Research Experiences for Teachers and Young Scholars in Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)

Application of Film Sensors for Feedback on Cyclists' Sagittal Ankle Flexion

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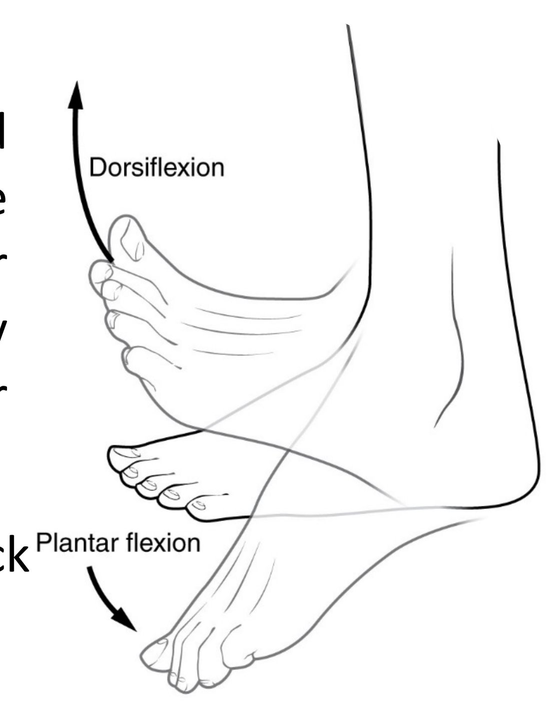
Problem

Ideal flexion of the talocrural joint about the sagittal plane for cyclists range from -2° plantar flexion to +22° dorsiflexion. Flexion outside of this range is more common with fatigued riders. In addition, outside of the ideal range muscular efficiency is noted to decreases.

Poor ergonomics may result in reduced desire to use cycling as a means of active hobby or exercise. For technical cyclists or professionals, reductions of efficiency may have a significant impact on their performance.



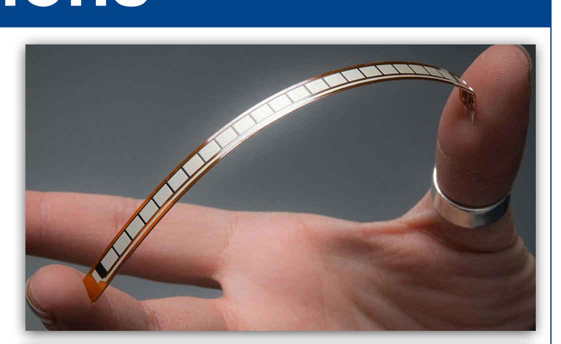
Currently, cyclists can receive form feedback from a cycling coach or analyze video of stationary cycling exercises, but those solutions are either cost prohibitive or requires complex equipment or software.

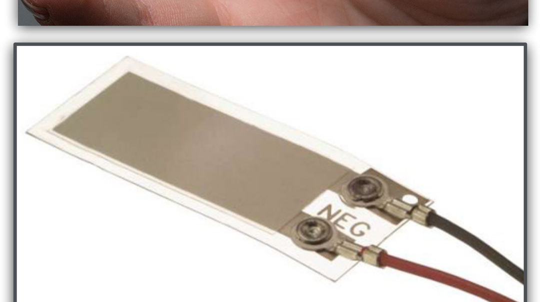
Response

Provide simple "coaching" that allows for both novice and experienced cyclists to ride with ankle flexion that falls within the ideal range, increasing efficiency and overall performance while in the saddle.

Engineered Solutions

A small, film-based sensor that analyzes ankle motion and alerts the rider when their range of sagittal ankle flexion is outside of the range of -2° plantar flexion and +22° Dorsiflexion. The sensors, investigated for installation over the anterior talus, were made of either a serpentine resistor or a piezoelectric material.



