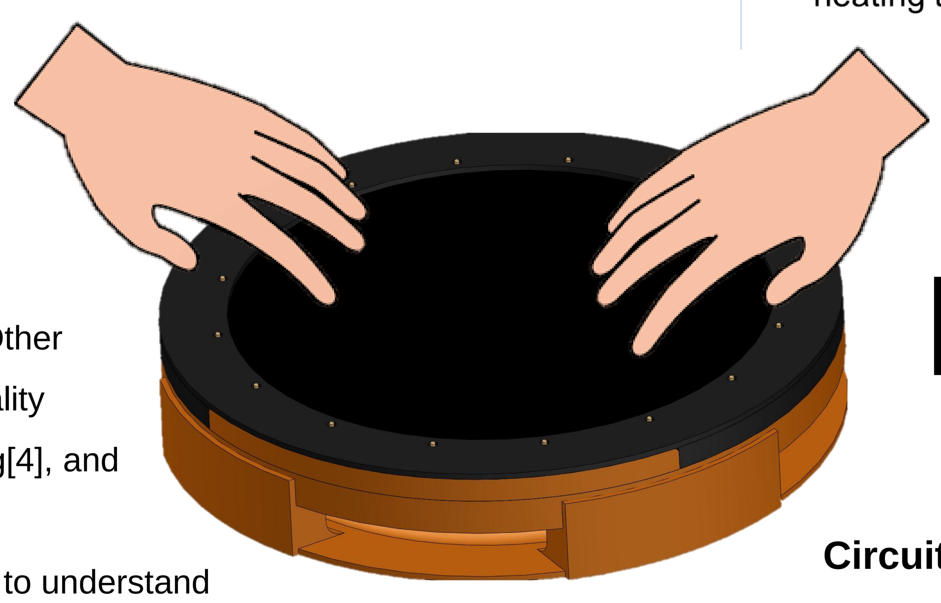
Carbon Black Silicone Composite Piezoresistive Electrical Impedance Tomography Strain Sensor Device

Richie Ellingham, Tim Giffney
Mechanical Engineering Department, University of Canterbury

MOTIVATION

Often biomedical devices require a flexible substance in their design which will not pierce or damage adjacent tissue during operative placement and throughout their lifetime. The deformation this flexible material can be determined through its piezoresistivity. In previous works[1] we identified and characterised transient piezoresistive effects seen in a carbon black silicone rubber composite in a pseudo-one dimensional case. To understand how the material acts within two and three dimensions a new measurement technique is required. Electrical impedance tomography (EIT) is the chosen imaging technique to obtain a tomographical two dimensional representation of the piezoresistive material during stress-strain transients. The key benefits of using an EIT imaging technique include:

- Non-invasive boundary electrode configuration
- Good temporal resolution
- Low cost setup
- Biocompatible



EIT is most commonly used for imaging and research in regards to acute lung injury[2]. Other research applications of EIT include fruit quality screening[3], geological sub-surface imaging[4], and fluid flow characterisation[5].

Although our main application for the device to understand and model the 2D transient electrical and mechanical phenomena, we can also apply this technology to various applications. Our focus is towards the medical industry where the technology could be used for:

- Wheelchair weight distribution mapping to in aid of preventing spinal stenosis.
- For use with existing silicone implants to record deformation.
- Within sports protective gear for early diagnosis of high impact injuries

EIT with a carbon filled polymer composites has been achieved previously[6], however the transient phenomena observed within this material have not yet been understood and modelled. In earlier works our research team has worked towards understanding and modelling such phenomena such as the transient relaxation effect seen in the below Figure 1.

