SpotMe!

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

ECE 445 Design Document

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Team 3

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Table of Contents

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 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 minimizes 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

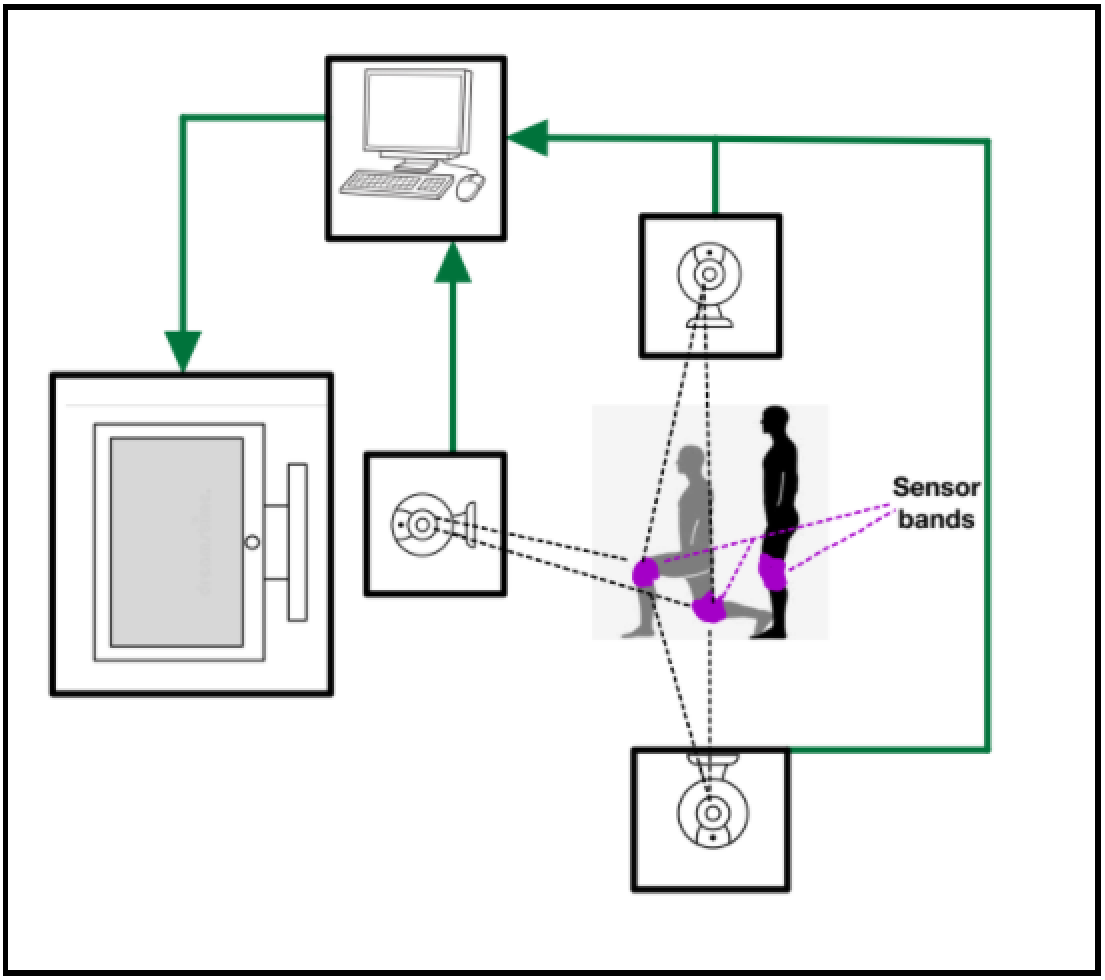


Figure 1: *Visual aid for proposed SpotMe! Solution*

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 V) [4] and the knee sleeve must compactly house the PCB, motor, and sensor.

