BME310

12 - Sensors

Many different Sensors

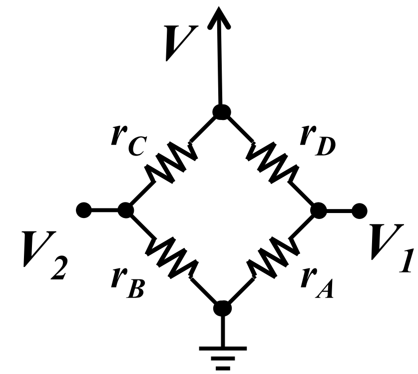
- Electrical
- Thermal
- Optical
- Electrodes
- Nanofiber devices

Electrical Sensors

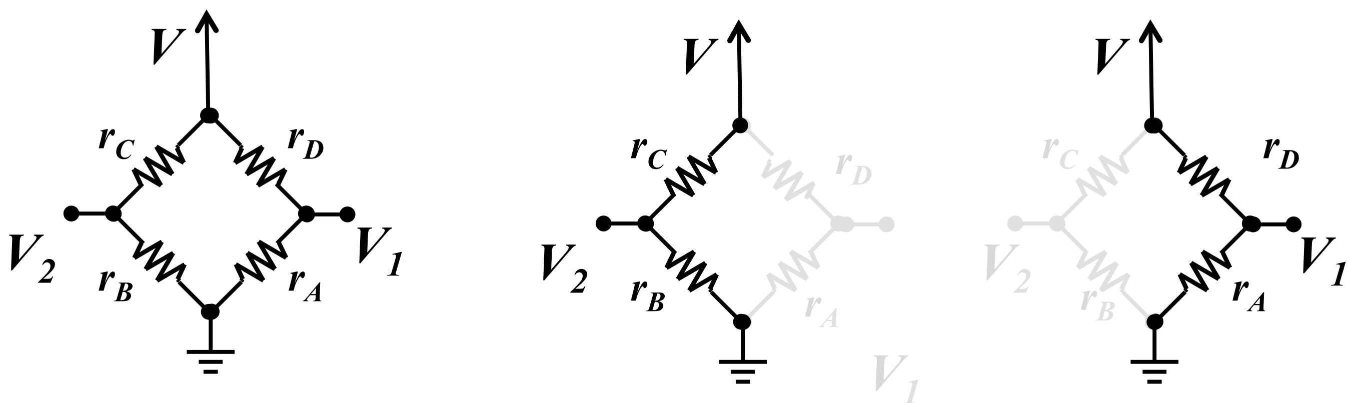
- Wheatstone Bridge
  - Pressure
  - Force Sensors
  - Strain
  - Flow

Wheatstone Bridge

- The bridge is the voltage difference between V_2 and V_1
- Nominally all of the resistors have the same resistive value and so the bridge voltage is zero
- One or more of the resistors are variable which depends some external activity (temperature, force, etc.)
- When the variable resistors change, then the voltage change.
- The amount of bridge voltage change is correlated to the external activity.



Wheatstone Bridge



To analyze let's break the circuit up into its two sides.

