How to Measure Things

Prof. Woody Yang
Yasha Iravantchi
ES 100
October 14, 2015

How to Measure Things

- **Every ES100 Project must have a [MEASUREMENT] component**
- **Quantitative measure of performance and/or functionality**
  - **Speed**
  - **Strength**
  - **Weight**
  - **Efficiency**
  - **Detection Sensitivity and Selectivity**
  - **Others?**
- **Verification/Confirmation of your [DEFINE] [DESIGN] & [BUILD] with *quantitative* [ANALYSIS]**
- **Complete demonstration of your Engineering Skills and Knowledge**

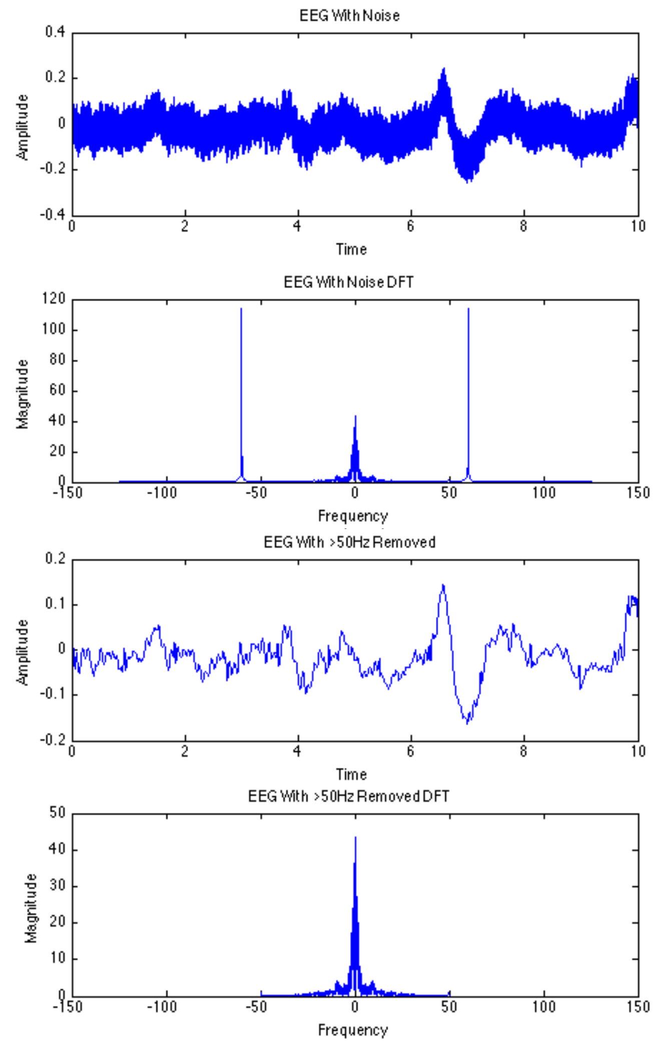
Limits of Physical Measurements

- To MEASURE something physical, you *usually* need a SENSOR/ TRANSDUCER to CONVERT that something into a SIGNAL which can be more easily measured
  - Distance can be directly measured with a tape measure
  - Force can be measured by using a strain gauge that converts force into voltage
  - Speed can be measured by measuring the elapsed time it takes something to traverse a known distance
- All physical measurements have limits. You need to understand and describe and analyze the fundamental limits of your measurements with respect to these factors

> - Noise
> - Resolution
> - Dynamic Range
> - Reproducibility/Calibration
> - Sampling Rate/Sample Size

Noise

- **There are many types of noise**
  - **White/Gaussian**
  - **Shot Noise/Poisson**
  - **AC Line interference**
- **Noise is the undesired part of the signal and interfere or limits the measurement**
- **Noise can be reduced through filtering and careful experiment setup**



EXAMPLE: 60Hz AC line noise

Resolution

- Resolution is the smallest measurable value possible with an instrument
- For a caliper, it could be 1mm, it could be 10um.
- For a pipette, it could be 1ml, 0.1ml, 0.01ml.