2. Design

2.1 Block Diagram

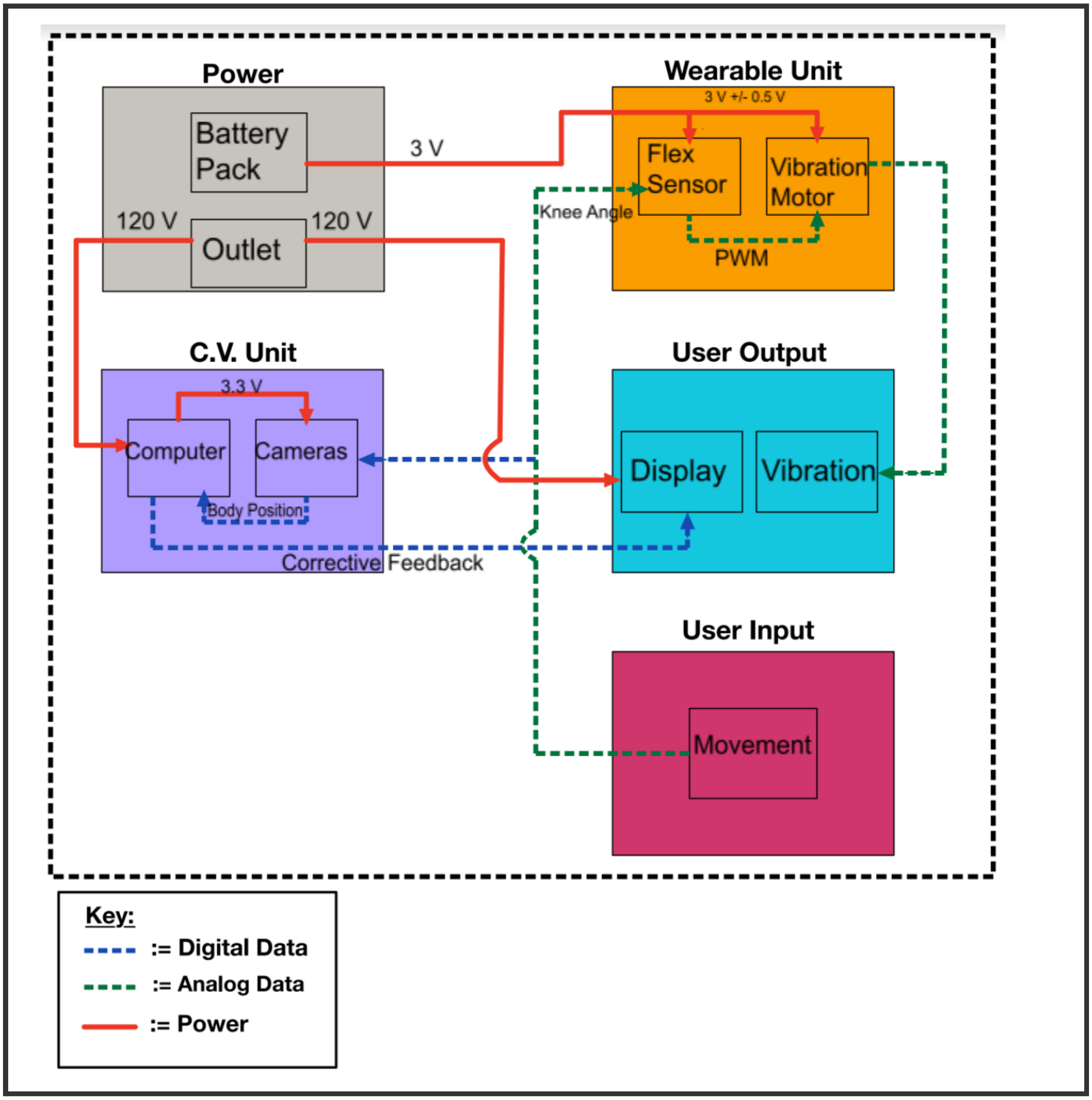


Figure 2: *Block Diagram for proposed SpotMe! Solution*

2.2 Physical Design

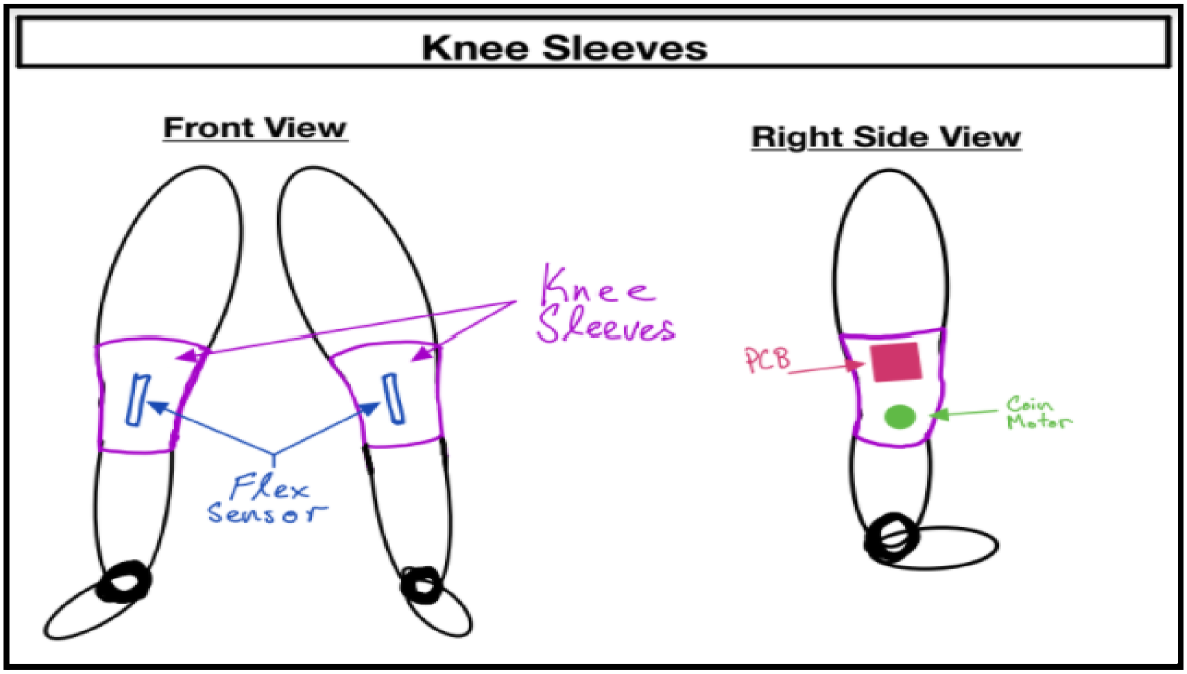


Figure 3: *Physical Diagram for Knee Sleeves*

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 is 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. One last consideration is the accessibility of parts. The potentiometer for variable tuning is accessible by the user to adjust it to their person before use, and the batteries are put into a surface-mount holder so that they are replaceable.

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. 2. System is tuneable to the individual (ROM).	1. Voltage divider value is below the threshold for the given source. Using a 3 V source, the threshold is 1 V (found experimentally). 2. Using a 100 kOhm Single-Turn Potentiometer, fine tune the voltage divider resistances to be about 1:2 pot:flex resistance. This must be done by placing a knee on a chair or elevated surface to achieve 85-90 degree flexion, and turning the potentiometer until vibration is active.

