Soft-robotics wearable device for rehabilitation of Achilles tendon rupture

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MOTIVATION AND AIMS

Motivation

Achilles tendon rupture affects 4500 people per year in the UK alone[1]. The current non-surgical protocol for rehabilitation involves wearing a functional orthosis for up to 16 weeks[2]. This limits the range of motion of the ankle and is adjusted depending on the time since injury. There is a wide demographic of people who rupture their Achilles tendon and they all have very different recovery times, therefore the current time based approach can lead to re-injury, muscle atrophy and immobility.

Overall aim

The overall aim of this project was to create a wearable device to track the range of motion of the ankle. This would allow for patients with Achilles tendon ruptures to be provided with specific, personalised rehabilitation programs to optimise recovery. This builds on a previous 4YP[3] in which a prototype of an instrumented sock to monitor ankle motion was created. This wearable device had two piezoresistive sensors, made using conductive fabric, to measure dorsiflexion and plantarflexion and has undergone some basic testing which demonstrated proof of concept. The current project should use engineering analysis to improve on the previous prototype, focusing on both design and testing.

Design aims

- Ensure reproducibility
- Increase number of sensors
- Optimise sensor attachment
- Optimise sensor placement

Testing aims

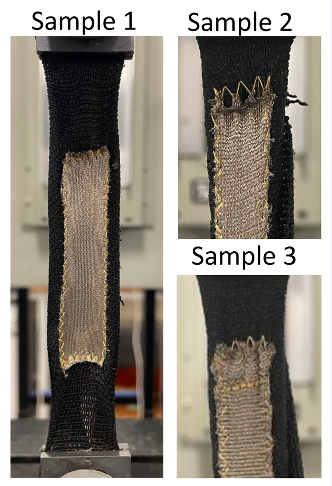
- Test prototype in a controlled environment
- Use more advanced models to obtain improved kinematic data

DESIGN EXPERIMENTS

Sensors attachment

An experiment was carried out to investigate the best method of attachment. An Instron materials testing machine was used. Three samples were tested, each one made up of a sensor attached with a different method to a piece of sock material:

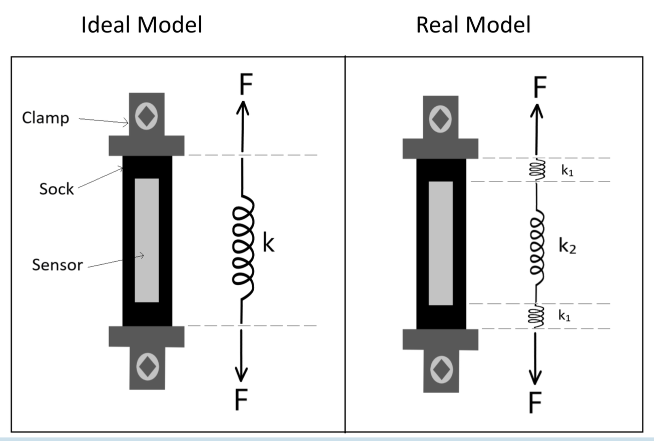
Sample 1 - fabric glue and zig-zag stitching around the perimeter
Sample 2 - zig-zag stitching around the perimeter
Sample 3 - zig-zag stitching around the perimeter and straight reinforcing stitches at the ends

