LIBERTY UNIVERSITY

Development of E-Skin Sensors and their Applications

A. Regel, T. Donica, C. Clark, J. Gray, and Dr. Zegeye

Abstract

Electronic skins, or e-skins, are electronic devices capable of sensing physical interactions such as strain, temperature, or pressure. These e-skins are of interest in a variety of areas including robotics, structural health monitoring, prosthetics, and medical applications. The sensors also have the potential to be seamlessly applied to soft surfaces such as human skins and textile fabrics and be used as wearable sensors in order to provide clinically relevant data. Consequently, development of materials and structures for innovative flexible sensors and their integration into systems for different application continue to be in the spotlight of research.

The basic construction of e-skin was introduced to Materials and Manufacturing Processing class students during spring 2018 and 2019 semesters and was incorporated as a final project. The students used the sensors to develop various systems. Three students were also engaged in a directed research and used e-skin sensors for developing a plantar pressure mapper, a large bi-axial strain mapper, and an automated palpable system for detecting breast tissue abnormality. This poster highlights the works of these three students.

Objectives

I. Plantar Pressure Mapper:
Two different commercially available systems exist: force plates and wearable systems. While the force plate based are generally stationary and too small for easy gait analysis, the wearable systems are expensive or need to be replaced after a few uses. Hence the objective is to develop an affordable wearable systems that would reduce healthcare costs and increase availability of plantar pressure evaluations as part of diagnosis and treatment.

II. Large Bi-Axial Strain Mapper
Ordinary metal strain gauges can measure only elastic strains, and in one direction. If surface strains need to be mapped, several of this sensors need to be placed at different orientation. The objective is to develop a strain sensor that is capable of detecting large strain values without sustaining the damage that a traditional metal strain sensor would experience.

III. An Automated Palpable System for Detecting Breast Tissue Abnormality
Manual palpation is an alternative clinical breast examination (CBE) technique to mammography in developing countries due to the high cost of equipment and lack of trained personnel. The process involves a thorough search pattern using four fingers and applying adequate pressure, with the objective of identifying solid masses from the surrounding breast tissue. However, it depends on the skill of the personnel and consequently, the palpation performance and reporting techniques have been inconsistent. The objective is to develop an affordable automated palpable technique that would optimize the performance of CBE and enable the visualization of breast abnormalities and assessing their mechanical properties.

Materials and Methods

- Graphite flakes were irradiated with microwave radiation to create expanded graphite. The expanded graphite was then sonicated in water to break up the particles further and create EG solution.
- A sensing solution was then made by mixing EG solution and liquid latex.
- The sensing solution was sprayed on latex substrate to make a piezoresistive flexible sensor.
- In order to collect data from the sensor, electrodes were attached to the sensing regions. These electrodes were made of carbon fiber and copper wires.
- The electrodes are attached to an electronic circuit for collecting deformation-induced electrical signals. The electrical signals were collected using an Arduino and a pixelated image was reconstructed using MATLAB.

