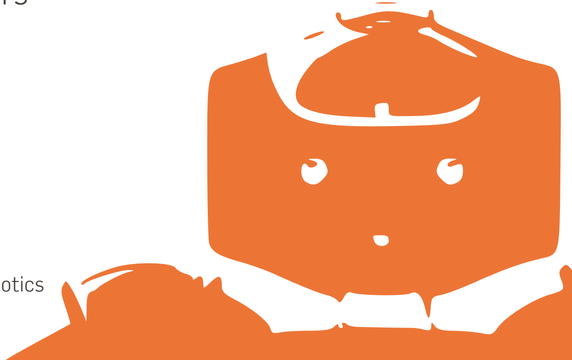
ROBOTICS WITH PLYMOUTH UNIVERSITY

# ROCO222
# Intro to Sensors and Actuators
## Force and Torque Sensors


Séverin Lemaignan

Centre for Neural Systems and Robotics
**Plymouth University**

# LABS ASSESSMENT

- Coursework: 60% of final mark
- Complete lab journal submitted **Thursday 16:00, 11th January 2018**

# LABS ASSESSMENT

- Coursework: 60% of final mark
- Complete lab journal submitted **Thursday 16:00, 11th January 2018**

Marking scheme for the lab journal:

- DC motor + encoder project: 35%
- Robotic arm project: 35%
- Other (GIT, command-line, stepper motors): 10%
- Presentation (Markdown syntax, photos, videos), use of GIT: 20%

Following and reporting on each of the steps in the lab instruction sheets should give you a 75% mark. Good analysis of your motor/arm supported by drawings and pictures, and design explorations/programming beyond what was requested bring you above that mark.

# LABS ASSESSMENT

I will pay particular attention to:

- Demonstration of actual understanding of the principles (with drawings/equations where needed)
- Reporting on the performance of your motor/arm, reflections on how to improve it
- Reflection on encountered pitfalls

Less important:

- The design of your robot arm (the design of the DC motor armature is important, though!)

**Individual reports**, but I accept a level of similarity within groups (e.g. photos). Please put the name of your teammate in your report.

# LAST LECTURE NEXT WEEK

Go to www.menti.com and use the code 57 51 24

# TODAY'S OBJECTIVES

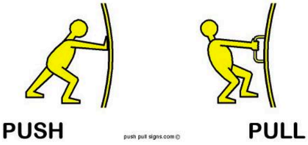
- Know how to measure force and torque
- (lots more on sensors during ROCO318 next year)

# MEASURING FORCE

# DEFINITION OF FORCE

- A push or a pull
- The ability to do work

- Is is a vector quantity
- Has magnitude and direction




- Measured in Newtons (N)

- **Newton's Second Law**
- A force acting on a mass will accelerate or decelerate it
- $F = ma$

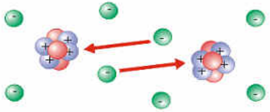
where F is Force (N), m is mass (Kg), a is acceleration ($ms^{-2}$)

# FOUR FUNDAMENTAL FORCES IN NATURE

1. Gravity
Dominates at large distances

2. Electromagnetic forces

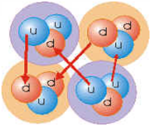
Observed in the interactions between atoms



3 . & 4. Nuclear forces

Strong & weak

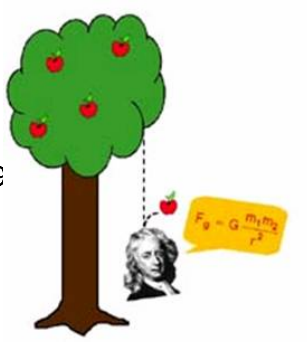
Both very short range



# FORCE ARISES FROM GRAVITY ACTING ON A MASS

- Force arises from gravity acting on a mass

- F = mg
  - where F is Force (N),
  - m is mass (Kg),
  - g is acceleration due to gravity ≈ 9



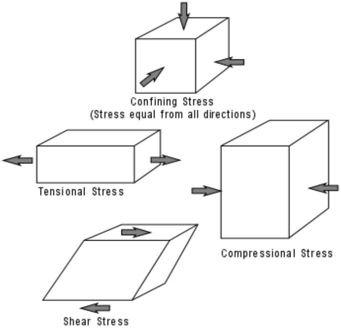
# MEASURING FORCE BY BALANCING KNOWN FORCE

- Use gravity acting on a known mass as source of known force


- Search for equilibrium position to find gravitational mass of test object

# MEASURING FORCE BY MEASURING STRAIN

- Stress defined as "force per area"
- Strain is defined as: "deformation of a solid due to stress”
- When we apply force
- Induced s**tress** results in a **strain**



