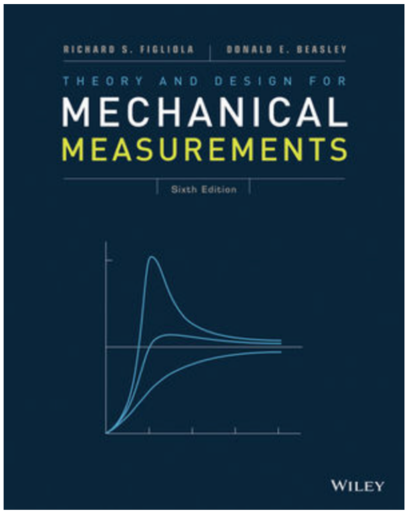



# Sensor Overview

Engr325

Instrumentation

Dr Curtis Nelson

# Lecture Overview

- IOS sensors
- Strain based sensors – force, torque, pressure
- Magnetic sensors
- Temperature sensors
- Inertial sensors
- Microelectromechanical systems (MEM's)
- Sensor fusion

# IOS Sensors

- **Proximity sensor**
  - A proximity sensor deactivates the display and touchscreen when the device is brought near the face during a call. This is done to save battery power and to prevent inadvertent inputs from the user's face and ears.
- **Ambient light sensor**
  - An ambient light sensor adjusts the display brightness which saves battery power and prevents the screen from being too bright or too dark.
- **Magnetometer**
  - A magnetometer is used to measure the strength and direction of the magnetic field in the vicinity of the device. Sometimes certain devices or radio signals can interfere with the magnetometer requiring users to either move away from the interference or re-calibrate by moving the device in a figure-eight motion. The iPhone also features a Compass app showing a compass that points in the direction of the magnetic field.

# IOS Sensors

- **Accelerometer**
  - A 3-axis accelerometer senses the orientation of the phone and changes the screen accordingly, allowing the user to easily switch between portrait and landscape mode. Photo browsing, web browsing, and music playing support both upright and left or right widescreen orientations. Unlike the iPad, the iPhone does not rotate the screen when turned upside-down, with the Home button above the screen, unless the running program has been specifically designed to do so. The 3.0 update introduced shaking the unit as a form of input (generally for undo functionality). It is also used for fitness tracking purposes, primarily as a pedometer. Starting with the iPhone 5S, this functionality was included in the M7 Motion coprocessor and subsequent revisions of the embedded chip.

# IOS Sensors

- **Gyroscopic sensor**
  - Beginning with the iPhone 4, Apple's smartphones also include a gyroscopic sensor, enhancing its perception of how it is moved.
- **Radio**
  - Some previous iPhone models contained a chip capable of receiving radio signals; however, Apple has the FM radio feature switched off because there was no antenna connected to the chip. Later iterations of the iPhone (starting with the iPhone 7), however, do not contain radio chips at all.

# IOS Sensors

- **Fingerprint sensor**
  - All iPhone models starting from iPhone 5S (excluding the iPhone 5C and iPhone X) feature Apple's fingerprint recognition sensor. It is used for unlocking the device and authenticating Apple Pay purchases (since the iPhone 6) using Touch ID. It is located in the home button.
- **Barometer**
  - Included on the iPhone 6 and later (excluding the iPhone SE), a barometer used to determine air pressure, and elevation from the device.
- **Facial recognition sensor**
  - The iPhone X features a facial recognition sensor, named the TrueDepth camera system. It is used for unlocking the device and for authenticating purchases using Face ID. It can also be used for Animojis and AR.

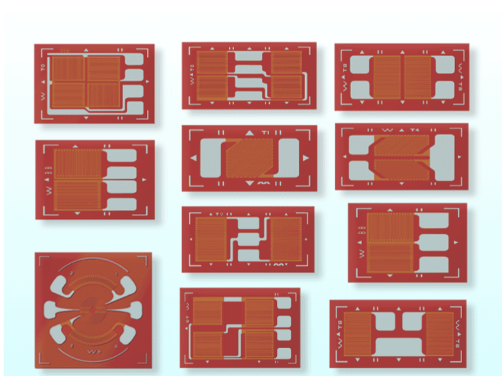
## IOS Access from the Matlab App

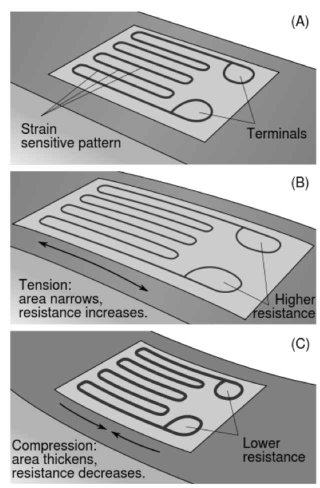
- Acceleration
- Angular velocity
- Orientation
- Magnetic field
- GPS

## Strain Gauge

- Resistance changes when the gauge deforms.
- Temperature affects.