Using voltage division on each side of the Wheatstone Bridge

Left side

$$V_2 = \frac{r_B}{r_B + r_C} V$$

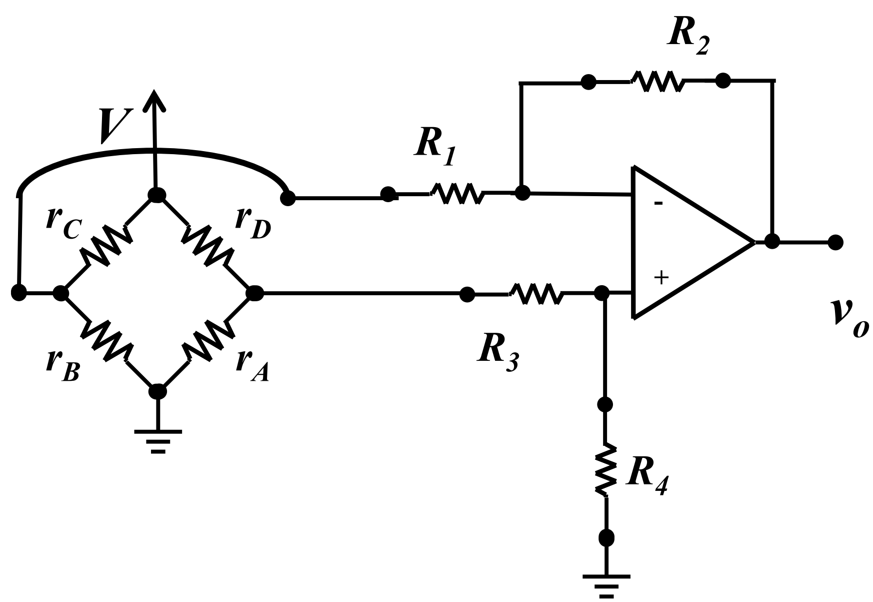
Right side

$$V_1 = \frac{r_A}{r_A + r_D} V$$

Therefore, the bridge voltage is

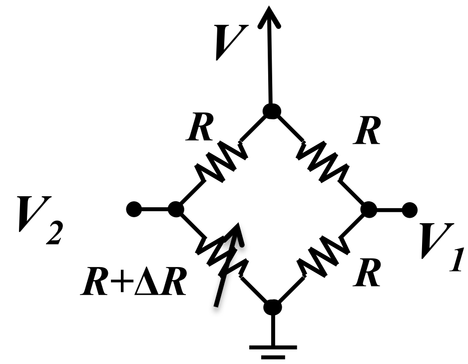
$$V_2 - V_1 = \left(\frac{r_B}{r_B + r_C} - \frac{r_A}{r_A + r_D}\right)V$$

Wheatstone Bridge as a sensor



- To detect small changes we connect the bridge voltage to an amplifier. In this case, it's a differential amplifier.

Wheatstone Bridge



To understand how the wheatstone bridge works, let's assume that three of the resistors have resistance, R. And the one on the lower left is the variable one which has nominal resistance R and variation ΔR.

$$V_{Bridge} = V_2 - V_1 = \left(\frac{R+\Delta R}{R+\Delta R+R} - \frac{R}{R+R}\right)V = \left(\frac{R+\Delta R}{2R+\Delta R} - \frac{R}{2R}\right)V$$

Furthermore, let's assume the ΔR is small compared to R. Then:

$$V_{Bridge}\big|_{\Delta R \text{ is very small}} = \left(\frac{R+\Delta R}{2R} - \frac{R}{2R}\right)V = \left(\frac{\Delta R}{2R}\right)V$$

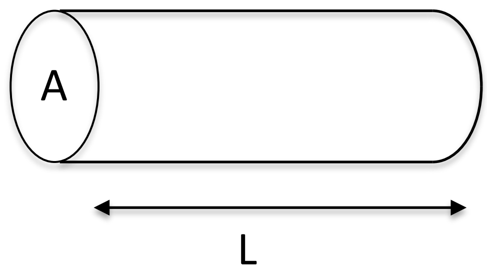
If there is no external activity then the bridge is balanced

$$V_{Bridge}\big|_{\Delta R = 01} = \left(\frac{0}{2R}\right)V = 0$$

Wheatstone Bridge

- Wheatstone Bridge are used in
  - Strain Gauges
    - Resistance is a function of the resistor's length, cross sectional area and the resistivity (a parameter associate with the material used to make the resistor), ρL/A. When a strain occurs, changes in length and area occur as well as the resistivity and therefore the resistance. Strain gauges which use the Wheatstone bridge may have all 4 resistor vary as a function of the strain
  - force sensors
    - Load Cells
  - Flow meters
  - Pressure meters