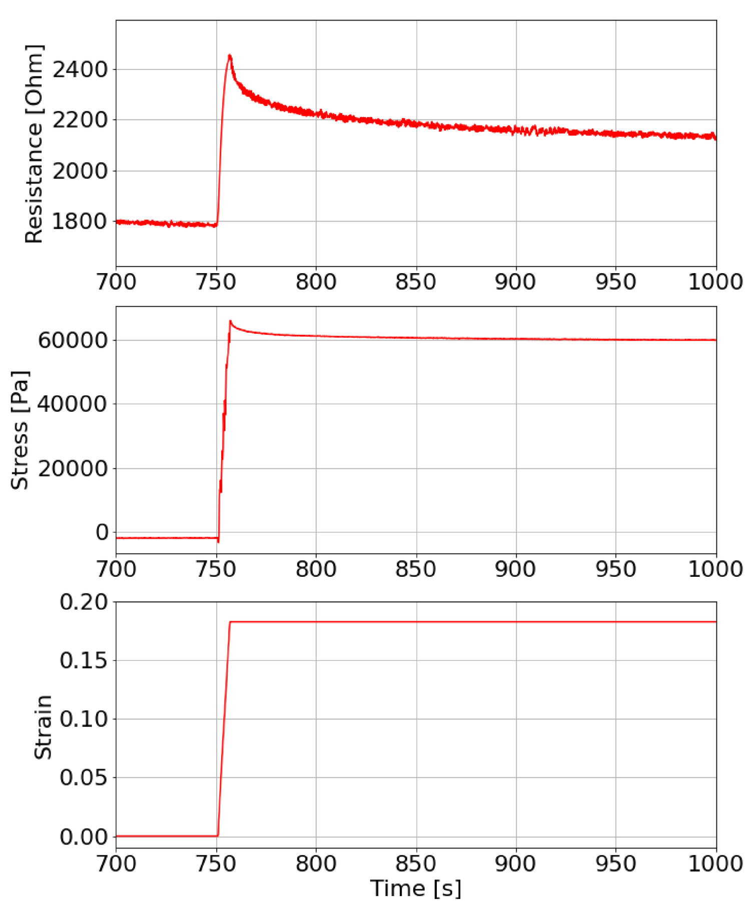


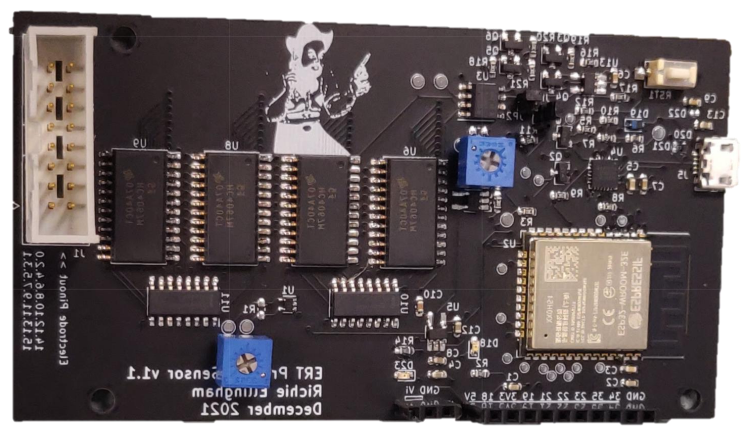
Figure 1: The apparent resistive relaxation and viscoelastic stress relaxation of a carbon black silicone composite

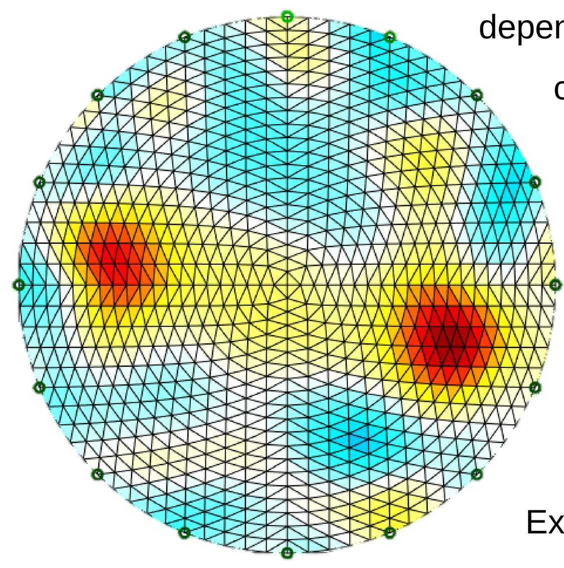
METHODOLOGY

The overall device architecture is made up of three key components: the domain under test (DUT), the measurement hardware and the image reconstruction software.

Material Fabrication

Every part of the device was designed in house to ensure control of all device and material qualities and maintain low costs. The DUT was a composite comprised of silicone (Smooth On Dragonskin 10 NV) with 50nm carbon black (Vulcan XC 72R) particles dispersed throughout. Particle dispersion was completed using a vacuum planetary mixer (Thinky ARV-310), to ensure homogeneity and minimise air cavities within the material volume. Upon completion of mixing, the uncured composite was poured into the circular DUT mould. The curing of the composite was accelerated by heating the just mixed material in the mould at 80°C for 90min.