Mapping Plantar Pressure

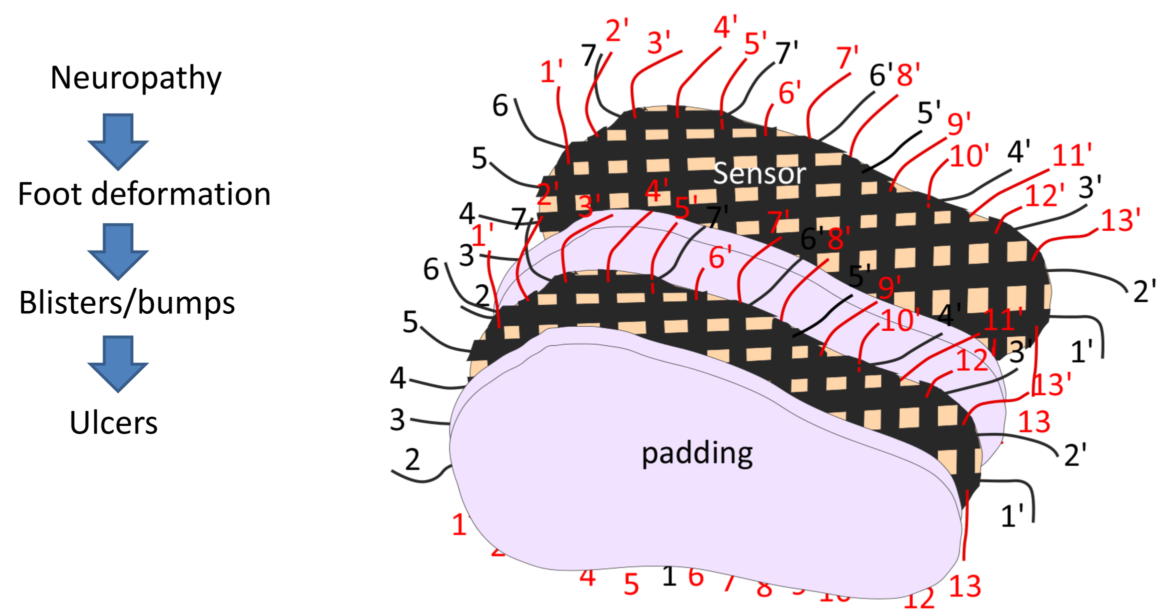


Figure 1. Schematic showing construction of foot pressure mapper

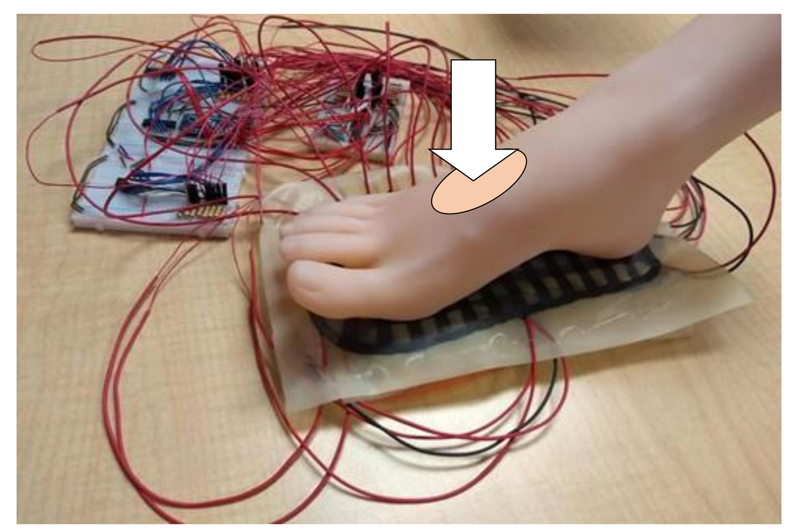


Figure 2. Schematic showing the application of force on the skin sensor during testing (Riegel, Gray et al. 2019)