Strain Gauges



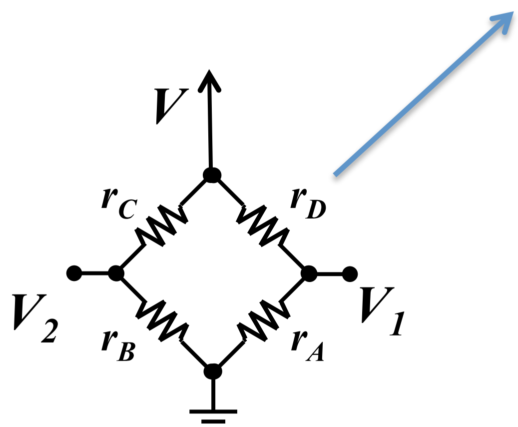
Resistance $R = \frac{\rho L}{A}$

where A is the cross-sectional area of the resistor, L is the length of the resistor and ρ is called the Resistivity of the material.

If we compress this resistor, the area increases and the length decreases. This yields a descrease in the overall resistance, R.

If we stretch this resistor, the area decreases and the length increases. This yields a increase in the overall resistance, R.

Strain gauges



If one pulls in this direction, then r_C and r_A will be stretched and r_B and r_D compressed. Since r_C and r_A is stretched then its resistance will increase, say by h and since r_B and r_D is compressed then its resistance will decrease, also by h. Then, assuming $r_A = r_B = r_C = r_D = R$ at zero strain and $h = \Delta R$, the voltage across the bridge will become

$$V_2 - V_1 = \left(\frac{r_B - h}{r_B - h + r_C + h} - \frac{r_A + h}{r_A + h + r_D - h}\right)V$$

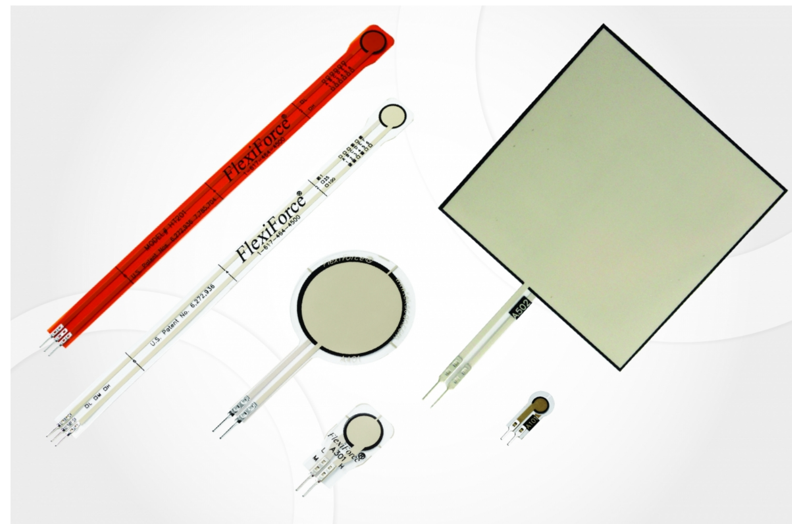
$$= \left(\frac{R-h}{R-h+R+h} - \frac{R+h}{R+h+R-h}\right)V$$

$$= \left(\frac{R-h}{2R} - \frac{R+h}{2R}\right)V = \left(\frac{-h}{R}\right)V$$

$$= -\left(\frac{\Delta R}{R}\right)V$$

Pressure and Force Sensor

- There also pressure and force sensors which are resistive devices that deform when pressure is applied. With no pressure the resistance is infinite. As pressure is applied, the resistance reduces.
- Using an amplifier such as a Inverting Opamp, the pressure and force can be sensed.

