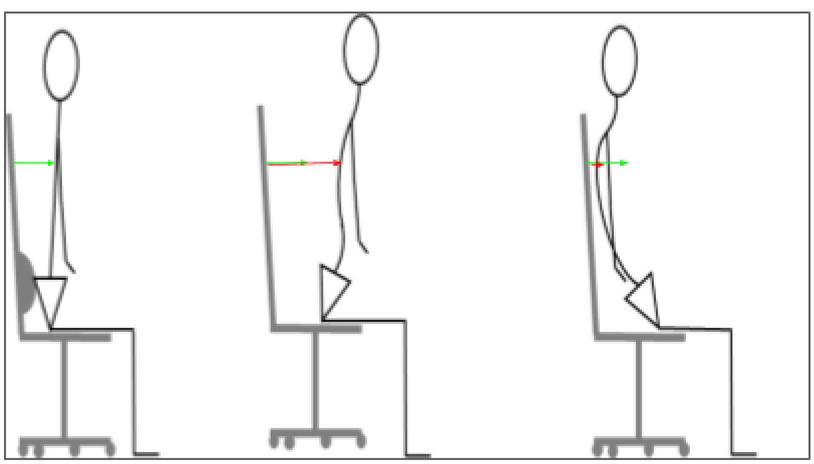

Figure 10: Posture Analysis

* The first diagram indicates that the current user posture is within the threshold of the standardized posture, the second diagram indicates that the current user posture is beyond the threshold, and the third diagram indicates that the current user posture is below the threshold.

We use the other two range sensors to measure the distances of the cervical spine and head positioning. Similar to the first case, our software will compare whether or not the placements of the head and neck are within the threshold of the standardized model of a good posture.

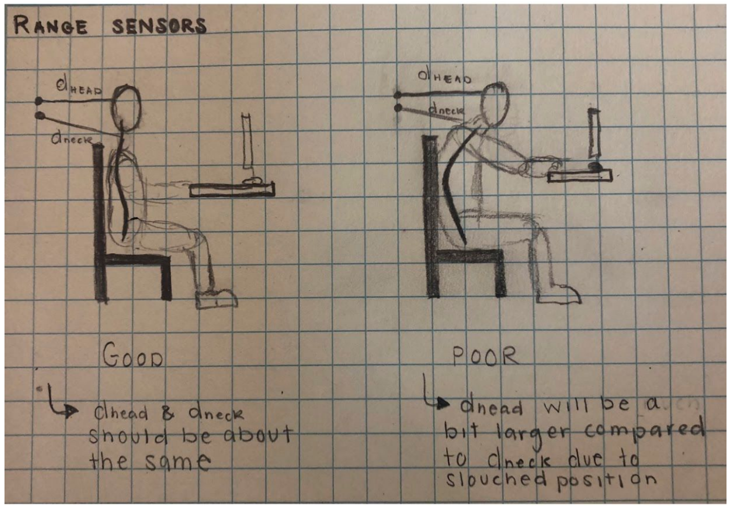

Figure 11: Range Sensors' Analysis

Due to limitations of how much these range sensors can read, we had to account for the coverage of area that the range sensors would measure. As specified earlier, the requirements of the range sensors are fulfilled and we do not anticipate any distances past 40cm. Therefore the maximum height of the head for accurate data measuring is around 10.717 cm.

$$Coverage_{sensor} = tan(\theta_{elevation}) * distance$$

Other range sensor coverage can be neglected due to the nature of how close they are to the body.

Force Sensitive Resistor - SEN-09376

We decided to use these models of the force sensitive resistors to measure the user sitting posture and the curvature of the back. These sensors cover 1.75” x 1.5” of sensing area with a measurement range of 100g-10kg. When no pressure is applied to the FSR, the resistance will be larger than 1 $M\Omega$. Because the readings are rather inaccurate with tolerance ranges of $\pm$15-25% of established nominal resistance, we will use the means of calibration in order to use the measurements to indicate weight balance in the seating and mid-back.