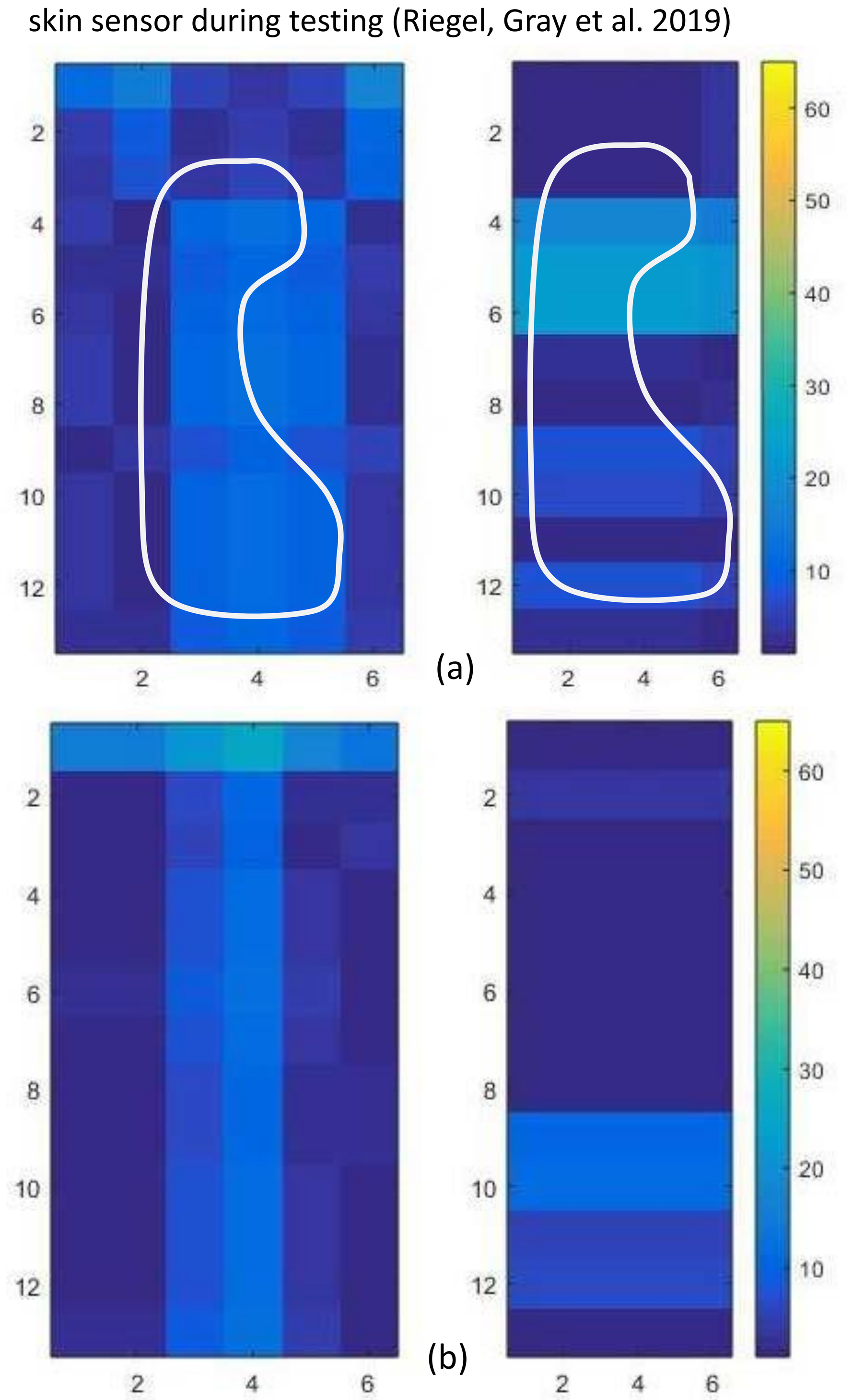


Figure 3. This figure shows maps of a) full foot pressure and b) forefoot pressure, with white curves indicating the areas of applied pressure. The lighter blue areas are at higher pressures. The bottom of the plot is the direction of the toe of the foot. The plot on the left is the upper sensor layer, right is bottom (Riegel, Gray et al. 2019).

Publication:
Donica, T., J. Gray, and E.F. Zegeye, *Strain Mapping and Large Strain Measurement Using Biaxial Skin Sensors*. 2019.

*This project funded by an **ILLUMINATE Grant** from the Liberty University Center for Academic Development.*

Strain Measurement Using Bi-axial Sensor

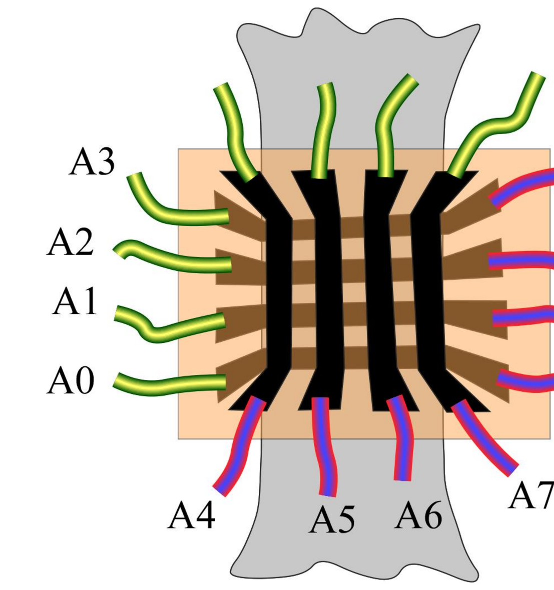


Figure 4. Biaxial strain sensor diagram with labels (Donica, Gray et al. 2019)