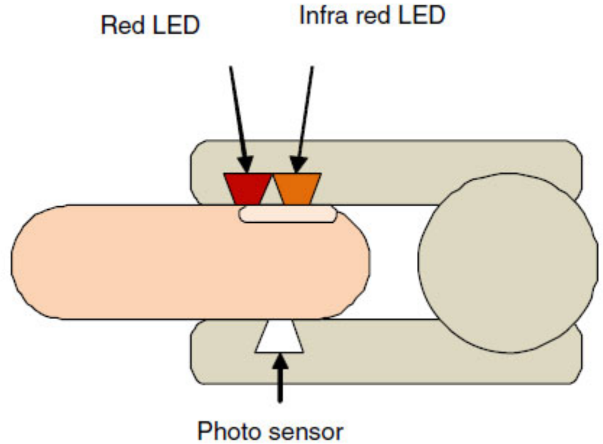


https://www.tekscan.com/flexiforce-load-force-sensors-and-systems?utm_source=google&utm_medium=cpc&utm_term=force+sensors&utm_content=eta3&utm_campaign=flexiforce&gclid=CjwKCAjwnPOEBhA0EiwA609ReYsyr4K0YiE5X6PPyh29W-Qj5EbR444sA1XcwHEavjmc_A14QRYgkBoC-bsQAvD_BwE

Temperature Sensors

- A Thermistor is another resistive device using semiconductor material whose resistance is a function of temperature.
- Thermocouples are metallic devices which use the Seebeck Effect and which consist of two wire of different metals electronically bonded together. The voltage between the metals reflect changes in temperature.

Optical Sensors

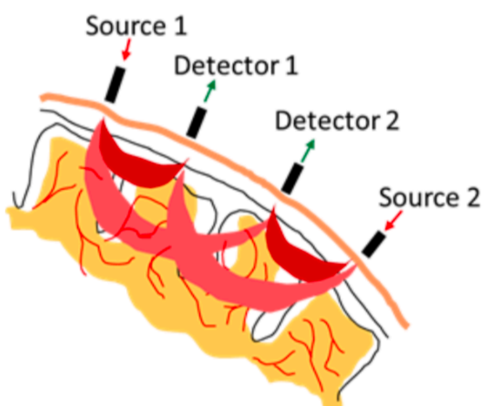


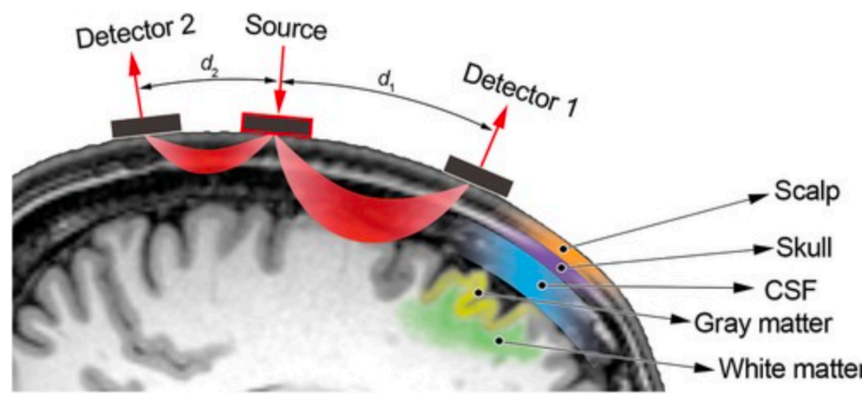
- Pulse Oximetry
  - Two lasers are used
    - Red laser 660nm
    - Infrared laser 940nm
  - One detector reads the transmitted light for each laser
  - The ratio of red light to infrared light is converted to Saturation of Oxygen in the blood.

https://www.analogictips.com/blood-oxygen-meters-part-1-background-and-principles-faq/

FNIRS

- Functional Near-Infrared Spectroscopy of the Human Brain
- It measures concentration changes of oxy- and deoxy-hemoglobin (Hb) by their different specific spectra in the near-infrared range between 700-1000 nm.