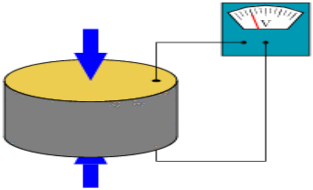

$E = stress\ /\ strain = (F\ /\ A_0)\ /\ (\Delta L\ /\ L_0)$

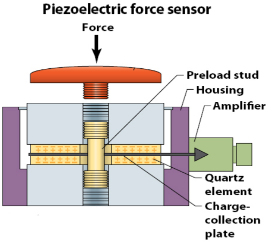
Where
E is the Young's modulus (modulus of elasticity)
F is the force exerted on an object under tension
$A_0$ is the cross-sectional area
$\Delta L$ is the amount by which object length changes
$L_0$ is the original length of the object

- By measuring strain of a material of known properties can estimate force

# PIEZO-ELECTRIC EFFECT

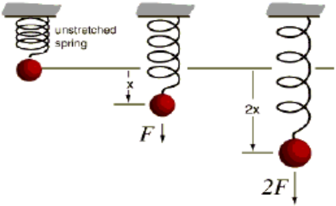
- Some materials generate electric charge under mechanical stress



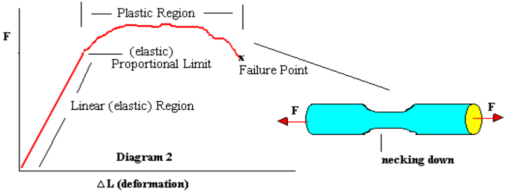




- Force results in a separation of charges with in structure
- Capacitive effect generates output voltage.
- Leakage causes charge dissipation and voltage decay over time
- Suitable for dynamic measurements

# MEASUREMENT OF ELASTIC DEFORMATION




Hooke's law: $F = -kx$




Hooke's law only holds over the elastic region

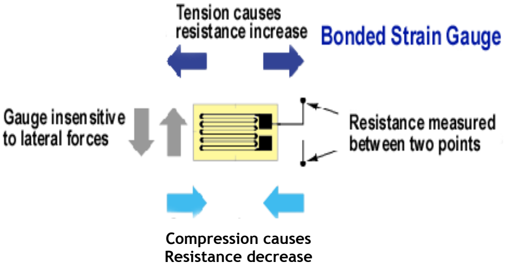
# DIRECT MEASUREMENT OF ELASTIC DEFORMATION

Can simply observe extension to estimate force

+


Other mechanical methods
Proving ring - Displacement measured directly using micrometer or dial gauge

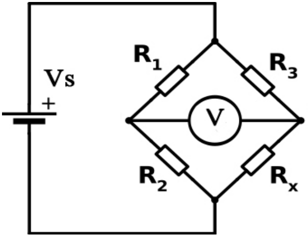
# STRAIN GAUGE




- This is an electrical method of force measurement
- The gauge measures strain of substrate to which it is attached
- Provided substrate load operated in elastic region of the material, this is linearly relates to the applied force by Young's modulus

- Strain gauge measures strain because when film stretches it becomes narrower and longer and this increases its resistance
- Gauge is much more sensitive to strain is direction along the longer thin regions
- Overall during use such a sensor delivers only a fraction of percent change in resistance
- Resistance change is usually measured using a Wheatstone bridge

# WHEATSTONE BRIDGE CIRCUIT




$$I_{LeftBranch} = \frac{V_s}{R_1 + R_2}$$

$$V_{R2} = \frac{V_s R_2}{R_1 + R_2}$$

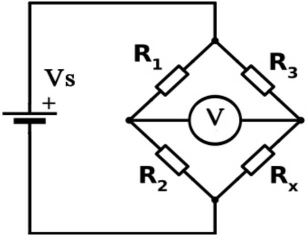
$$I_{RightBranch} = \frac{V_s}{R_3 + R_x}$$

$$V_{Rx} = \frac{V_s R_x}{R_3 + R_x}$$

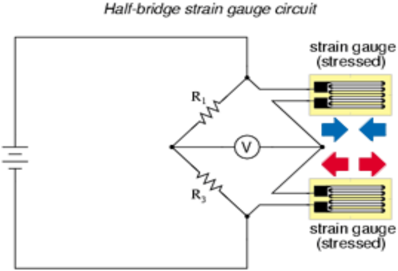
- Wheatstone bridge converts change in resistance to change in voltage

$$V = \left( \frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

# WHEATSTONE BRIDGE CIRCUIT



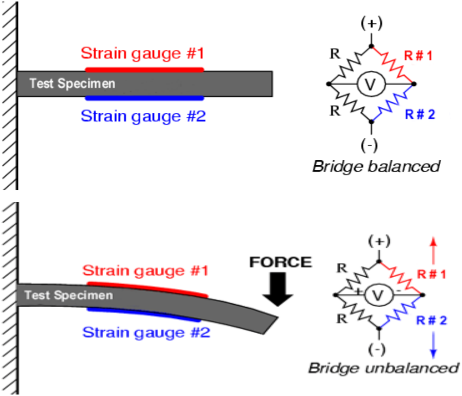

$$V = \left( \frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$




- By placing strain gauges into the bridge, changes in their resistance resulting from the strain in the substrate gives rise to changes in voltage that can be measured

