# SpotMe!

**S**ynchronized **P**iezoelectric and **O**ptical **T**racking
Feedback for **M**otion and **E**xercise

**ECE 445 Design Document**
Spring 2022
Team 3

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# 1. Introduction

## 1.1 Problem

With COVID-19, many people lost access to gyms and recreation centers, and the quarantine sedentary lifestyle has motivated people to work out at home, bringing to life the phrase “move like no one is watching.” For beginners, some simple body-weight exercises can lead to injury if done incorrectly but can produce fantastic results if executed properly. Not having anyone to critique and correct a person's form increases the likelihood of improper movements and thus injury, but also decreases the return value of the motions themselves. Specifically, there are two main paths to injury: incorrect range of motion and incorrect alignment of the body. Furthermore, if we take a look at the body-weight lunge, incorrect range of motion does not activate the larger leg muscles, and not aligning the knee behind the toes increases the stress placed on the injury-prone knee joints. There is a need for a device that can measure the range of motion and alignment of the body for body-weight exercises and provide feedback to the user to ensure proper execution of movements which will minimize the chance of injury.

## 1.2 Solution

Our solution for this problem has two main subsystems: a set of piezoelectric-based sleeves for the knees and a computer-vision-based software. The combination of these two measurement systems address the primary functions of this device: to measure the range of motion and the body alignment. Thus, our solution is a wearable device that works in conjunction with a three-camera setup to capture three different angles of motion that has the capability to provide accurate form correction feedback while in use.