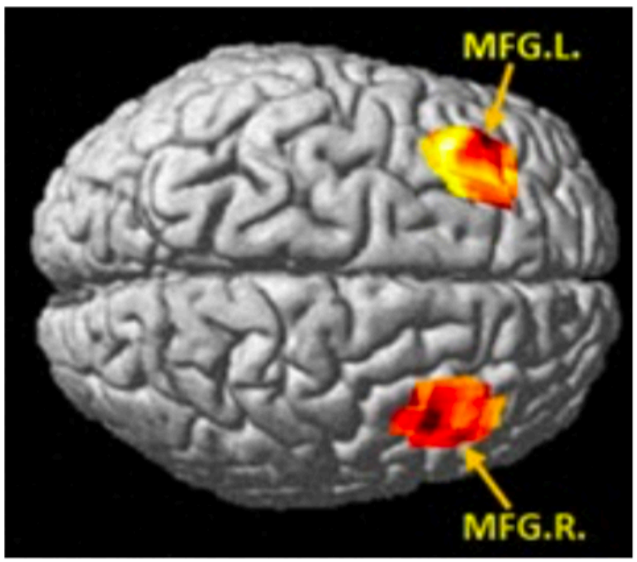


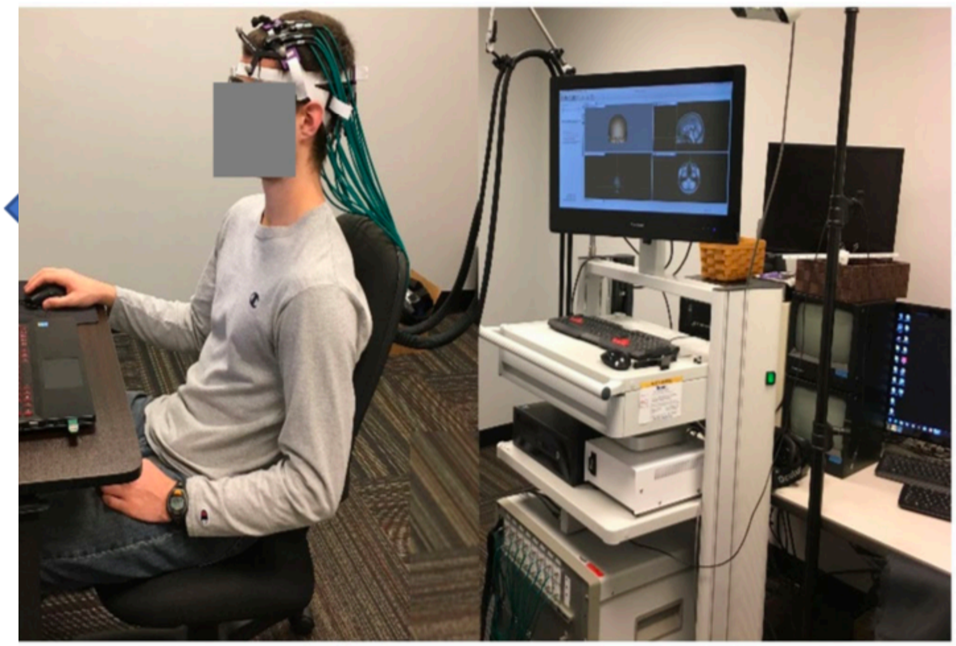
FNIRS
Hemodynamics during a Task

- When a task starts, HbO (oxygenated hemoglobin) is utilized
  – Leading to a decrease in HbO and increase in HbR (deoxygenated hemoglobin)
- Oxygenated Blood flows into region of brain controlling activity
  – Leading to an increase in HbO and decrease in HbR
- Thus, increase in HbO might not be observed until 3 – 5 seconds after start of task
  – Blood moves “slowly”
- Total blood flow (HbT) = concentration of HbO + concentration of HbR