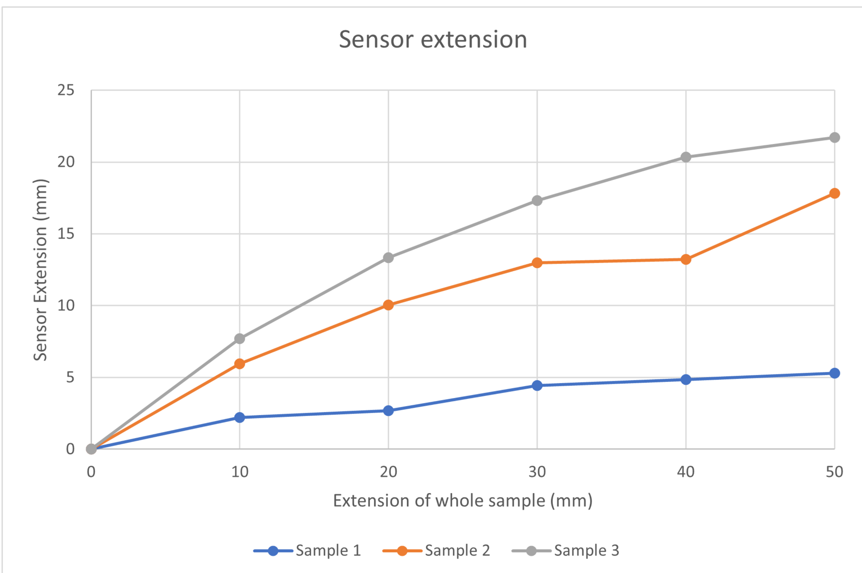


The samples were stretched to a preload force of 1N to ensure they were under tension, then increased in increments of 10mm, up to 50mm extension. The extension of the entire sample and the extension of the sensors were measured at each increment.

Spring models were used to find that sample 3 had the lowest value of both k and k_2, therefore restricting movement as minimally as possible. A graph of sensor extension vs whole sample extension was also plotted, revealing the highest gradient for sample 3 - suggesting it is the most responsive sensor to movement.

Sample 3 was chosen as the best attachment method.





Sensor placement

The placement of the resistive sensors on the sock needs to be optimised to track the motion of the ankle as accurately as possible. The primary focus was to be able to track plantar and dorsiflexion of the ankle.

Two possibilities for sensor placements were tested to see which would be most suited to this wearable device. A range of movements were performed whilst wearing each sock with the measurement circuit attached. The aim was to choose the placements that provided the larger range of output values throughout the movements as this would allow for more precise mapping of sensor values. Sock 1 was chosen.