Dynamic Range

- **Instruments also have limits on the largest possible measurable value**
  - **For example, values above some maximum are just saturated or beyond the capability of the instrument**

- **Dynamic Range is the ratio of maximum to minimum measurement**

$$\text{Dynamic Range} = \frac{\text{maximum valid measurement}}{\text{minimum valid measurement}}$$

Reproducibility/Calibration

- Reproducibility is how well the same measurement can be performed repeatedly with the same instrument and/or different instrument
- Calibration is matching the readings of an instrument to given standards

→ **Making measurements without calibration will lead to erroneous results**

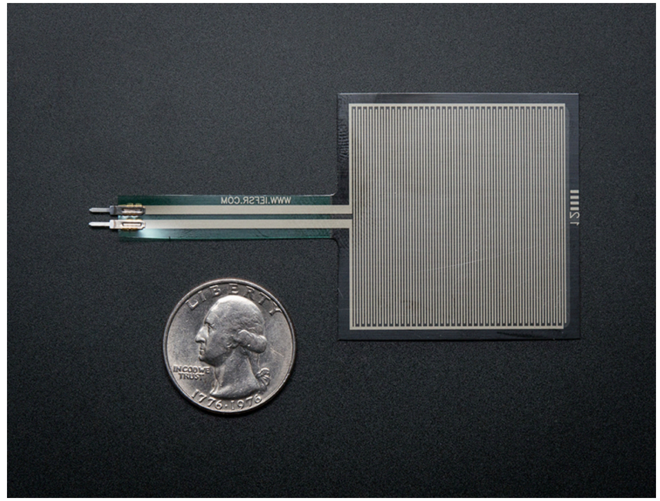
Sampling Rate / Sample Size

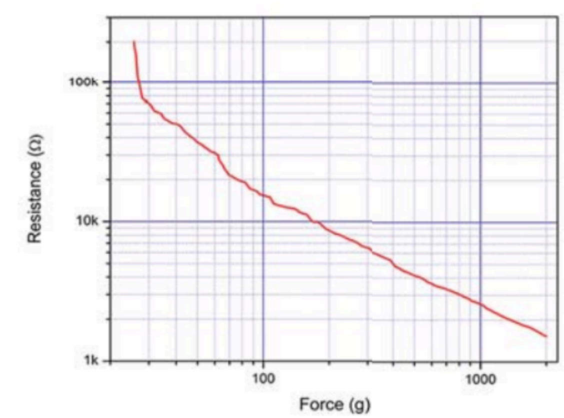
- **Measurements can vary in time. How often must measurements be repeated in time in order to *capture* the time-varying behavior?**
  - **SAMPLING RATE**
    - **Must be fast enough so that you don't miss any details**
    - **Bandlimited Signals → Nyquist Rate**

- **Every measurement is subject to error/noise. Multiple measurements of the same phenomenon can reduce possibility of error/noise (improve statistical significance).**
  - **SAMPLE SIZE**
    - **Must be large enough to demonstrate measurement is statistically significant and valid**

Force Sensor Exercise

- Force Sensor Resistors (FSRs) are sensors that detect pressure, squeezing, and weight
- They use a polymer thick film that is embedded with metal along the traces.
- The FSR decreases in resistance as the metal particles come into contact when compressed
- These sensors do "bottom out", so they do have limitations to their use
- They can exhibit a bit of hysteresis
- The data sheet can show us its specific characteristics.