FNIRS

- Experimental Task – Visual Sustained Attention Task

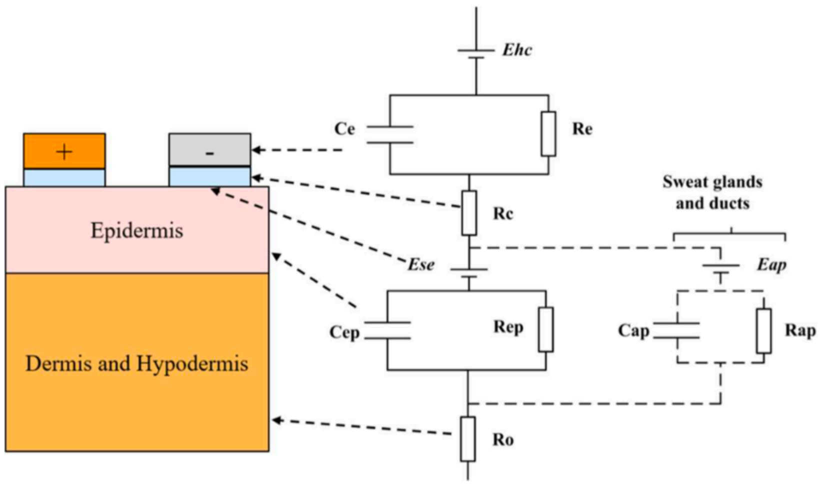




Brain activation map

Electrodes

- Electrodes need to receive biosignals by attaching to the skin.
- The biosignal needs to pass through the body and through the dermis (and lower layers) and epidermis of the skin.
- The demis acts resistive while the epidermis has resistive and capacitive effects.

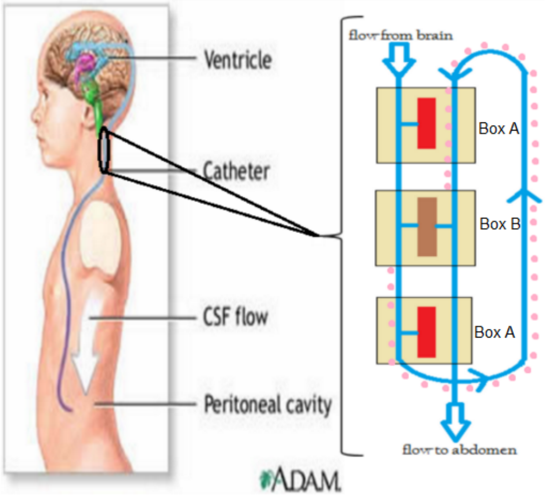


- The part of the electrode touching the skin is a highly conductive gel which adds addition resistance.
- Thereafter there is a metal contact which has also has both resistive and capacitive effects

Fei Lu,et.al., Review of Stratum Corneum Impedance Measurement in Non-Invasive Penetration Application, *Biosensors* 2018, *8*, 30

Nanofibers

- In 2015, a flow device to measure cerebrospinal fluid (CSF) flow in the brain. This device was approximately 0.24" x 0.2" x 0.021"
- Future may bring nanofiber sensor to measurue heart rate, glucose, respiration, etc.



Rahul Raj, et.al., "Demonstration that a new flow sensor can operate in the clinical range for cerebrospinal fluid flow" ; Sens Actuators A Phys. 2015 Oct 1; 234: 223–231
Schroeder, et.al., "Electro-fluidic Interface for Monitoring Brain Injuries", Capstone Project 4/2016

Other Areas

- Piezoelectric
- Imaging
- Ultasound
- Implantable devices

Homework

1. A load cell uses a Wheatstone Bridge and an OpAmp to measure the force on the knee of a person using an exoskeleton. What should the gain of the amplifier be to yield an output voltage between -10 and + 10 volts measuring 0.5 – 10 Newtons. Assume that the Wheatstone Bridge is powered with 10 volts has a sensitivity of 50mV/V/Newton

Homework

2. You have place a force sensor in a shoe and want to measure the weight of a object a person is carrying. What sort of amplifier should you use. Assume the force sensor is a variable resistor. Draw the circuit diagram and show where the force sensor is placed in the circuit. Explain how you circuit will work.

Homework

3. HONORS STUDENTS ADD THE FOLLOWING

Research and describe how resistors can be used in Wheatstone bridge configuration as a strain gauge. Draw the strain gauge Wheatstone bridge circuit and calculate the bridge voltage under the cases of tension and compression.