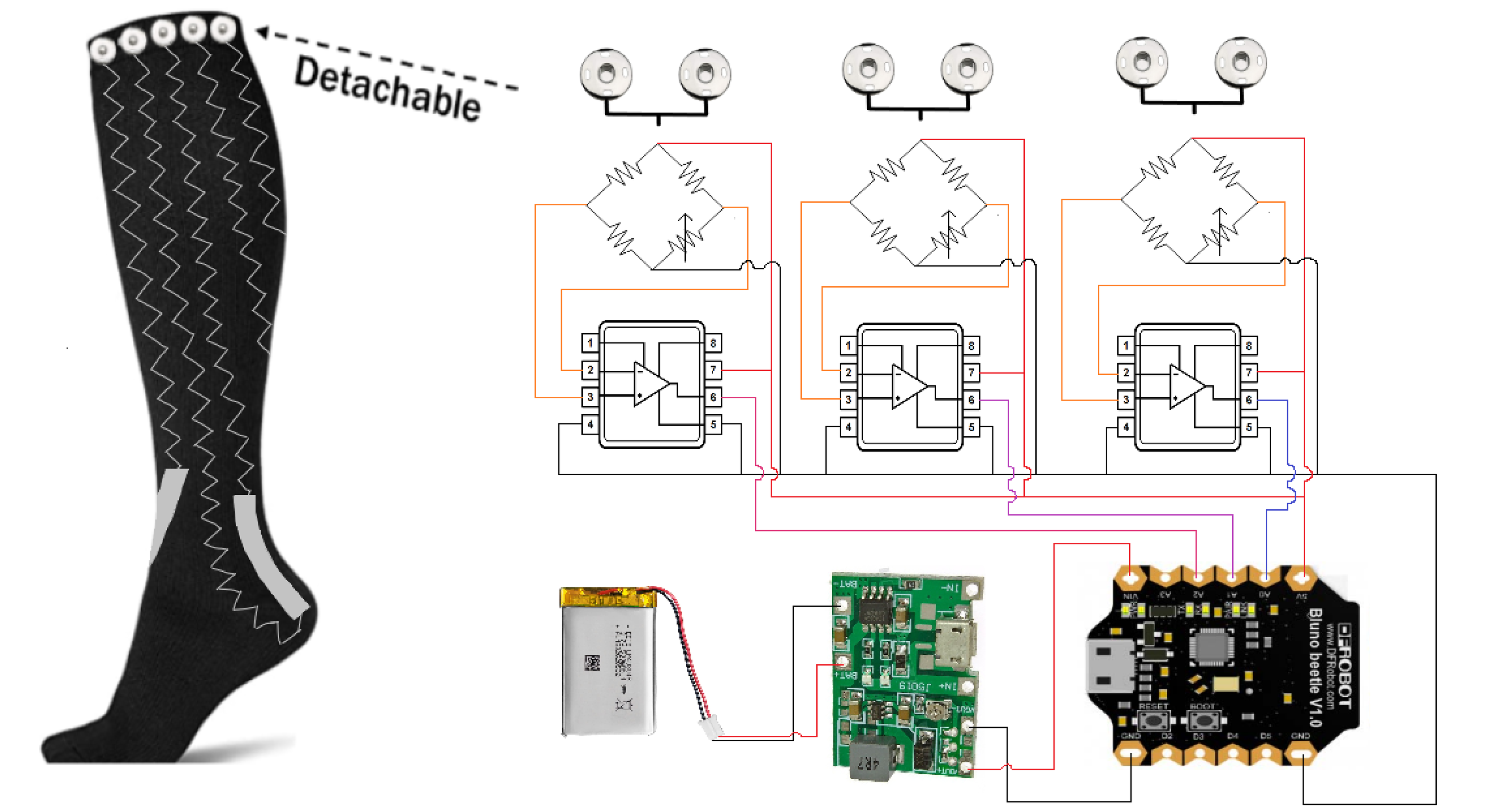
CONSTRUCTION

The developed wearable device needs to be comfortable and non-restrictive but able to adapt to the body's complicated geometry and multi degree of freedom movement. An instrumented sock has been designed to meet these requirements.

A compression sock is used as it is tight, non slip and recommended for use during the recovery of Achilles tendon rupture. Sensors are attached to this sock, these are made using resistive material which changes resistance depending on its extension or compression. Conductive thread is used to connect each end of the sensors to press stud terminals at the top of the sock. A detachable battery powered circuit allows the voltage across each sensor to be measured from the press studs. These voltage measurements can be sent via Bluetooth from an attached Arduino board to a nearby device for analysis.

Meeting design aims:

The use of a sewing machine for sensor attachment and the creation of a standard protocol for sock construction ensured reproducibility. The design allows for readings to be taken of three sensors which is more than the two used in the previous 4YP prototype. Experiments allowed for optimisation of sensor attachment and placement for most informative data collection.



PROTOTYPE TESTING

Testing aims

The aim of testing the prototype was to use a motion tracking system to collect kinematic data while simultaneously recording sensor outputs from the instrumented sock during a range of movements. This would allow for a comparison between sensor outputs and joint angles - correlations could be investigated and mappings between values made.

Motion Capture

The motion tracking system used was the Vicon in the Oxford Gait Laboratory. There are 12 motion capture cameras that detect the 3D position of small reflective spheres that are stuck on the body in specific anatomical locations. The Vicon Polygon software has model pipelines that use the detected markers to define segments and joint centres, which allow for calculation of joint angles.

Testing Protocol

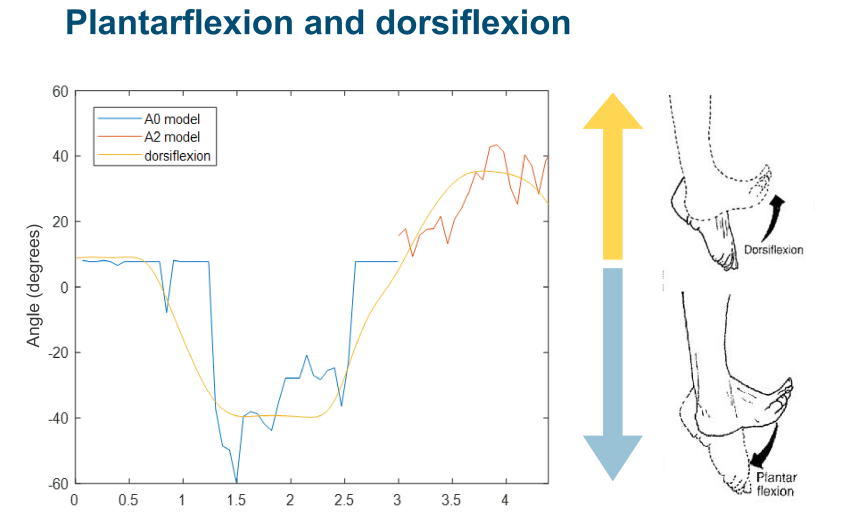
The instrumented sock was worn on the participant's right foot. Reflective markers were placed using double sided tape in the correct anatomical locations for the Oxford Foot Model [4] and Lower Body Plug in Gait Model[5] - these allow for calculation of ankle angles.