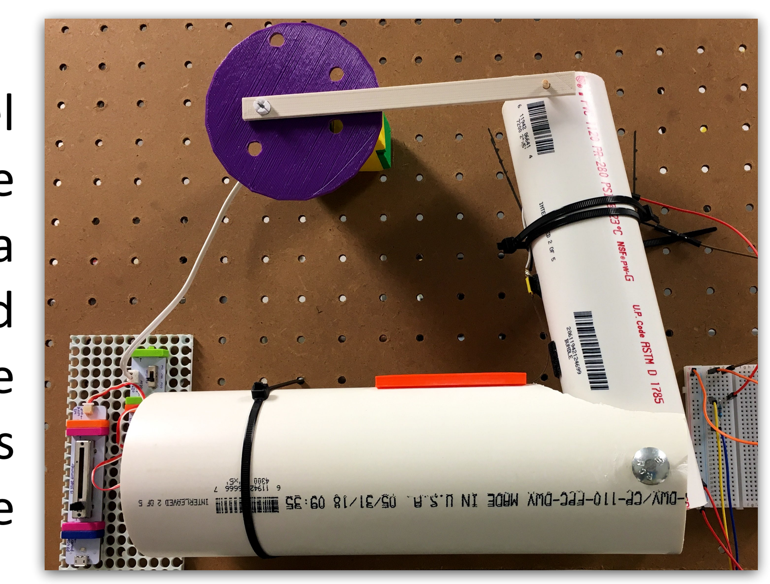


Application Constraints

- must be designed small enough to remain comfortable for the user — no noticeable increase in load on the ankle during flexion
- must withstand a significant amount of repetitive cycles of flexure and relaxation
- materials must be affordable
- Films must be thin enough to flex freely in narrow protective plastic sleeve

Modeling the Talocrural Joint

Two pieces of PVC pipe were cut and joined at a pivot point using a bolt. The foot and lower leg were represented by 4" diameter and 3" diameter PVC pipe, respectively. The joint had free motion from what would model 25° dorsiflexion to approximately 90° plantar flexion.



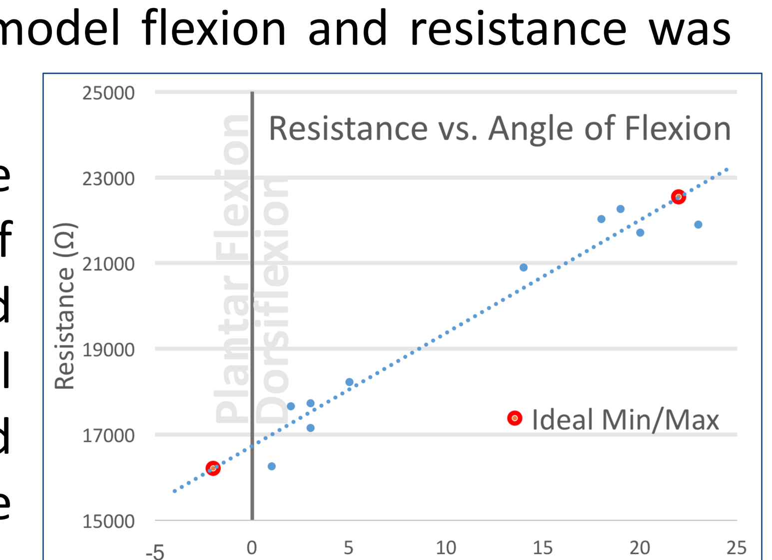
A coupling rod and driving wheel with five attachment points were 3D printed and driven by a littleBits DC motor. This allowed for a variety of total flexions to be tested. The actuation rate was controlled using a littleBits Slide Dimmer.

Sensors were connected to an Arduino Uno R3 and transferred through its serial port to CoolTerm for data collection and analysis.

Angle Measured Using Flex Sensor

During manufacturing conductive ink is printed in a serpentine pattern onto a flexible substrate. When bent the conductive ink is stretched, and the length and resistance of the material increases. The element provides a resistance as a function of its bend angle. Resistance through the element is static and does not require constant actuation in order for a signal to be produced.

A large Flex Sensor element with leads supplied by Spectra Symbol was installed on the talocrural joint model. The signal was analyzed and a relationship between the model flexion and resistance was established.