2.9 Schematic Diagram

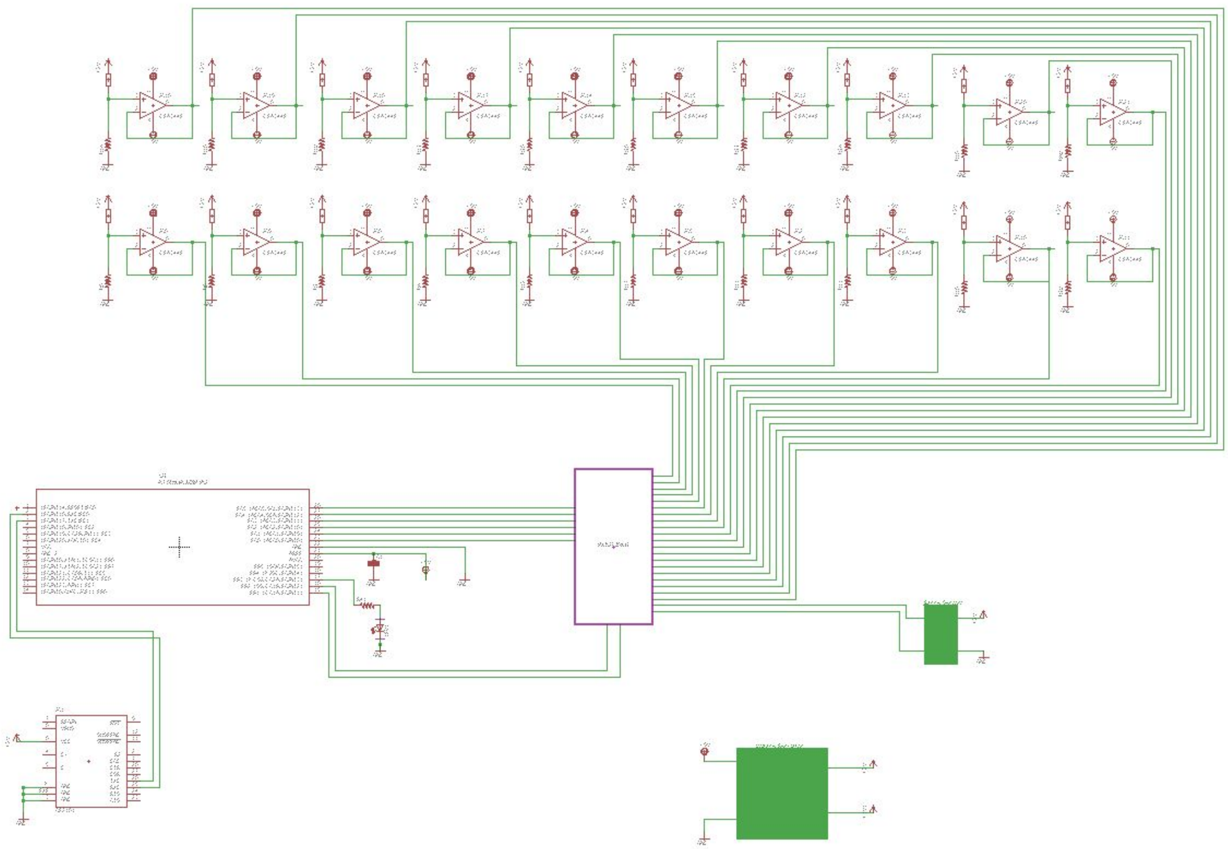

Figure 12: Full Schematic Diagram

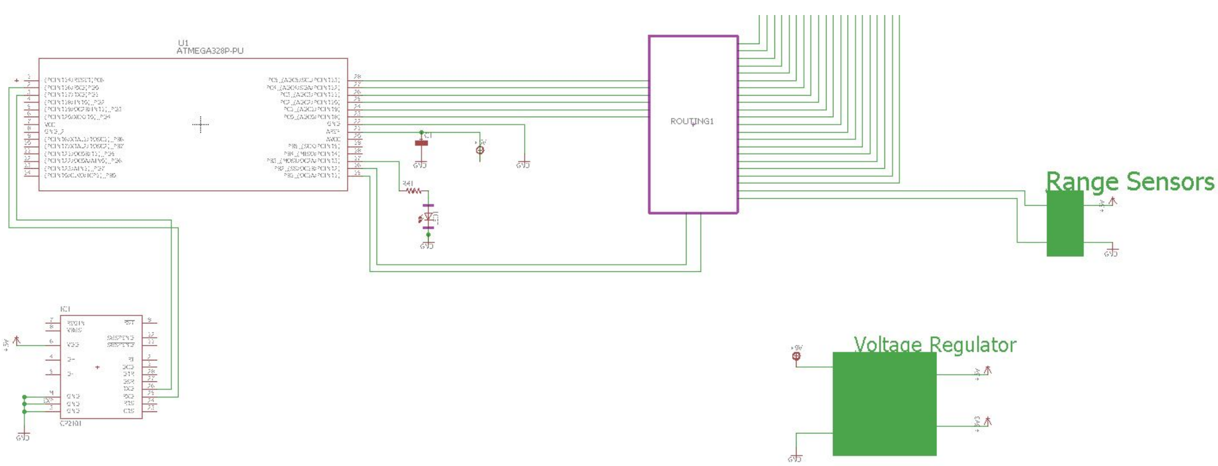

Figure 13: Lower Schematic Diagram

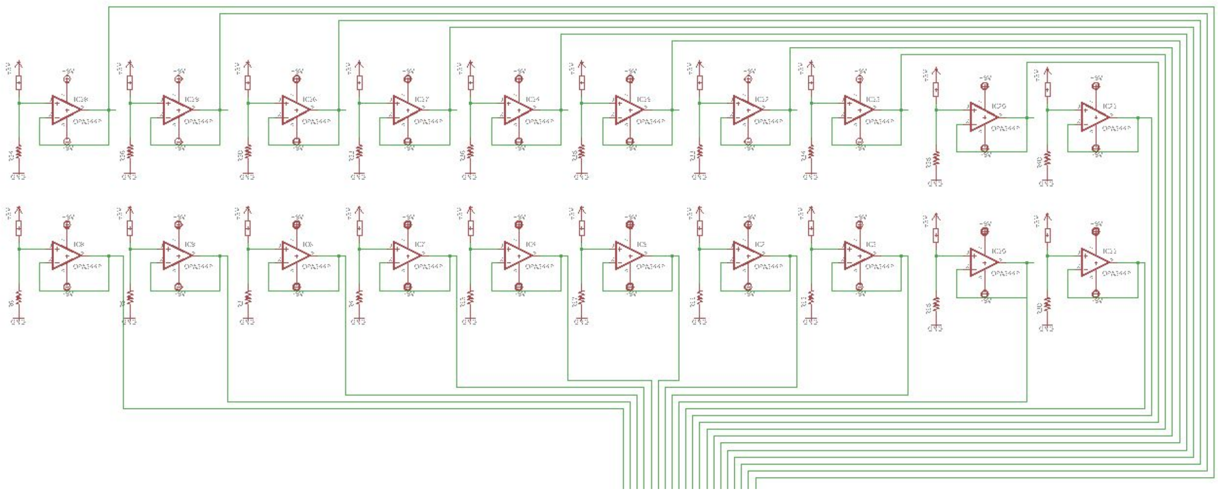

Figure 14: Upper Schematic Diagram

3 Cost & Schedule

3.1 Cost Analysis

Tentative Supply Cost Chart

Parts	Quantity	Price
Chair	1	$62.99
Force Sensitive Resistor - SEN-09376	8	$74.00
Force Sensitive Resistor - SEN-09375	12	$83.40
Ultrasonic Distance Sensor - HC-SR04	4	$15.80
LED lights	12	$5.16
Vibration Motor - ROB-08449	4	$17.20
Microcontroller - ATmega328	1	$1.86
USB to TTL Adapter -	1	$12.76

FT232RL		
Total Cost:		**$273.17**

Goals	**Estimated hours**
Installing necessary components to chair + considering design placements	10
Designing, building, and testing PCB	20
Web application + data analysis features	40
Forming successful data stream architecture	15

The workload would be split between us three as even as possible so that we try to avoid some members working harder than others. Therefore, the estimated salary for the labor between three people is roughly the equal. Since the average salary of a ECE graduate is $80,000/yr which is roughly $40 an hour, that is what we are planning to project until completion of the product.

3.2 Schedule

Week	**Team Goals**	**Primary Responsibilities**
Week 1	Purchase the prototype chair, pressure/range sensors, and microcontroller.	Geonil, Brian, Steven
	Start testing methods of reading and analyzing data from a user's sitting posture with the given parts.	Geonil, Steven, Brian
	Planning web application frameworks and feature implementation	Geonil, Steven
	How to stream the data from the chair to the web application	Brian
Week 2	Designing and building the PCB	Brian, Geonil, Steven
	Begin attaching necessary components on to the chair	Brian
	Set up a web server and install necessary frameworks + start creating layout	Geonil, Steven

Week 3	Begin connecting the sensor subsystems to pcb block and adjusting any physical designs on the chair	Brian
	Test few trials of sitting posture to examine pcb's measuring/analyzing data.	Geonil, Brian, Steven
	Develop and test several methods of streaming information from pcb to web server	Geonil, Steven
Week 4	Create the algorithms to determine posture status and feedback system to notify user's need to fix posture	Geonil
	Use user data to visually display an understanding/analysis of their posture over time	Steven
