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Investigation into the resistive response of wireless knitted textile pressure sensors

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Background

- Knitting is the process of creating and joining multiple loops of yarn to produce a textile.
- Footfalls and Heartbeats (UK) Ltd have found a way of incorporating conductive fibres with conventional yarns.
- These yarns can be used to create wireless, knitted textile pressure sensors which can be integrated into any kind of knitted fabric.
- These sensors act as large variable resistors, where resistance decreases with an increase in applied pressure.
- This technology is being used to develop socks which may act as an early detection system for diabetic ulcers.

Project Inspiration and Aim

- During prolonged use, the relationship between applied pressure and sensor resistance may not remain constant.
- The aim of this project is to carry out a series of tests which would allow for the development of machine learning algorithms to accurately determine applied pressure over these periods of use.

Testing

Two separate types of tests were designed and carried out:

Sensitivity

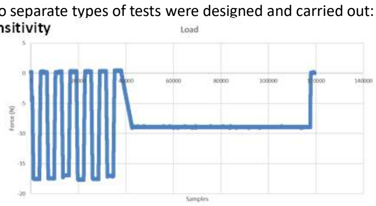

Figure 1 – Example of a load against sample graph from a sensitivity test

This test was to determine the sensitivity of a sensors resistance after prolonged and changing pressure:

1. 18N was applied and then released for 6 cycles.
2. The applied pressure was set to either 3, 5, 7, 9 or 11kpa for the remainder of the test.
3. The logged resistance and force readings were then compared.

Repeatability

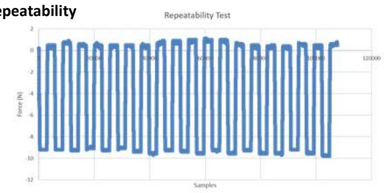

Figure 2 – Example of a load against sample graph from a repeatability test

This test was to determine the consistency of sensor resistance when the same pressure is applied in cycles:

1. 3, 5, 7, 9 or 11kpa was applied to a sensor for a 50 second period.
2. The pressure was then returned to 0kpa for 50 seconds.
3. This process was repeated 18 times.
4. The logged resistance and force readings were compared.

Testing Issues

Multiple complications were discovered during the testing process:

- Occasional inaccurate resistance readings
- Sudden jumps/ spikes in resistance values
- High and inconsistent resistance noise
- Occasional Low accuracy of force application

Resistance Modelling - The Motivation

Current development steps:

- Develop the yarn
- Knit the sensor
- Test the sensor

This process can be costly and time consuming. A model capable of accurately predicting the resistance of a sensor would reduce these factors.

Resistance Modelling

This process would be made simpler if a mathematical model was produced which could predict resistance.

Resistance of a single jersey stitch segment can be modelled using the hexagonal resistance model.

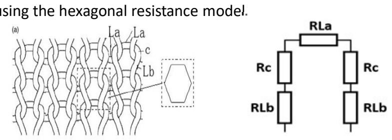

Figure 3– Single Jersey stitch ands it equivalent hexagonal resistance model

There are two types of resistances:

- Contact resistance (Rc_n) – Resistance between two contacting loops:

$$Rc_n = \frac{\rho}{2na}$$

p = resistivity
n = number of contact points
a = area of contact points

Equation 1 – Contact resistance equation

- Length Resistance(RLn) – Resistance of the yarn between contact points:

$$R_{Ln} = \frac{\rho L}{A}$$

p = resistivity
L = length of yarn segment
A = cross sectional area of yarn

Equation 2 – Length resistance of a yarn segment

The resistance network becomes very complicated when used on a large scale.

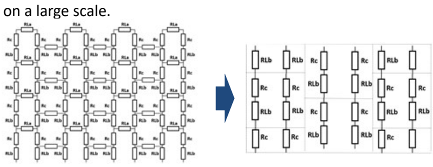
Figure 4 – Parallel equivalent resistance model for a hexagonal resistance network

When used in large networks, the parallel resistances are large enough to be ignored, leaving branches of series resistance.

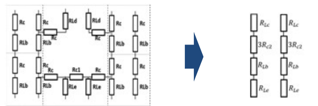
Figure 5 – Parallel equivalent resistance model for a miss stitch

Not all stitches are jersey stitches, leading to more complex resistance models. Equivalent models had to be found.

Final Equation

- The model could be broken down into two stitch combinations allowing for a customisable knit structure.

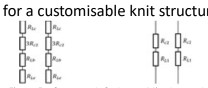
Figure 5 – Segment 1, 2 : Jersey-Miss-Jersey, Jersey-Tuck

- Using these two segments, an equation was derived which can approximate resistance of a resting pressure sensor.

$$R_T = 2 * ((n_1 R_{JMJ} + m_1 R_{JT})^{-1} + (n_2 R_{JMJ} + m_2 R_{JT})^{-1} + \cdots + (n_n R_{JMJ} + m_n R_{JT})^{-1})^{-1}$$

Equation 3 – Total resistance calculation of a knitted textile sensor

- R_{JMJ} is the resistance of one of n numbers of segment 1, and R_{JT} the resistance of one of m numbers of segment 2.
- The equation calculates the series resistance of each individual courses, then works out the corresponding parallel resistance.

Testing

- No two sensors have exactly the same rest value. Early tests place results within a sensors resistance range.

Testing Results

Sensitivity

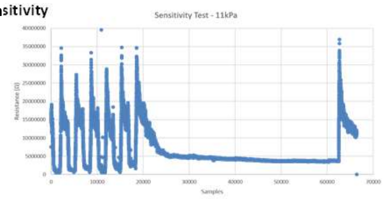

Figure 6 – Resistance response corresponding to Figure 1

- Sensitivity tests showed that the resistance response to a prolonged pressure was relatively linear.
- This test campaign proved successful, allowing for the development of a suitable machine learning algorithm.

Repeatability

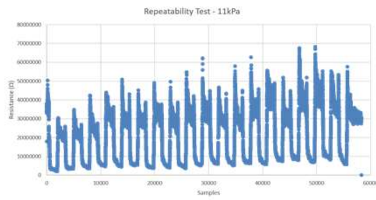

Figure 7 – Resistance response corresponding to Figure 2

- The repeatability tests provided ideal results for the 7kPa and 9kPa tests.
- For smaller pressures the resistance response decreased over the cycles, and for larger pressures it increased.

Resistance Modelling - Future Expansion

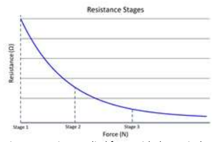

Figure 8 – Resistance against applied force with theoretical resistance stages

Stage 1: Sensor at rest

Stage 2: R_{Ln} variables reach there limit causing a constant value

$$R_{Ln} = k_1$$

Equation 4 – Length resistance following stage 1

Stage 3: Rc_n variables become a constant. Resistance change is now proportional only to force

$$Rc_n = \frac{k_2}{\sqrt{F}}$$

Equation 5 – Contact resistance following stage 3

By finding k_1 and k_2 for a given material, the resistance response of a sensor to force can be predicted.

Summary

Testing

- All encountered issues were either solved or successful work-arounds were implemented.
- The collected data was able to be used to train a machine learning algorithm to recognise data.

Model

- The current model can predict resistance to a sufficient level and is being adopted by Footfalls and Heartbeats (UK) Ltd to influence size and material choices for future sensors.
- The steps required to expand this model to provide resistance response to changing pressures have been created and outlined.

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