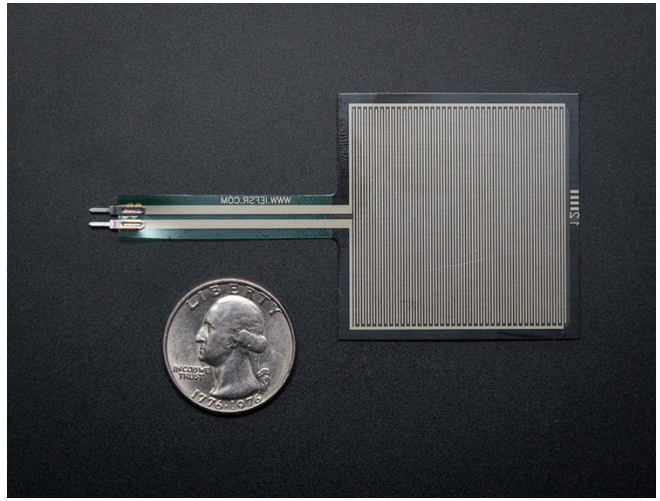
Force Sensor Exercise

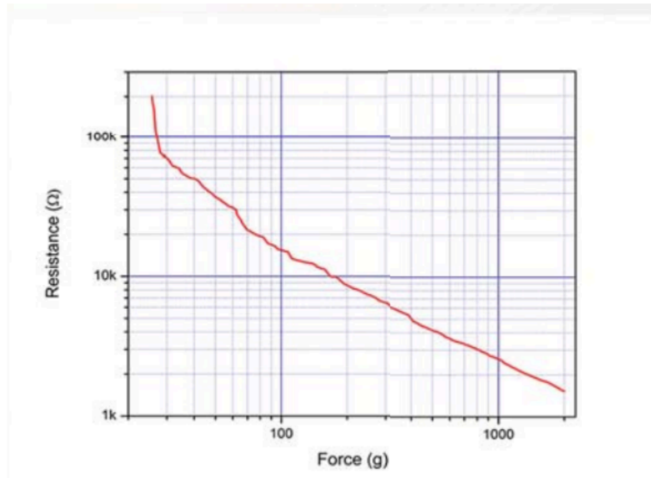
- **We won't be measuring the resistance directly, we'll be using a voltage divider and a buffer amplifier to measure the voltage across the FSR.**

- **On the oscilloscope, we'll be monitoring the change in voltage as we add weight. Where's the fuzziness come from? NOISE**

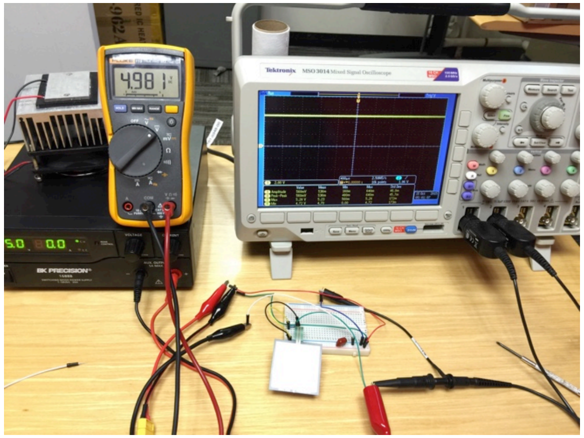
- **Notice when I add low amounts of weight it doesn't change in voltage…high amounts of weight? What is this? DYNAMIC RANGE**

- **When I put the same weight back on, do I get the same REPRODUCEABLE signal?**

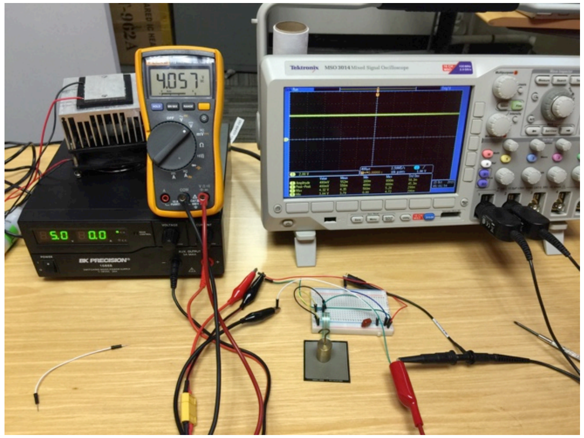




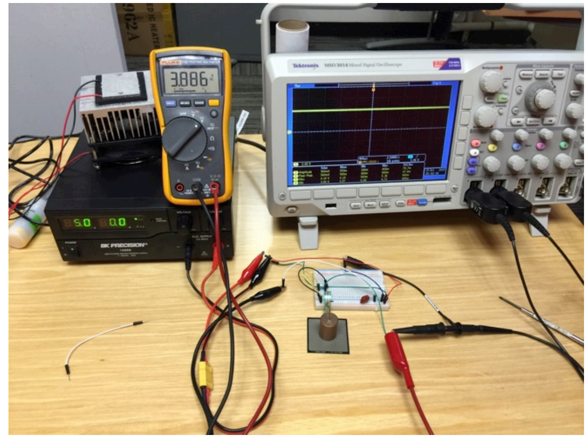
Force Sensor Exercise (Measurement)



