SpotMe!

[**S**ynchronized **P**iezoelectric and **O**ptical **T**racking feedback for **M**otion and **E**xercise]

ECE 445 Senior Design Project Proposal
Team 3

Arjun Shamaraya [arjunms2]
Jason Vaccarella [jasonav3]
Pablo Sanchez Jr. [psanch22]

Introduction

With COVID-19, many people lost access to gyms and rec centers, and the quarantine sedentary lifestyle has motivated people to try working 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 since this will minimize the chance of injury.

Our solution for this problem comes in the form of two main subsystems: a set of piezoelectric-based sleeves for the knees and a computer-vision-based software. The combination of these two systems will address the two big needs for this device, which are to measure the range of motion and to measure the alignment of the body. Thus, our solution will be a wearable device that works in conjunction with a 3-camera setup to capture three different angles of motion.

The wearable hardware components will be implemented with flex sensors that can measure the range of motion of the knees, and a localized vibration motor will be driven at the proper threshold as haptic feedback. The range of motion components has to be variable, as not all human bodies are the same, and this can probably be achieved with variable potentiometers and voltage dividers in order to turn these analog variables into digital logic computations. The computer-vision software component will utilize OpenCV to track limbs and joints from three different angles to measure the alignment of the body (further details below).

Below is a visual aid of our modular design that shows how user motion information is distributed to the CV and wearable units, and their respective feedback.

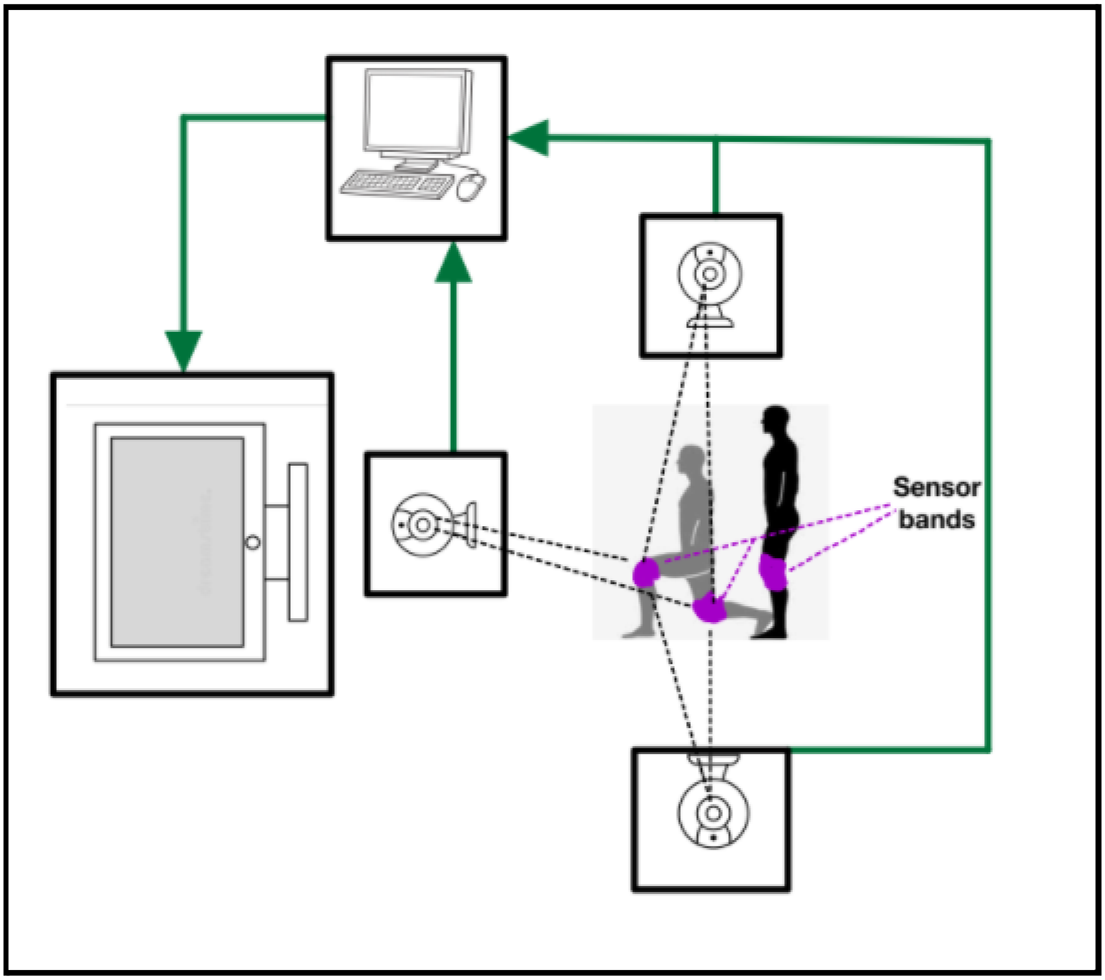

Figure 1: Visual Aid for proposed SpotMe! solution

This project will be centered around the body-weight lunge, and thus the quantitative criterion for success are as follows:

- The software must be able to identify three key points of alignment (feet, knees, hips).
- The hardware sleeves must be able to measure 85-90 degree range of motion.
- The device must run on battery-power limitations (~5V-9V).

Design

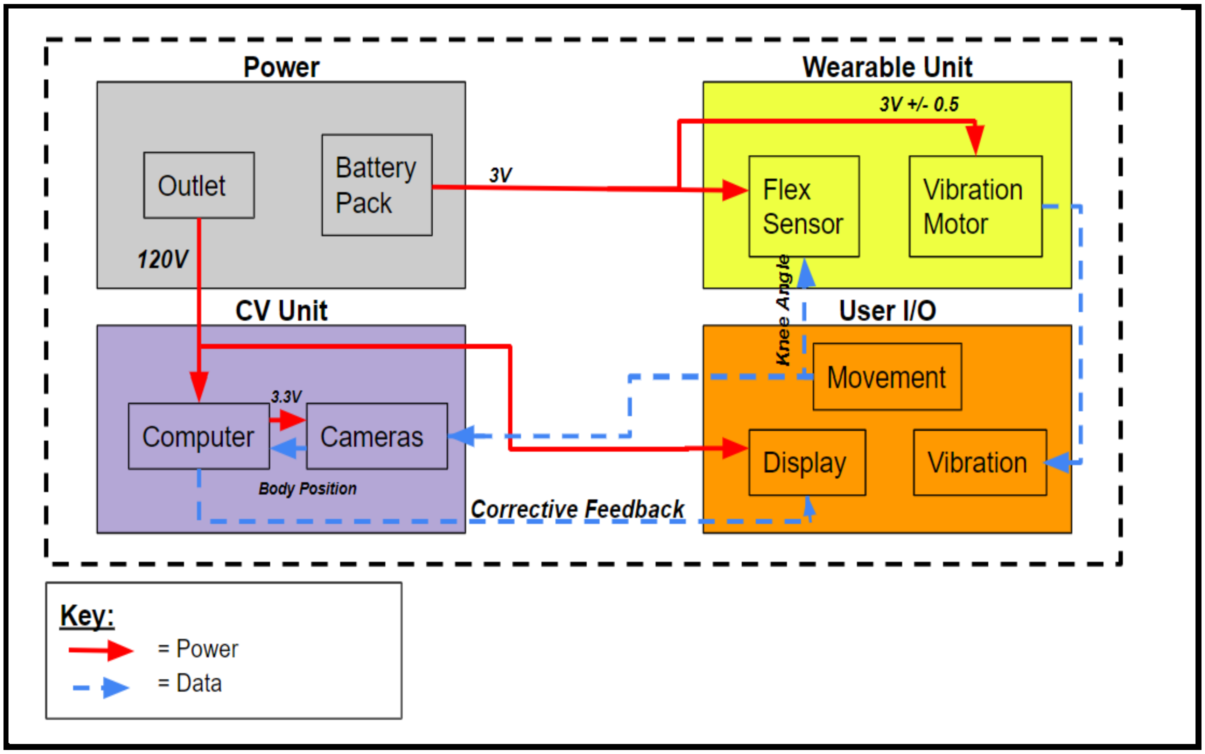

Figure 2: Block Diagram for proposed SpotMe! solution

Subsystem 1 - Wearable Unit

Overview and Requirements:

The hardware component will include wearable sleeves for the knees primarily since we will be focusing on the lunge, and the PCB will also be worn by the user. This subsystem will be responsible for measuring the range of motion of the knees, and within a viable range, provide haptic feedback to the user.

The sleeves themselves can be made from existing fabric sleeves for exercise, and they would be rigged with flex sensors, and then connected to the centerpiece PCB. These can be calibrated with other parts of the circuit via voltage dividers, to set the proper threshold for each user. The PCB can then send some pulse feedback signals to haptic actuators that will also be a part of the sleeves.

We are thinking of using common 4.5” flex sensors, and a pancake motor for the haptic feedback.