- Bridge arrangement cancels out changes that occur in all the resistive elements
- This compensates for resistance changes due to changes on temperature and also for strains in unwanted directions

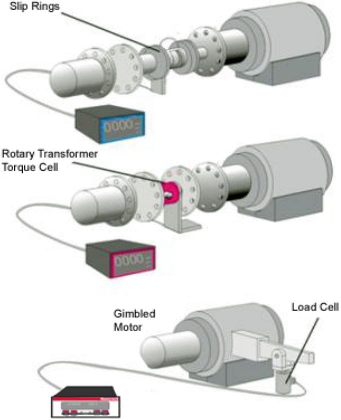
# SIMPLE CANTILEVER LOAD CELL




- If gauges are centrally mounted then
- no change in output voltage due to a side load

# MEASURING TORQUE

# MEASURING TORQUE

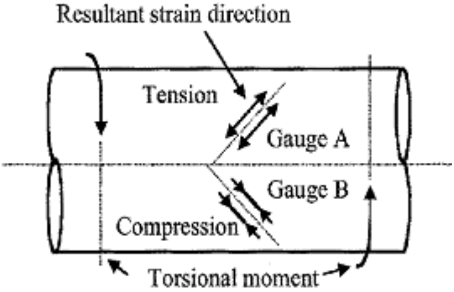



- Two common ways to obtain torque measurements are by strain-gauging the shaft and by using in-line torque cells.

- Both have two technical obstacles: getting power to the gauges over the stationary/rotating gap and getting the signal back.

68

# MEASURING TORQUE USING A GAUGE ON SHAFT




- The gauges lie perpendicular to one another at 45 deg to the plane about which the tensional moment is applied.

# 6 DOF LOAD CELLS

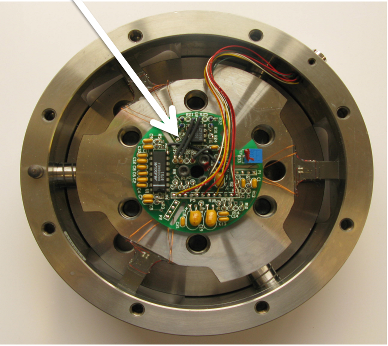
1 translational DOF

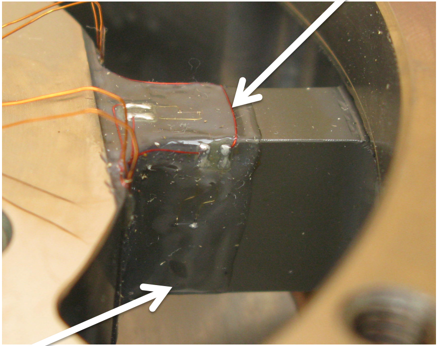

3 translational & 3 rotational DOFs

# INSIDE A LARGE 6 DOF FT

Signal conditioning circuitry

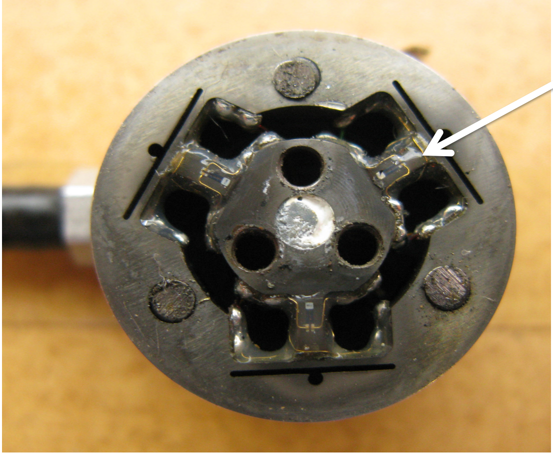
Silicon strain gauges





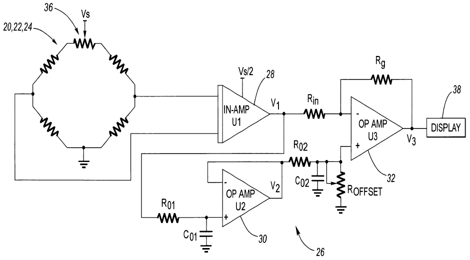
Massive structure which deforms under stress

# INSIDE A SMALL 6 DOF FT



Silicon strain gauges

# A SIGNAL CONDITIONING AMPLIFIER IS NEEDED




- The amplifier needed because voltage changes generates by Wheatstone bridge are small
- Need differential input to cancel interference
- Also it can filter unwanted signal outside the bandwidth of interest

That's all, folks!

Questions:
Portland Square B316 or **severin.lemaignan@plymouth.ac.uk**

Slides:
github.com/severin-lemaignan/module-introduction-sensors-actuators