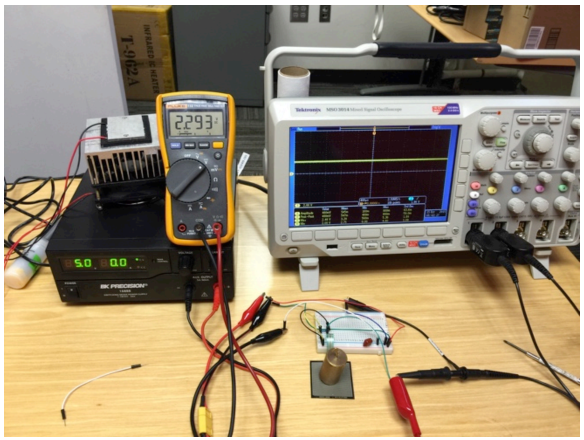
0 g reading 4.98 V



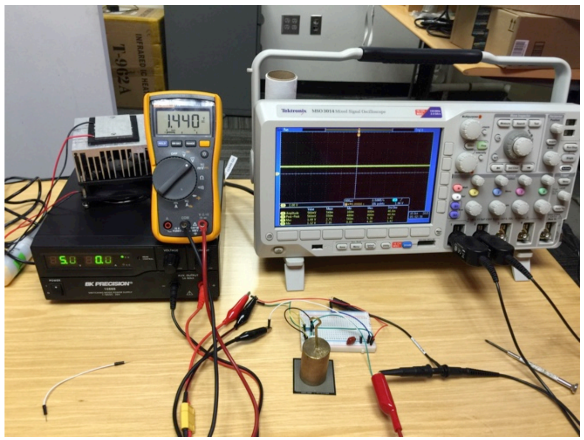
20 g reading 4.06 V



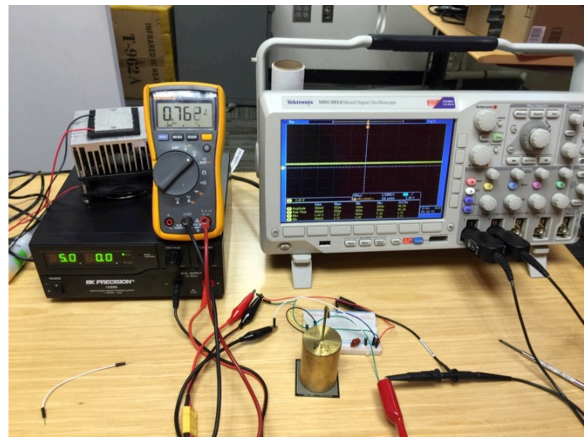
50 g reading 3.89 V



100 g reading 2.29 V



200 g reading 1.44 V



500 g reading 0.76 V

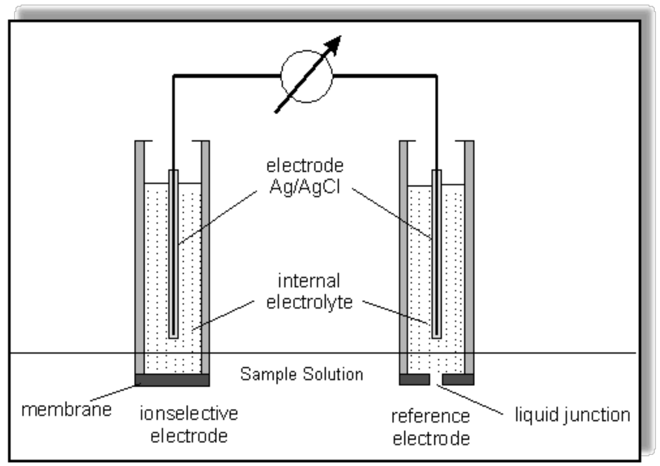
Ion Selective Electrode Exercise

- An Ion Selective Electrode (ISE) is a membrane Electrode that responds selectively to ions

- Transducer converts the activity of a specific ion dissolved in a solution into an electrical potential, which can be measured by a voltmeter or pH meter

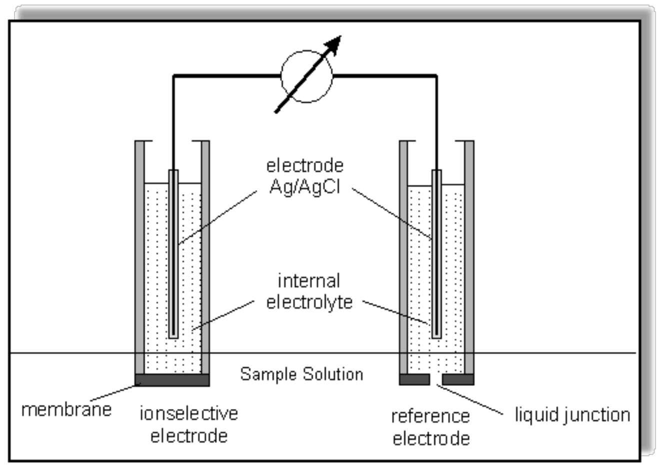
- Before making a measurement, the electrode needs to be rinsed off with DI water and calibrated against a known concentration sample