### 1.3 Visual Aid

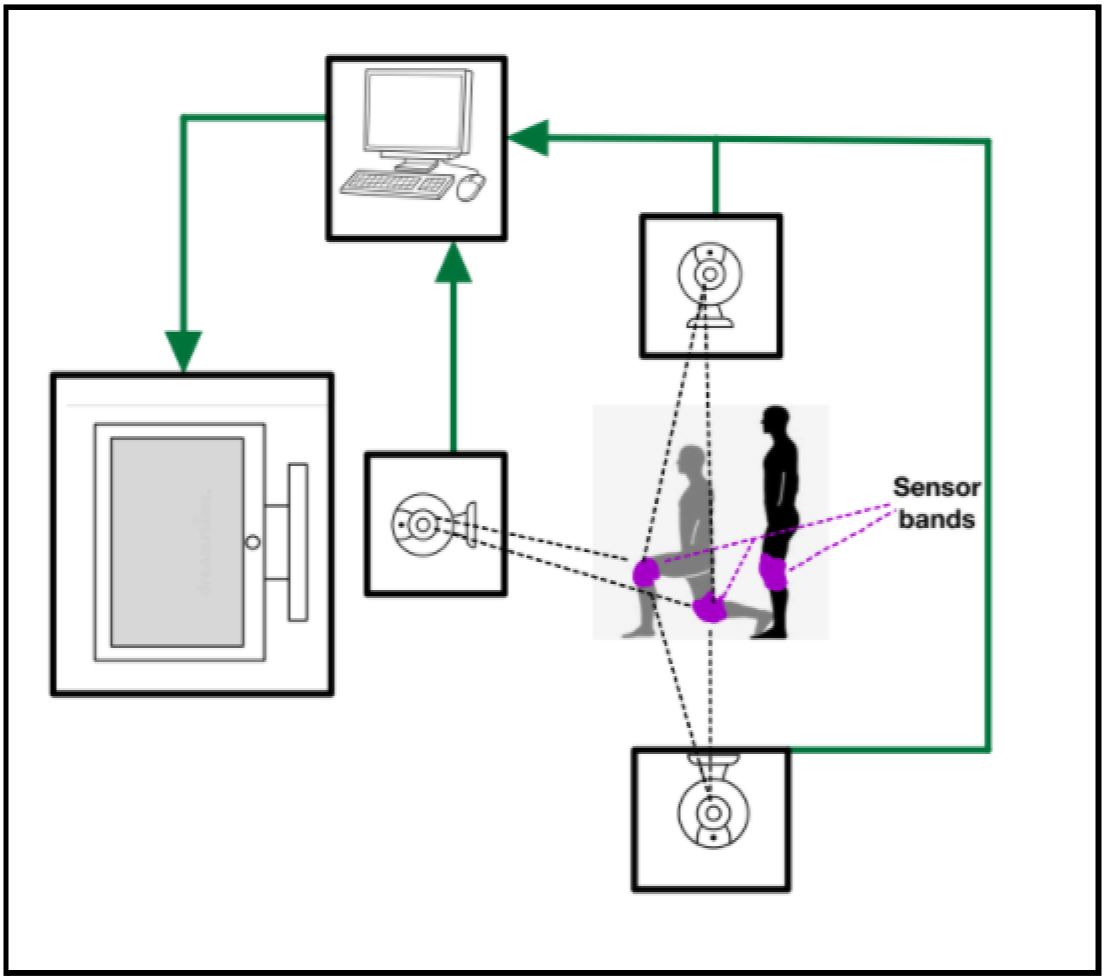



***Figure 1:*** *Visual aid for proposed SpotMe! Solution*

### 1.4 High Level Requirements

- The software must be able to identify three key points of alignment (feet, knees, hips) and relay full body position back to the user through the computer display
- The hardware sleeves must be able to measure 85-90 degree range of motion and accurately provide feedback to the user once the correct range of motion has been achieved
- The device must run on battery-power limitations (~3-6 V) and the knee sleeve must compactly house the PCB, motor, and sensor.