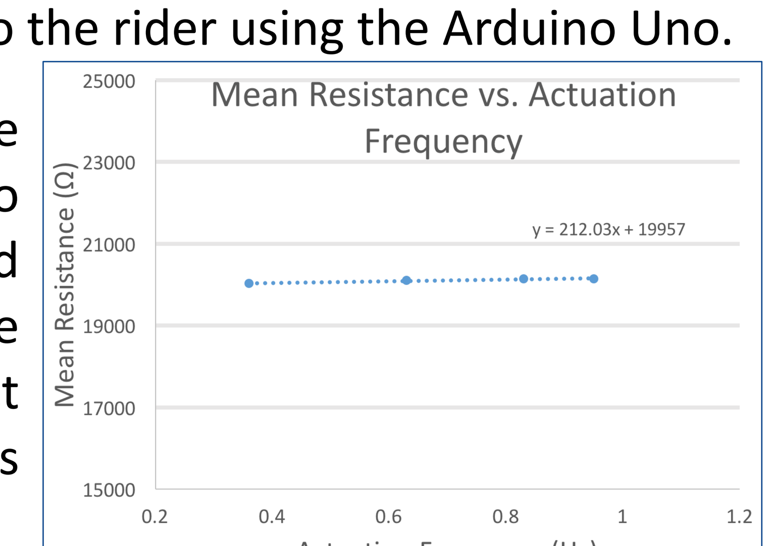


According to the model, the minimum and maximum values of resistance that should be detected while a rider is maintaining ideal talocrural flexion are 16,200 Ω and 22,500 Ω, respectively. These values were used as thresholds in order to product visual feedback to the rider using the Arduino Uno.

Below -2° plantar flexion

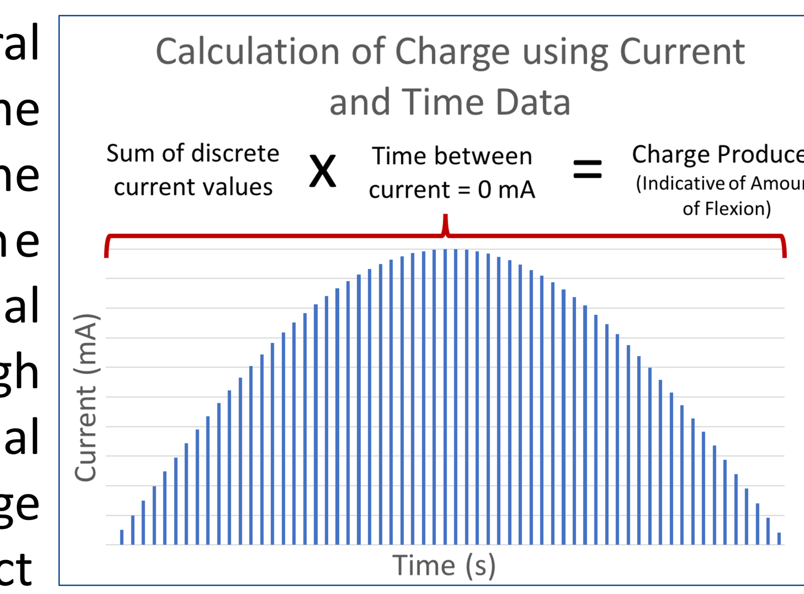
Above 22° dorsiflexion

The rate of ankle flexion was also measured and noted to have minimal impact on the sensor's data (< 0.4%).



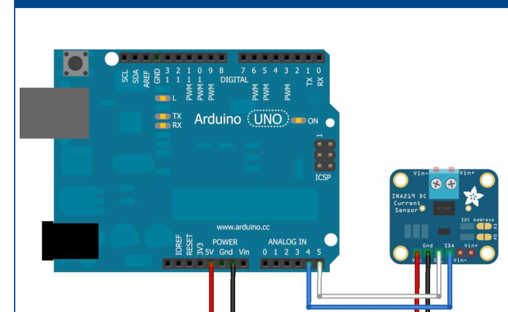
Conceptual Model of PVDF Film as Sensor

Polyvinylidene Difluoride (PVDF) is material that is commonly used as piezoelectric element in film applications. When the film is bent or vibrated, a current is produced across the film that can be analyzed. Utilized in a talocrural joint sensor, PVDF provides some challenges when compared to the serpentine resistor, as the material only produces a signal when actuated. Using a high sampling rate, there is potential to approximate the total charge produced by the film as a product of the sum of discrete measurement and the total time of measurement.



Despite the challenges in using PVDF, the material present some advantages that make it worth exploring. Because the sensor is producing a current, there is potential to use the PVDF element as a mechanical energy harvester. This may serve to reduce the load on the battery used to operate the Arduino, prolonging its life between charges. PVDF may also show less variance in signal during extreme hot and cold than a resistance-based sensor.

Future Work



The next step in the development of this device is establishing a means of collecting high-frequency current measurement using a current sensor breakout such as the Adafruit INA219. This will allow for further development of a PVDF-based sensor. Because of the flexible nature of the PVDF film, integration of the material into the fabric of cyclists' clothes may be a realistic possibility. Finally the opportunity also exists to develop a means of wireless communication between either device and a handlebar-based display to increase usability and reduce accidental damage.

Acknowledgements

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