- After each measurement, the electrode needs to be rinsed off with DI water again in order to prevent cross contamination



Ion Selective Electrode Exercise

- For this exercise, the electrode had been previously CALIBRATED against a known sample.
- Before taking a measurement, I must clean off the electrode with DI water (to clean off any contaminants)
- After taking a measurement, I need to clean it off again to ensure the measurement is REPRODUCEABLE
- In this case, where can NOISE come from?
- What is my RESOLUTION? What is my DYNAMIC RANGE? For a measurement to be valid, what will my SAMPLE SIZE need to be?

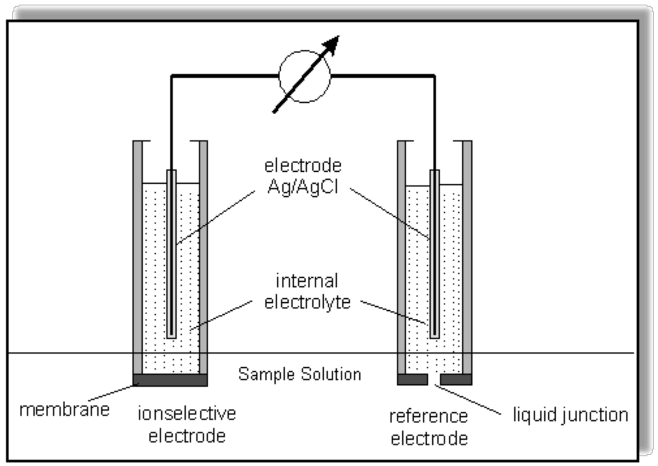


Ion Selective Electrode Exercise (Calibration and Measurement)

- **Below is a link to the specific sensor we will be using:**

http://www.vernier.com/products/sensors/ion-selective-electrodes/cl-bta/

- **In the above link, there is a video that demonstrates how to calibrate and measure using a Vernier probe.**



CV Measurement Exercise : Chaotic Pendulum

- **What is a double pendulum?**

- **What do we want to know?**
  - **Position, angle, velocity, force**

- **How do we measure its motion?**
  - **Shaft encoders**
  - **Accelerometers**
  - **Computer vision**
  - **Anything else?**

- **What are some drawbacks?**
  - **Shaft encoders add bulk and weight**
  - **Accelerometers have very limited accuracy (you will see soon)**
  - **CV may require proper lighting, high framerate, may not be realtime**

$$\dot{\theta}_1 = \frac{6}{m\ell^2}\frac{2p_{\theta_1} - 3\cos(\theta_1 - \theta_2)p_{\theta_2}}{16 - 9\cos^2(\theta_1 - \theta_2)}$$

and

$$\dot{\theta}_2 = \frac{6}{m\ell^2}\frac{8p_{\theta_2} - 3\cos(\theta_1 - \theta_2)p_{\theta_1}}{16 - 9\cos^2(\theta_1 - \theta_2)}.$$

CV Measurement Exercise : Chaotic Pendulum

- **So you've watched the two videos:**
- **Let's go talk about Noise, Resolution, and Sampling Rate (though for every measurement you make, you will need to include details on ALL characteristics)**
- **How does the NOISE change from the Nikon to the HSC?**
- **How does the RESOLUTION change from the Nikon to the HSC?**
- **How does the SAMPLING RATE change from the Nikon to the HSC?**

$$\dot{\theta}_1 = \frac{6}{m\ell^2} \frac{2p_{\theta_1} - 3\cos(\theta_1 - \theta_2)p_{\theta_2}}{16 - 9\cos^2(\theta_1 - \theta_2)}$$

and

$$\dot{\theta}_2 = \frac{6}{m\ell^2} \frac{8p_{\theta_2} - 3\cos(\theta_1 - \theta_2)p_{\theta_1}}{16 - 9\cos^2(\theta_1 - \theta_2)}.$$