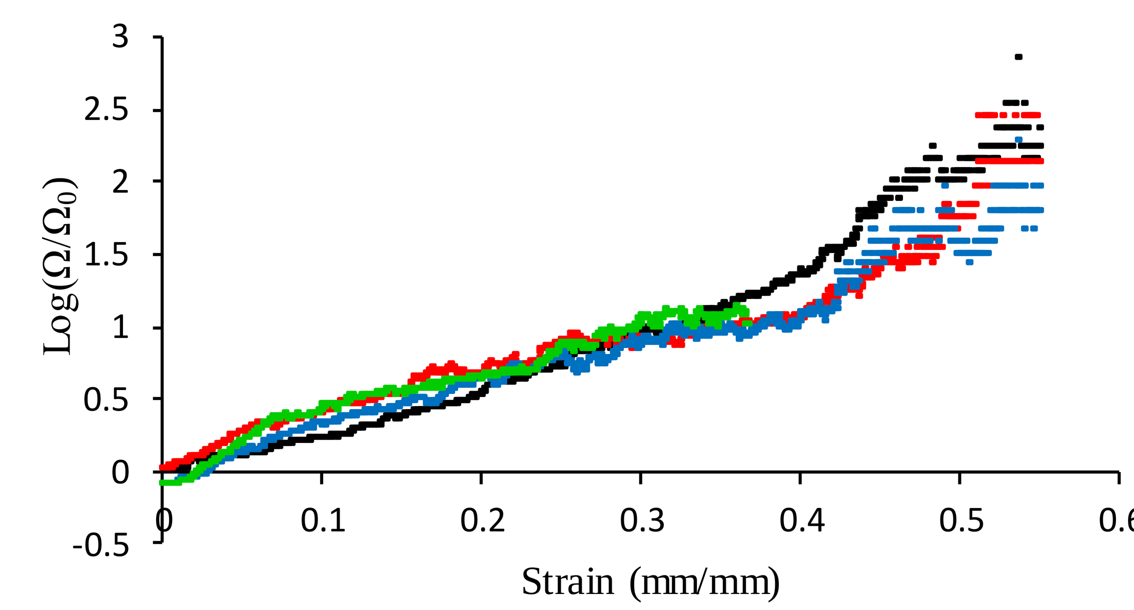


Figure 5. Four-cycle resistance vs strain graph of one of the 1 x 1 sensors (Donica, Gray et al. 2019)