Tolerance Analysis:

The first consideration for proper usability is comfort with regard to the hardware subsystem. While being used, each component of the device should be as comfortable as possible since it will be directly worn by the user. To account for this, the power and data distribution circuitry for the resistive flex sensors and haptic motors should be compactly contained within the sleeve and should **not** affect the mobility of the user. Another potential risk is the possibility of too small or large of a voltage tolerance from the resistive sensors to the haptic motors. The circuitry should be able to quickly and accurately account for a range of values and changes in the resistance of the flex sensor. Every person is different, so he or she may require different initial calibration settings. Furthermore, it is impossible to achieve exact 90-degree knee bends all the time, so the vibration feedback circuitry must be able to tolerate a range of voltage values based on the resistive output from the sensor based on what these initial calibrations might be, otherwise, we would be either too strict or too lenient on the user’s movement, which defeats the purpose of this device.

Subsystem 2 - Computer Vision Unit

Overview and Requirements:

The computer vision aspect of our project will be used to provide corrective instructions when the user's lunge form is detected to be incorrect. We will provide this feedback using keypoint estimation on the body. Keypoint estimation will highlight the joint positions and if certain joint positions are not in alignment then that would mean the user’s form needs to be corrected. For example, from the side view if the knee-joint location is beyond the toes then the user is doing the lunge incorrectly. The following are the aspects of the lunge movement that would constitute incorrect form by the user:

- Front knee is not past the toe when lowering to the ground
- Rear knee is not touching the ground
- Back is straight and upright
- Hips are symmetrical
- Feet are hip-width apart

This subsystem will involve 3 USB cameras and a computer to do the processing for the computer vision. Two of the cameras will show either side of the user and the third camera will show the front view of the user. The computer will be used to not only do the computation needed for the computer vision but will also display to the user if they are doing something incorrectly.

Tolerance Analysis:

Since we will be using a camera feedback display system, it is of utmost importance that we relay accurate limb position data back to the user. Incorrect placement of the cameras with respect to the user can skew the data and confuse the user as he or she will not be able to look behind themselves to correct their form. Improper placement of the cameras could alter the true positioning of the user’s form, and the data coming from each camera must work together to paint the full picture of the user, as well as work separately as to not confuse one section of the body with another due to potential obstructions, for example when one leg passes over the other while switching lunge positions. We would not want the user to correct their form based on skewed output data.

Subsystem 3 - Power

Overview and Requirements:

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 - most probably 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. The appropriate voltage range for the motor will be anywhere between 2.5 to 3.5V DC, with a starting voltage of 2.3V and a max current of 80mA.

To power the PCB, the ideal battery would be 3V Lithium coin batteries (connected in series to achieve a higher voltage) to distribute power within the board. The coin cell batteries seem ideal for this project as they will sit horizontally flush against the inner layer of knee-sleeve fabric to ensure user comfort. The battery, in the context of our device, will act as the power supply, as shown in the block diagram section.

The flex sensor will range from 10k to 110k**Ω** and will require a voltage divider amplification circuit using an operational amplifier to account for low-degree bends. This output voltage can be used to control a transistor network to power on the haptic motors based on the resistance value of the flex sensor. The pulsed signal that is sent to the motors can be designed by either using a circuit that implements a square wave oscillator, an astable multivibrator circuit, or a clever implementation of the 555 timer IC to output 2.5-3.5V to repeatedly pulse the motor.

Furthermore, any individual transistor network that we decided to use for any part of the circuit will require appropriate Gate-Source and Drain-Source voltage biasing to operate between the cutoff and saturation regions of the transistor, depending on the type of PWM signal we send to the motor.

Tolerance:

One thing we will have to account for regarding power are the manufacturing inconsistencies. For example, a battery can say that it is rated for 3V, but in reality could actually measure around 2.7 to 2.8. This poses a risk to the success of the project because without the correct voltage being provided to the motors and PCB, the devices will not turn on. We can design our system to work within a range of voltage outputs so that any inconsistencies can be mitigated.

Subsystem 4 - User I/O

Overview and Requirements:

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 and the outputs will be in the form of tactile and visual feedback using the haptic motors and laptop display respectively. The requirements for this section are quite simple, as the only thing we require is accurate feedback to the user so that his or her form can be corrected if the vibration of the motors is not felt.

Tolerance:

A possible hangup with User I/O is the variety of body shapes and sizes, which in turn varies a comfortable range of motion. However, we account for that via a voltage divider to manipulate the threshold of the range of motion.

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.

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.