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. All four major limbs and torso must be in the frame, both standing and at the bottom of the	1. Place a camera in front and on either side of the user. Check the body placement in frame by

motion. 2. Identify the 10 following pose key points standing/still and with motion: - Toes x 2 - Ankle x 2 - Knee x 2 - Hip x 2 - Low center back/torso - High center back/torso 3. Identify when a user is using the incorrect form. The following constitutes correct form: - Torso is Straight - Front knee is not past toes - Back Knee is not touching the ground - Hips are symmetric 4. Latency of keypoint projection should be less than or equal to 100 ms.	using the display output. Adjust the camera distances accordingly until the requirement is met. 2. Output camera feed and key points to display. First have the user stand still and visually verify that the keypoints are projected over the correct joints. Then have the user move and once again visually verify if the keypoints are still projected over the correct joints. 3. Test all incorrect positions and verify the display shows incorrect form. Torso alignment must be within five degrees of vertical. Knee-to-toe alignment will be sensitive to an inch. Back knee key point must be greater than or equal to two inches from the ground. Angle between hip points must not exceed five degrees from horizontal. 4. Let x be the measure of time between the reception of camera input to display output. Let y be the measure of time between reception of camera input, key point estimation, and display output. Compute: $$\text{Latency} = y - x$$

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 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. 2. Current should not exceed specified maximum current (0.19A). 3. Each IC must be supplied with appropriate source voltage.	1. DC Sources can be quickly analyzed with a multimeter before first use. If the battery drops below 2.7 V, it is considered dead and needs replacing. 2. Using variable resistors (flex sensor and potentiometer), with baselines of 10 kOhm and rough maximums of 100 kOhms each, the current will never be larger than 150 uA. 3. The Schmitt-Trigger should be supplied with 3 V, in order to supply the motor with enough voltage to vibrate.

2.3.4 User Input Subsystem

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

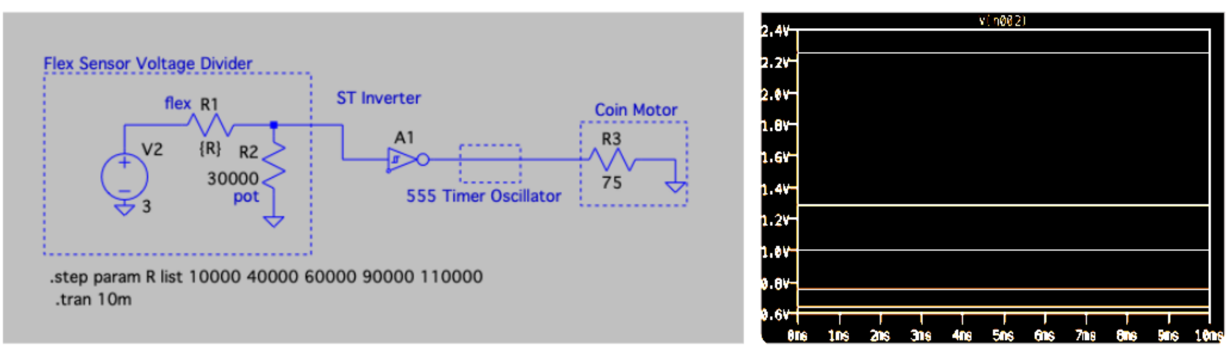
Requirement	Verification
1. The user must attempt the body-weight lunge to	1. The device verifies accomplishment of the

completion.	range of motion and the software verifies body alignment. This can be verified physically by the user when their quadriceps are perpendicular to their shins.

2.3.5 User Output Subsystem

Requirement	Verification
1. Haptic feedback must be provided by the device. 2. The user should be able to see the three camera angles marked up with the key alignment points.	1. The user should feel haptic pulses from the coin motor when achieving the 85-90 degree range of motion. 2. The user should be able to see their motion within the specified latency in the CV subsystem.

2.4 Plots and Schematics



Voltage Divider Values (trigger input terminal)

Figure 5: *Schematic for haptic feedback*

This is the first concept schematic of our design. The circuit works by first generating an output voltage from the flexion of the flex sensor [2] due to the change in resistance.