# 2. Design

## 2.1 Block Diagram

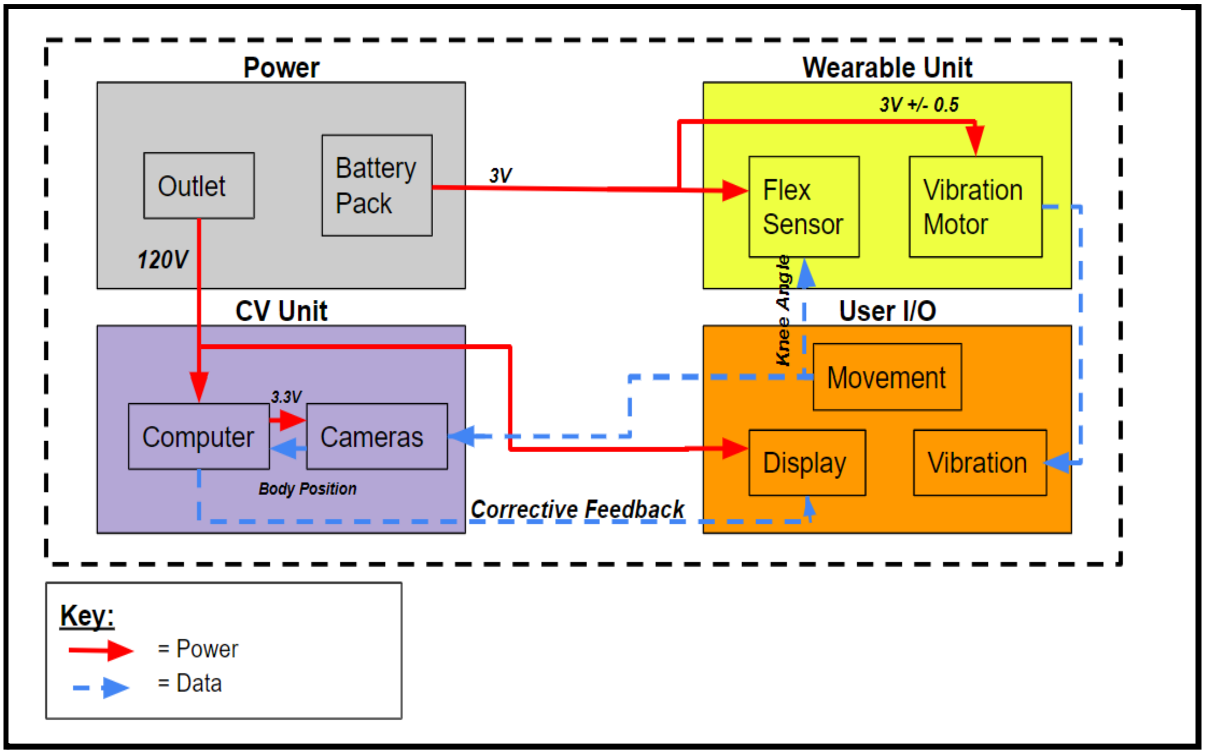



***Figure 2:*** *Block Diagram for proposed SpotMe! Solution*

## 2.2 Physical Design

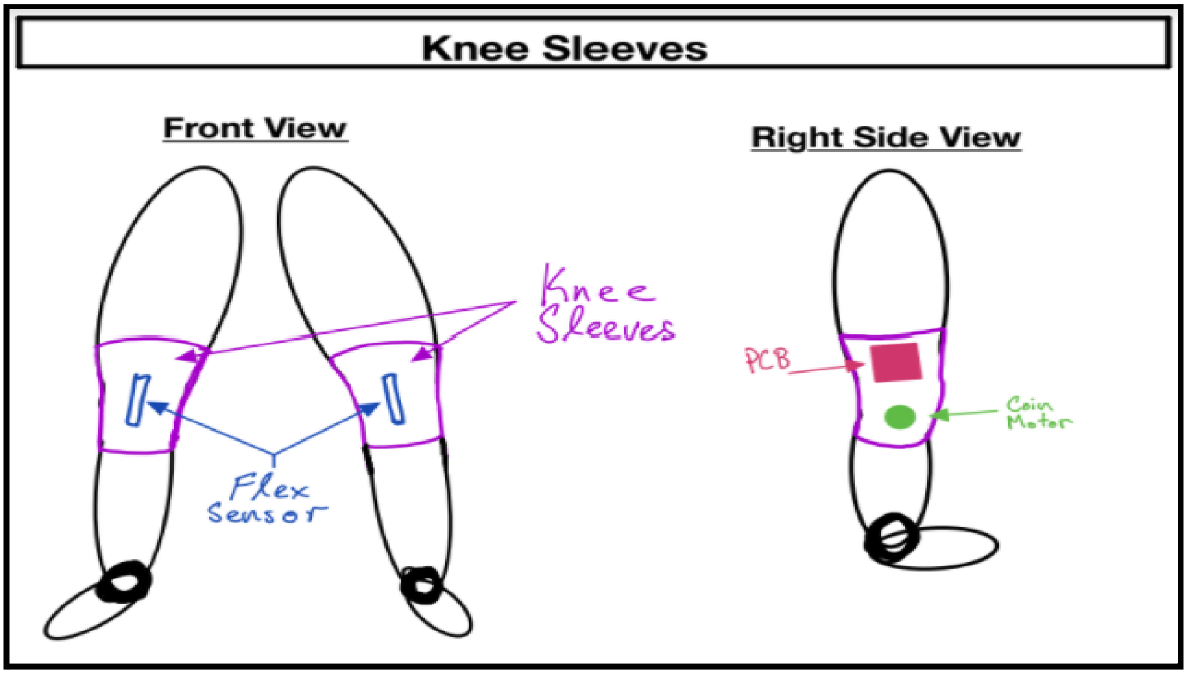



***Figure 3:*** *Physical Diagram for Knee Sleeves*

The knee sleeves in our design are a modified version of existing knee sleeves on the market. There are three different modifications that are made. First, a flex sensor will be placed on the sleeve in line with the knee. Then, as the knee bends, so will the sensor. The second modification is a velcro pouch to house the PCB. This pouch also has some padding to ensure user comfort. The final modification is the addition of a coin motor. The coin motor provides physical feedback in the form of a vibration to communicate with the user that they have completed the range of motion.

## 2.3 Subsystem Requirements

### 2.3.1 Wearable Unit Subsystem

The hardware component will include wearable sleeves for the knees primarily since we will focus on the lunge, and the

PCB will also be worn by the user. This subsystem will function to measure the range of motion of the knees, and within a viable range, provide haptic feedback to the user.

| Requirement | Verification |
| --- | --- |
| 1. Haptic feedback is provided by the coin motor at 85-90 degree flexion.<br>2. System is tuneable to the individual (ROM). | 1. Voltage divider value is below the threshold for the given source (3 V).<br>2. Physical testing. |

### 2.3.2 Computer Vision Unit Subsystem

The computer vision aspect of our project is used to provide corrective instructions when the user's lunge form is detected as incorrect.

| Requirement | Verification |
| --- | --- |
| 1. Cameras must be positioned to see user from the neck down<br>2. CV algorithm must successfully locate all 10 key points standing/still and with motion<br>3. Algorithm must identify when user is using incorrect form | 1. Check camera feedback on computer<br>2. Check key points location on display<br>3. Test all incorrect positions and verify the display shows incorrect form |

### 2.3.3 Power Subsystem

It is necessary to appropriately provide power to the components and circuitry within the hardware subsystem if we want our device to function correctly. The main devices that will require a power supply - preferably of the coin cell variety - are the haptic vibration motors and PCB itself. Our PCB design will account for the voltage regulation that is necessary to power the motor when the motor control voltage is pulsed.