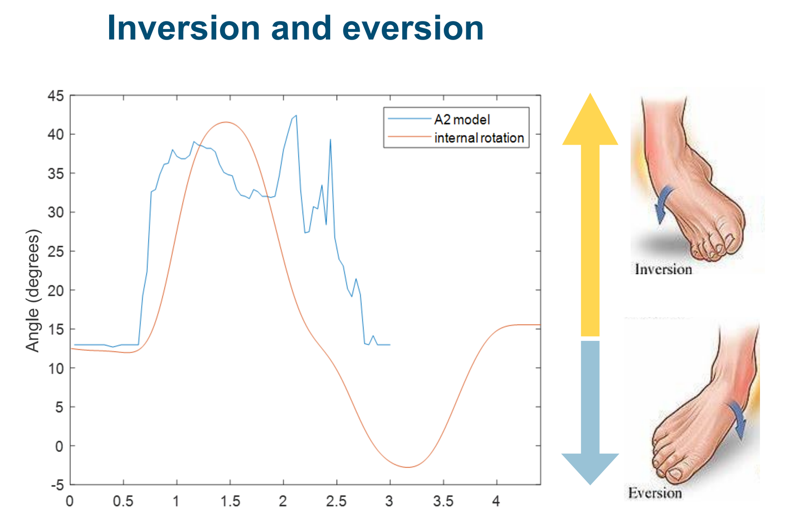
Data collection was started on both the Vicon and the instrumented sock, before a range of movements were carried out, these movements were chosen to cover a large range of motion and were:

- Static: standing still for calibration
- Non-weight bearing (seated): plantar-dorsiflexion, inversion-eversion, circumduction
- Weight bearing (standing): heel lift, heel lift hold, inversion-eversion, squat
- Walking: standard gait