The voltage divider consists of a resistor and potentiometer to allow for variability of threshold voltages between different users. This signal is then passed through an odd number of schmitt trigger [3] inverter stages and outputs a high signal when the voltage coming out of the voltage divider drops below a certain threshold voltage. The output from the schmitt trigger acts as the switch to operate our 555 timer IC [6]. The 555 timer is responsible for generating a PWM signal only when the output from the schmitt trigger goes high. A voltage amplifier is required to increase the output voltage after the schmitt trigger and 555 timer stage as we need at least 2.5 V to turn on the motor [5]. This circuit must be replicated, as each circuit is placed onto each knee. Each circuit is small enough to fit within the housing of the knee sleeve.

Figure 6: *Human Pose Estimation Example*

Figure six is an example image of what the computer vision subsystem will display on the monitor. However, for our application the key points on the arms are not necessary. This is because for the lunge the key points in the torso and legs give us all the necessary information to give corrective feedback to the user.

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.

Another important aspect of the project is the camera feedback. Since the cameras are used for real time corrective feedback it is of utmost importance that we relay low-latency accurate limb position data back to the user. A system is considered low latent if the time difference from input to output is less than or equal to 100ms. To test this, we define “Time 1” as the time between the camera feed input and display output. We also define “Time 2” as the time from the camera feed input through pose estimation calculation to display output. The difference between the two, “Time 2 - Time 1”, is the latency that needs to be minimized.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Costs

Engineer	Arjun	Pablo	Jason
Rate	$33/Hour	$33/Hour	$33/hour
Hours per Week	15	15	15
Total Labor Cost per Member	$1238	$1238	$1238
Total Labor Cost	$37,130.00		

3.1.2 Parts Costs

Part	Part Number	Price p. Unit	Quantity	Cost
Knee Sleeves (Pair)	N/A	$20.00	1	$20.00
Flex Sensors	SEN-08606	$9.84	2	$19.68
Vibration Motor	1597-1244-ND	$1.20	2	$2.40
USB Cameras	Logitech C270	$27.99	3	$83.97
3V Battery	CR2032	$0.74	2	$1.48
PCB Battery Holder	140-760	$0.98	2	$1.96
CMOS 555 Timer IC	TLC555CP	$0.82	2	$1.64
Schmitt	SN7414N	$1.61	2	$3.22

Trigger				
Total parts Cost				**$134.35**

3.1.3 Total Costs

Labor Costs	**Parts Costs**	**Grand Total**
$37,130.00	$134.35	$37,264.35

3.2 Schedule

Week	Arjun	Pablo	Jason
2/28	Design PCB and make PCB corrections	Design PCB and make PCB corrections	Order and Obtain cameras, Begin work on keypoint estimation
3/7	Finish PCB and order first PCB draft	Finish PCB and order first PCB draft	Continue key point estimation, Get key points to display in real time
3/14	Solder PCB, revise circuit schematic if possible and debug	Revise circuit schematic if possible in preparation of 2nd PCB order	Start evaluating key point display latency while moving
3/21	Finalize circuit and order 2nd PCB	Finalize circuit and order 2nd PCB	Start displaying feedback based on keypoint positions

3/28	Prefabrication and testing	Prefabrication and testing	Clean up user interface
4/4	Fabrication and testing, work on final paper and presentation	Fabrication and testing, work on final paper and presentation	Buffer week
4/11	Fabrication testing, demo preparation, finish final paper and presentation	Fabrication testing, demo preparation, finish final paper and presentation	Prep for mock demo and real demo

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

[3] "SN74AHCT14." *SN74AHCT14 Data Sheet, Product Information and Support | TI.com*, https://www.ti.com/product/SN74AHCT14.

[4] "*CR2032" 3v Coin Cell - Murata*. *Product Search Data Sheet Ltd.*. https://www.murata.com/en-us/api/pdfdownloadapi?cate=cgsubMicroBatteries&partno=CR2032.

[5] "316040001. Vibration ERM Motor 3v" *DigiKey*, https://www.digikey.com/short/mjpfjph1.

[6] "LM555 Timer." *Data Sheet, Product Information and Support | TI.com*, https://www.ti.com/lit/ds/symlink/lm555.pdf