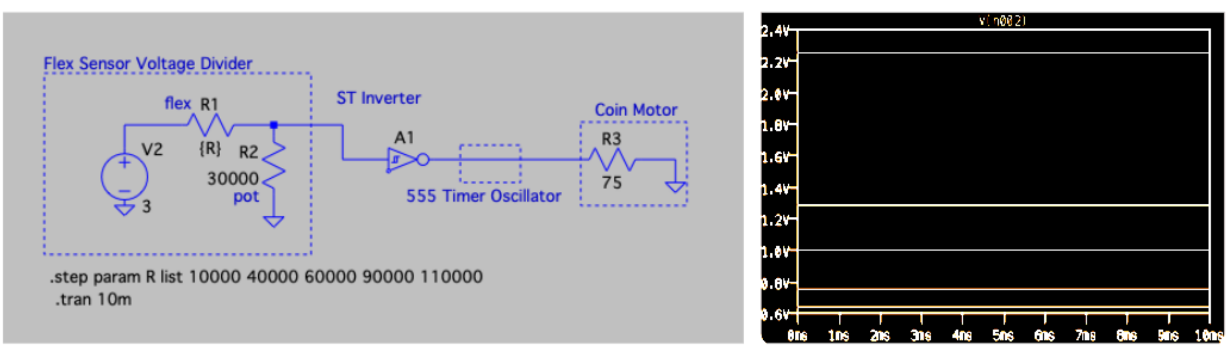
| Requirement | Verification |
| --- | --- |
| 1. Battery Voltage should not be below 10% of the defined nominal voltage.<br>2. Current should not exceed specified maximum current (0.19A). | 1. DC Sources can be quickly analyzed with a multimeter before first use.<br>2. Physical testing prior to final device construction to ensure proper biasing and resistor values. |

### 2.3.4 User I/O Subsystem

The three main components of the User I/O subsystem are user movement, laptop display, and haptic feedback. The movement of the user will serve as the input to SpotMe with outputs in the form of tactile and visual feedback using the haptic motors and laptop display respectively.

| Requirement | Verification |
| --- | --- |
| 1. The user must attempt at least one motion in order to achieve success with this device. | 1. Physical motion. |

## 2.4 Plots and Schematics




Voltage Divider Values (trigger input terminal)

***Figure 5:*** *Schematic for motor pusles*

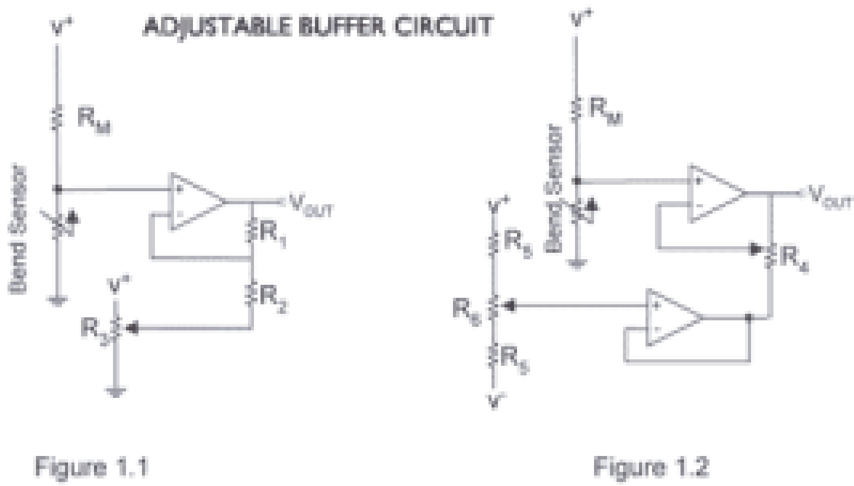



***Figure 6:*** *Schematic for flex sensor resistance to voltage conversion adjustable buffer*

## 2.5 Tolerance Analysis

The haptic feedback circuit is the central hardware part of this project, and is going to have the most challenging requirements. It needs to function under the maximum output capacity of the CR2032 coin cell battery, which has a maximum output current of 0.19 A per the datasheet. Thus we need to operate under the power maximum of 0.57 W.