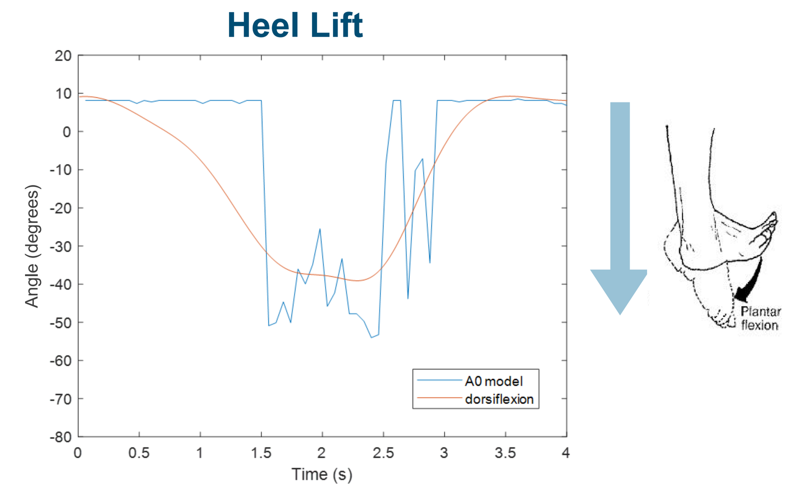
RESULTS

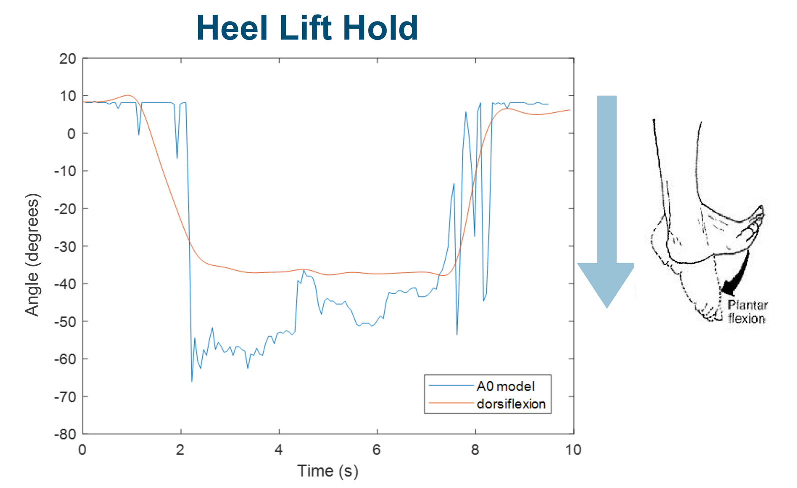
Data collected during the prototype testing was used to create linear mappings between sensor outputs and ankle angles for plantar/dorsiflexion and inversion/eversion. The sensors were only used for mappings for the ranges they were in extension for.

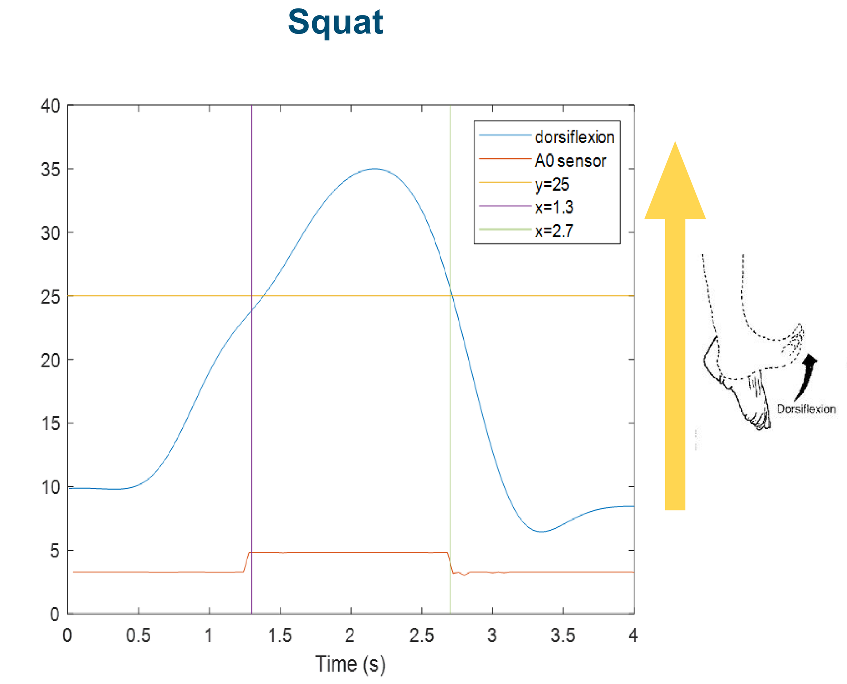




These models were applied to sensor data collected during heel lift and heel lift hold. Then looking at the squat results an estimation of compressed sensor value to large dorsiflexion angles was made.







The estimation is that when A0 sensor values are between 1.3V - 2.7V the dorsiflexion ankle angle is larger than 25 degrees.

CONCLUSION

A prototype of an instrumented sock to track ankle motion was successfully made and tested, revealing the potential for development with this technology. Models were trialed to see if ankle angle could be estimated from the instrumented sock sensor outputs, these showed good estimations of ankle motions but improvements need to be made to the accuracy of specific ankle angle estimation. This could be done through collecting large data sets with motion capture and developing machine learning techniques to map between the collected data and kinematic joint angles.

References

(1) Dr Lawrence Knott, Achilles Tendon Rupture. Patient 21.12.22.
(2) AM Hutchison, C Topliss, D Beard, RM Evans, and P Williams. The treatment of a rupture of the Achilles tendon using a dedicated management programme. The Bone Joint Journal, 97(4):510–515, 2015.
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(4) Oxford foot model. https://www.vicon.com/soft ware/oxford-foot-model/.
(5) Lower body modelling with plug-in gait. https: //docs.vicon.com/display/Nexus25/Lower+body+modeling+with+Plug-in+Gait.