	Optimize the pcb and sensors to provide accurate usable data	Brian
Week 5	Group meetings to cover knowledge of every single area to everyone, come together as a collaborative effort to debug/improve existing physical/software features	Geonil, Steven, Brian

4 Ethics and Safety

Our project has several potential safety issues.

Like addressed in 2.6 Risk Analysis, our electrical/mechanical components will be attached to where someone will sit on daily. The electrical circuits need to be safely placed in order to prevent potential dangers to the users. In order to prevent this, we need a protective and insulating material that can be put between the sensors and the user. At the same time, we need a material that is comfortable enough that a user can sit on the chair for multiple hours. By ensuring that nobody will be endangered by sitting on this electrical chair with enough insulation and protection, we believe that our Posture Sensing Smart Chair is in compliance with the IEEE Code of Ethics #1 [10].

Another risk we need to be careful is what IEEE Code of Ethics #9 states: to avoid injuring others by false or malicious action. Since our chair measures data from the pressure and ultrasonic sensors and assess the user's sitting posture, we need to be careful when we make the measurements and accurately analyze these values. Improper reporting of these values may lead to aggravation of back problems or injuries. In order to avoid this risk, we include a calibration system in order to make our data readings as accurate as possible.

We believe that our design follows the ACM Code of Ethics 1.1: contribute to society and to human well-being [11]. Like it states, our design supports improving people's poor posture which is an important problem in society today. As the world is becoming more technology-based, people often tend to spend a lot of time sitting on their chair and work in their offices for several hours. Our design contributes to the society by providing feedback to their poor postures and lowering the risk of back or neck injuries.

We also intend to follow the ACM Code of Ethics 1.6: respect privacy. We will not disclose any information or data gathered through this design or share them with any other parties. The data gathered through the chairs will only be for personal use and knowledge.

Citations

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