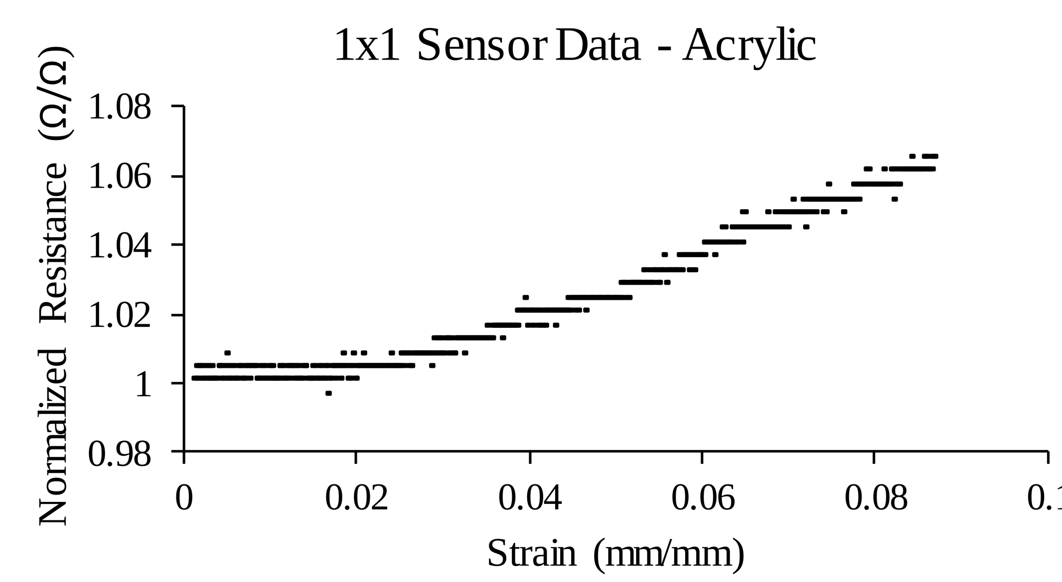


Figure 6. Single-strip Sensor attached to acrylic specimen (Donica, Gray et al. 2019)

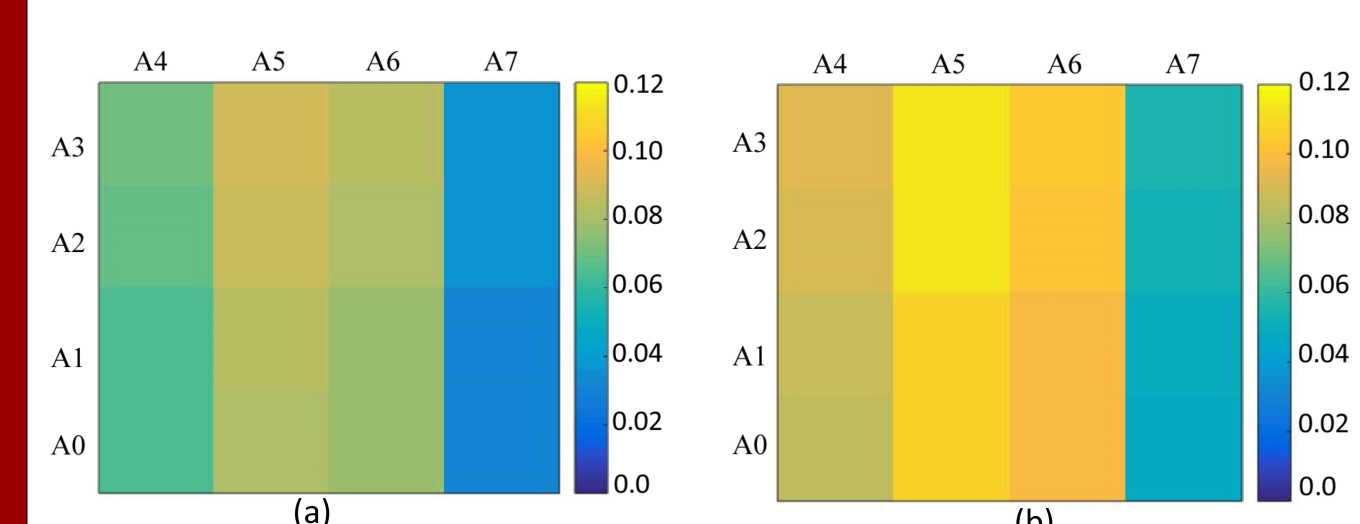


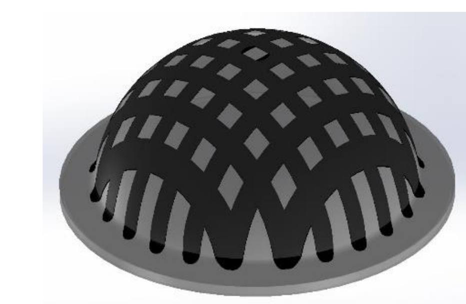
Figure 7. (a) Heatmap of the normalized voltage in the biaxial strain sensor during a strain of 0.02, (b) heatmap of the normalized voltage in the biaxial strain sensor just prior to breakage of the acrylic specimen (Donica, Gray et al. 2019)

Publication:
Riegel, A., J. Gray, and E.F. Zegeye, *Exfoliated-Graphite/Latex Piezoresistive System for Mapping Plantar Pressure*. 2019.