Circuit Design

The main components of the circuit design consist of a constant current source, four multiplexers (MUXs), an instrumentation amplifier (INA), an analogue to digital converter (ADC) and a microprocessor (MCU). The current source and INA are connected to the multiplexers which are connected to all of the perimetral electrodes. Different electrode drive patterns will determine how the multiplexers are selected. The voltage measurements for each electrode configuration and constant current value are stored and sent to a PC via Bluetooth or USB serial for image reconstruction. The signal to noise ratio (SNR) of all voltage measurements was known to have a large effect on the image reconstruction, so in the design of the device EMI was taken into consideration by using low-noise components, coaxial electrode cables and good PCB routing practices. Low-cost components were used where possible.

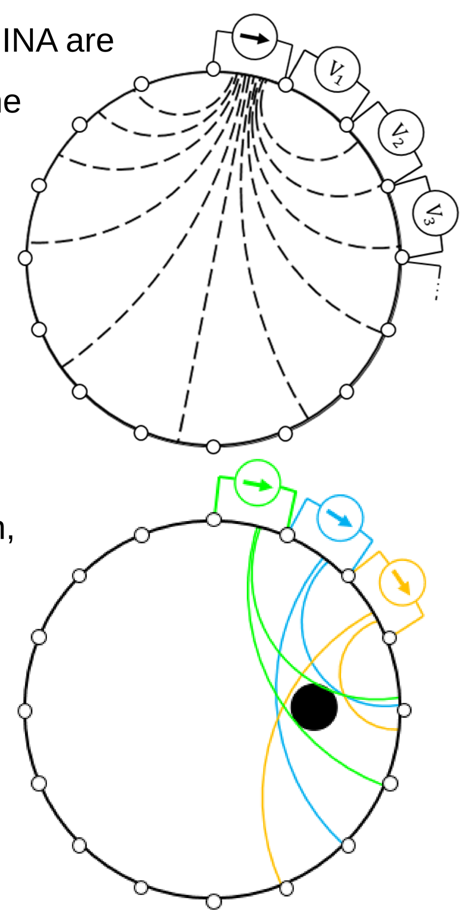


Figure 2: (Top) Adjacent electrode drive pattern showing equipotential lines. (Bottom) Three consecutive current source injections shown.

Electrode Drive Pattern

The electrode drive pattern used for the DUT was the adjacent method exemplified in figure 2. Where current is passed through two adjacent electrodes on the perimeter of the material. While a constant current was being applied to two adjacent electrodes, voltage measurements were made by iterating through pairs of adjacent electrodes around the perimeter of the material.

Image Reconstruction

To initially validate the EIT circuit was working correctly a reference material was made out of a resistor network and tested with EIDORS[7] to reconstruct an image. A simulated resistor network was generated with PySpice. The real resistor network result was within the expected tolerance of the simulated resistor network.

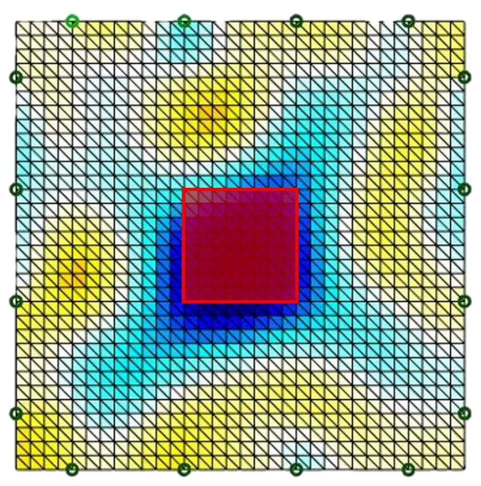


Figure 3: Resistor network reconstruction validation with the specific resistance inhomogeneity location indicated by transparent red square

RESULTS

For initial testing of the compressive stress was applied to localised areas of the material as shown in the figure 4 image reconstructions. The first image (a) displays the noise floor of the material. The subsequent images (b) – (f) show the DUT reconstruction relative to the stress compression area, which is indicated with the green transparent shapes.

Each stress compression on the material was applied with similar force, however the piezoresistive response was varied depending on the compression location.