Per the datasheet for the coin motor, it can be modeled as a 75 Ohm resistor (based on average measurements). We would then expect to see the motor current cap at 40 mA, which would put us at around 0.12 W in the ideal battery scenario. These numbers are smaller when we start to consider the imperfect batteries, where voltage in practice is not exactly 3 V.

Furthermore, the tuning of the voltage divider is also a bit challenging. Due to the large range of resistance values, and operating at lower than standard voltages on the Schmitt Trigger, we have to navigate reaching the threshold values properly, but because of the straightforward design, this can be done experimentally.

# 3. Cost and Schedule

## 3.1 Cost Analysis

### 3.1.1 Labor

| Engineer | Arjun | Pablo | Jason |
|---|---|---|---|
| Rate | | | |
| Hours per Week | | | |
| Total Labor Cost | | | |

### 3.1.2 Parts and Total Sum

| Part | Part Number | Price p. Unit | Quantity | Cost |
|---|---|---|---|---|
| Knee Sleeves | | | 2 | |
| Flex Sensors | SEN-08606 | $9.84 | 2 | $19.68 |
| Vibration Motor | 1597-1244-ND | $1.20 | 2 | $2.40 |
| USB Cameras | | | 3 | |
| Camera Mount | | | 3 | |
| 3V Battery | CR2032 | $0.74 | 2 | $1.48 |
| PCB Battery Holder | 140-760 | $0.98 | 2 | $1.96 |
| 555 Timer IC | LM555CN | $0.55 | 2 | $1.10 |
| Schmitt Trigger | SN7414N | $1.61 | 2 | $3.22 |

## 3.2 Schedule

| Date | Meeting Minutes | Arjun | Jason | Pablo |
|---|---|---|---|---|
| Tuesday, 1/18 | First lecture and initial brainstorming, went through six ideal total (2 each), and made six project idea posts to the web board, and awaited instructor feedback. | Posted the car catalytic converter theft RFA and the habit tracker device RFA | Posted the automatic walker for the handicapped RFA. | Posted the initial SpotMe! idea, and the equipment cleaning station idea. |
| Thursday, 1/20 | Discussed the feedback that was provided by instructors, worked together to answer questions and provide elaborations for those comments. | Brought up that the TA was going to pitch the catalytic converter project that was basically what we had pitched, which gave us optimism for selecting a project. | Elaborated on the automatic gas pump idea, and provided comments for automated walkers. | Provided comments for why SpotMe! was unique from previous gym related projects [this was not a personal trainer, and had components for wearable technology instead of on free weight equipment], and pointed out to others on the web board that their ideas were too similar to this one. |
| Tuesday, 1/25 | Went to OH to discuss with TA. TA gave details on what would be required of the three narrowed down ideas, and we settled on SpotMe! since it was given the greenlight for the RFA. Finished RFA for SpotMe! and awaited project approval. | OH & RFA | OH & RFA | OH & RFA |

| | | | | |
|---|---|---|---|---|
| Thursday, 2/3 | Laid out requirements for circuitry, programming, prototyping, and formal logistics (deadlines, meeting times, and a rough draft of the parts list). Research on parts and models began. General availability was established. Work on the proposal began. | Laid out some concepts for the circuitry and prototyping. Discussed background with wireless systems if desired, and brought up a professor who could help if we needed wireless communication. | Laid out requirements for programming and did some research about the computer vision models, said he would talk to his professor about them sometime during the coming week. | Copied over the proposal requirements and started up the Proposal document. Revised RFA components that would be included in the proposal. Discussed various implementations of the circuitry to ponder whether wireless communication was a necessary component, or if we could keep the programming and circuitry apart. Discussed how sleeves would be designed, and what components would be necessary to achieve this in hardware. |
| Tuesday, 2/8 | Wrote and Submitted Proposal to website, met with TA during class time to discuss scheduling and requirements of the project | Proposal - wrote power and user I/O subsystem requirements and tolerance analysis | Constructed and labeled the block diagram for the proposal | Initial Formatting, Introduction, Ethics and Safety, |
| Wednesday, 2/9 | Had an initial conversation with the Machine Shop to discuss possible machine shop help for our project, they mentioned possible casings and mounts and alternatives. Concluded that we didn't really need to use the machine shop, but there were | n/a | Visited the machine shop in the ECEB to talk to machinists about potential machineable devices for our project and let the other team members know about it | n/a |