*This project funded by an **ILLUMINATE Grant** from the Liberty University Center for Academic Development.*

Automated Palpable Device For Detecting Abnormal Breast Tissue

- Manual palpation is a low cost, risk free breast examination
- Needs skills, depends on individual feeling
- Automated palpation-optimize CBE/SBE, visualize abnormalities



Latex-formed exfoliated graphite electrode sensor.

assembled probe head

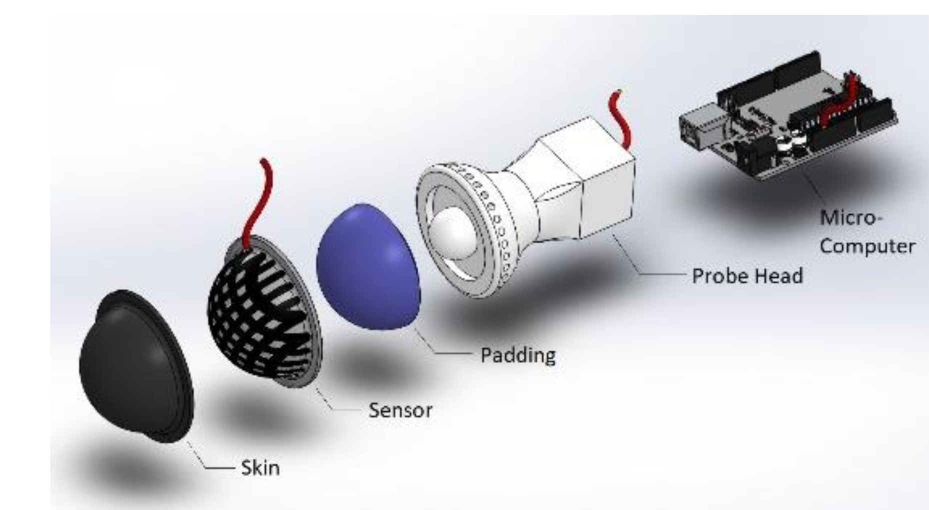


Figure 8. Schematic showing components of the palpable device

***Current work**:*
- Fabrication of the skin sensor
- Developing the electronics and a smart phone app for visualizing the abnormalities using a cellphone screen (By three computer engineering students)

This project is funded by CRS faculty Tier 1 Grant from the Liberty University Center for Academic Development

Conclusions

- The EG/latex blend is a suitable material for creating low-cost strain/pressure sensors.
- Applications of the sensor for plantar pressure mapper and bi-axial large strain measurement showed promising results. Sensitivity, data quantizing, and color mapping can be improved by designing a better microcontroller and developing a code.
- In order to accurately correlate the pressure/strain to the electrical signals, the sensors will be calibrated

References

Kujawski, M., Pearse, J. D., & Smela, E. (2010). Elastomers filled with exfoliated graphite as compliant electrodes. *Carbon, 48*(9), 2409-2417.

Lin, S. (2010). In-Shoe Plantar Pressure Measurement and Analysis System Based on Fabric Pressure Sensing Array. *IEEE Transactions on Information Technology in Biomedicine, 14*(3), 767-775.

Tan, A. M., Fuss, F. K., Weizman, Y., Woudstra, Y., & Troynikov, O. (2015). Design of Low Cost Smart Insole for Real Time Measurement of Plantar Pressure. *Procedia Technology, 20*, 117-122.

Tiwana, M. I., Redmond, S. J., & Lovell, N. H. (2012). A review of tactile sensing technologies with applications in biomedical engineering. Sensors and Actuators A: Physical, 179, 17-31. doi:10.1016/j.sna.2012.02.051

Büscher, G. H., Kõiva, R., Schürmann, C., Haschke, R., & Ritter, H. J. (2015). Flexible and stretchable fabric-based tactile sensor. Robotics and Autonomous Systems, 63, 244-252. doi:10.1016/j.robot.2014.09.007

Future Work

- Determine correct graphite thickness for good sensitivity
- Calibrate the sensor to correlate the color mapping to pressure/strain
- Improve packaging and/or make wearable for gait analysis testing
- Induce a pre-strain into the sensor so that it can be used to measure compression and design a strain sensor that can be applied to a cylindrical or spherical specimen