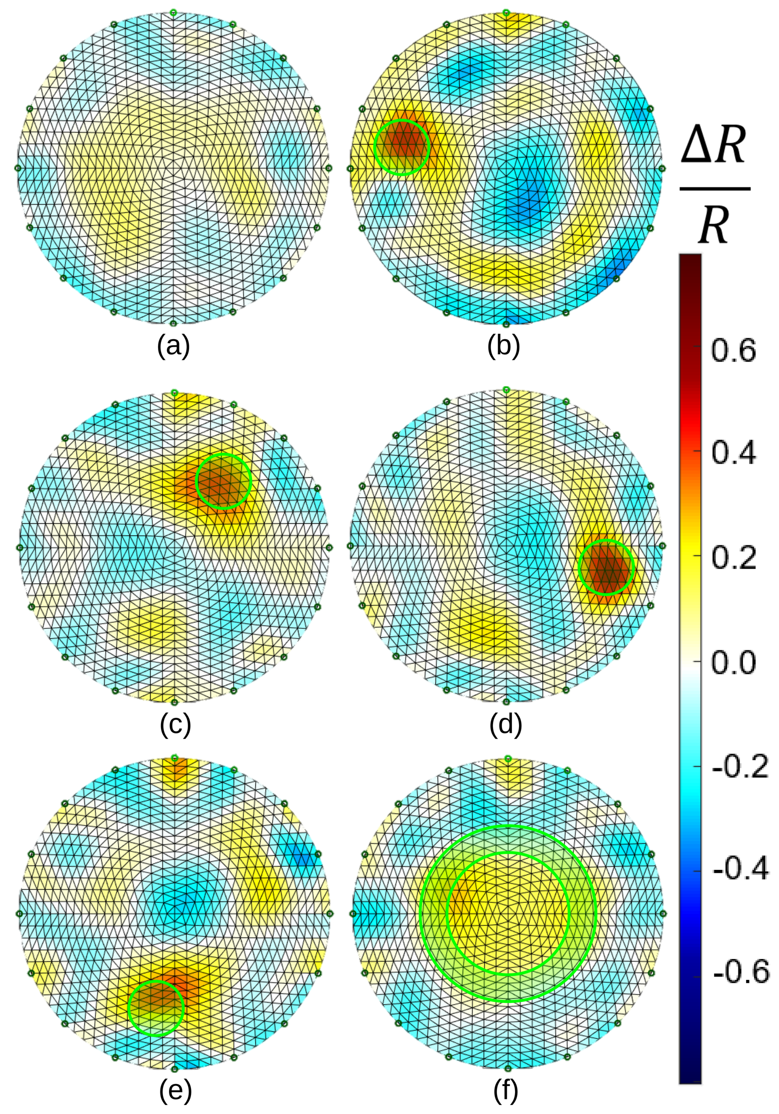


Figure 4: Carbon black silicone composite resistivity maps shown after a stress event applied to the green shapes.

Experimentation was completed to test the resistive relaxation of the material in two dimensions by creating an image reconstruction of the material at 4s time intervals. As expected the material showed an exponential decay in resistance (Fig. 5) after a stress event comparable to the relationship seen in Figure 1 [1].

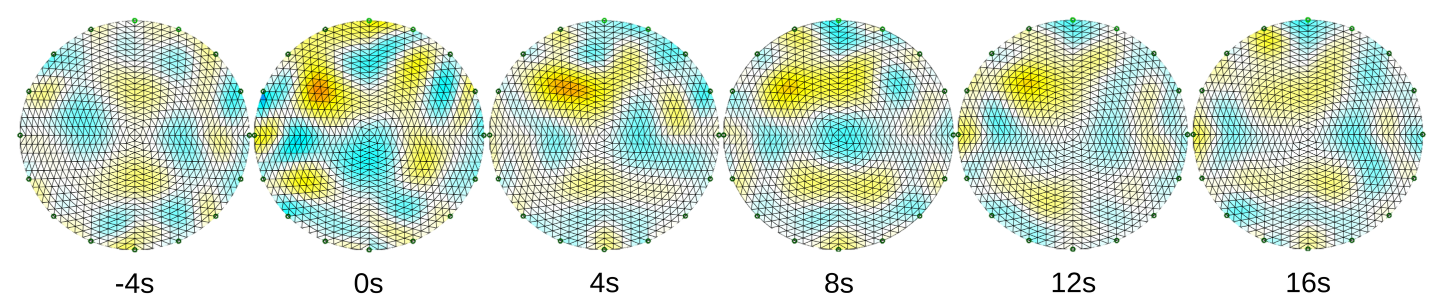


Figure 5. CB black silicone composite resistivity maps at 4s intervals after stress compression event occurring at 0s.

CONCLUSIONS

1. The EIT method for highlighting piezoresistive material inhomogeneities can be seen by applying known stresses in known DUT locations.
2. A two dimensional representation of transient behavior within the material can be displayed ready for further analysis.
3. The device shows promise for sensor applications as well as further material characterization

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Contact info: R. Ellingham, richie.ellingham@pg.canterbury.ac.nz