| | | | | |
|---|---|---|---|---|
| | ways in which they could help. | | | |
| Tuesday, 2/15 | Went through the parts list and discussed sub-circuits and what ICs would be needed, submitted an online order form and decided what parts to acquire from the Parts shop. Revisions to the proposal were made since that would be needed for the design document. Sent emails to TA about requesting approval for orders. Decided to begin prototyping with some of the acquired parts this week. Created the schedule excel sheet to document when progress is made in the project | Revised the proposal based on corrective feedback from editor, rearranged parts of the text to follow example proposal guidelines, placed the order for two motors from digikey | Looked through camera reviews to decide which cameras would be the best to use. | Wrote out some of the sub-circuit requirements, and will place the order through the ECEB Supply Shop the next morning, created schedule excel sheet to document progress |
| Thursday, 2/17 | Attempted to move further with obtaining parts for the project, but because of the incoming winter storm, there were unpredicted closures of all non-essential services. The ECE Supply Shop closed early so we could not obtain the part order form to get our TA's signature. We did not meet per usual due to the storm, and decided to try again | n/a | n/a | n/a |

| | | | | |
|---|---|---|---|---|
| | tomorrow. | | | |
| Sunday, 2/20 | Worked on the design document in preparation for the review session with the professor tomorrow morning. With parts still not acquired, theoretical work was attempted within the limitations of LTSpice Models. Circuitry was drafted, and tolerance analysis was done to see if the design was feasible. Added additional documentation to collection of sources. | Began the initial formatting and outlined all of the necessary requirements for the design document for tomorrow's design document check. Noted down each of the part numbers and costs for the cost analysis in addition to setting up tables for future values that need to be implemented after the design document check as we still need to obtain parts to move forward. | Created figures for the physical design of the devices, and continued work on part acquisition. | Designed a sample haptic circuit schematic on LTSpice and attempted the simulation but Schmitt Trigger model was unclear. Did a power tolerance analysis calculation for the motor. Started a Google Slides presentation to store pertinent datasheet links and information, and models and specifications for parts, in order to combine images to form more complete figures for the design document. |

# 4. Ethics and Safety

Our project does not breach any ethical guidelines on the basis of discrimination because it is meeting a need that serves a general community of those affected by the pandemic, independent of race, ethnicity, gender, and sexual orientation. This device does have a target audience of people without excessive limb loss in their lower extremities as it is designed to be wearable technology that measures the flexion of the knee. However, that is a necessary feature for the hardware component solution and therefore cannot be discriminatory. Our device, therefore, complies with section 7.8.II-7 of the IEEE Code of Ethics.

The use of OpenCV software will not record or harbor any personal data or imagery other than what is necessary for its intended purpose of real-time feedback. User identity is not a factor in our device solution, therefore protecting the privacy of the user, complying with section 7.8.I-1 of IEEE's guidelines [1].

We aim to avoid presenting our solution in esoteric terms and aim to make our device easily understandable for the general public's use, which improves the understanding of individuals and society as described by guideline 7.8.I-2.

Other guidelines are not applicable to the project but to each of our team members as individuals, and we aim to abide by and hold each other accountable to these guidelines as specified by 7.8.III-10.

Our solution delves into the realm of wearable technology, which has its own guidelines and regulations. The wearable component does not track any personal information, nor does it provoke a false sense of safety or unnecessary anxiety with the data that is taken and the feedback that is given. The wearable devices are low-voltage and will not pose a threat to the user, and they will be added to commercially available knee sleeves. We intend to integrate the device on the outside (forward-facing) of the knee, but we imagine that because the flex sensor supports bi-directional flexion that if the user sports the equipment incorrectly, it won't necessarily interfere with the results or harm them in any way, so long as they align the device with one of the two directions of flexion.

All engineers should also have a commitment to sustainability. Our design will optimize our part list to maximize the product life cycle. We will test a few power sources and see what works best for the device, and try to make it as sustainable as possible.

# 5. Citations

[1] "IEEE Code of Ethics." *IEEE*, https://www.ieee.org/about/corporate/governance/p7-8.html.

[2] Flex Sensor 4.5" Datasheet https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/FLEXSENSORREVA1.pdf