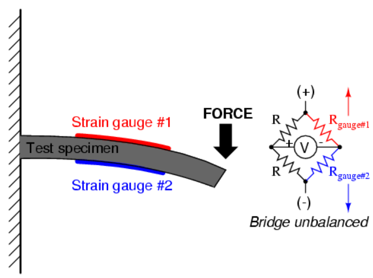
$$R = \rho \frac{l}{A}$$

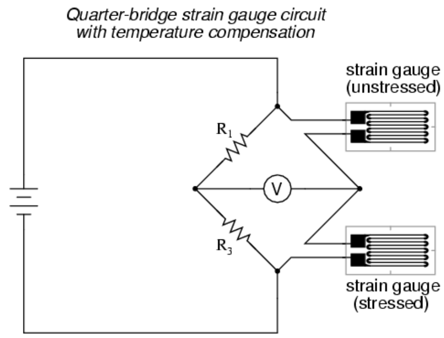




## Wheatstone Bridge

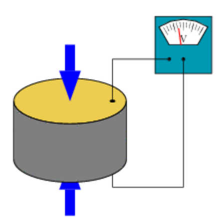
- Zero centered, sensitive output.
- Temperature compensation possible.

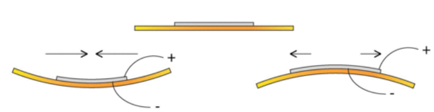



## Piezo-Electricity

- Mechanical strain generates electric charge in material
  - Or charge generates strain
- Very high dynamics
- Used in
  - Sensors and actuators
  - Oscillators – quartz clock



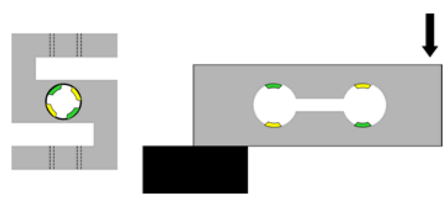


# Piezo-Resisivity

- Mechanical strain induces a change in semiconductor's electrical resistivity
  - Highly temperature sensitive
    - But can be compensated for
  - Larger change than in normal strain gages
    - More sensitive sensors

# Force Sensors (Load Cell)

- Strain gauge
  - Measures deformation
  - Stable, linear
- Piezoelectric load cells
  - High dynamics, very sensitive
  - Small size
  - Charge leaks -> measurement drifts



# Torque Sensors

- Usually strain gage based
- Also encoder based measurement of axle torsion

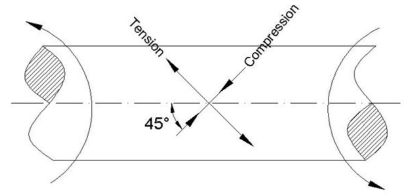
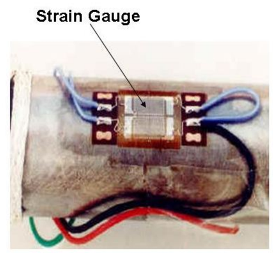



Figure Showing the Stress Developed in a Shaft Under Torsion

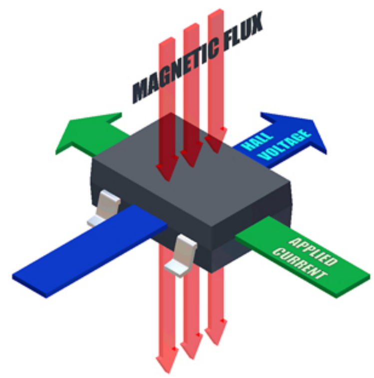



# Pressure Sensors

- Piezoresistive
  - Most common
- Piezoelectric
  - High dynamics.
  - Drifting due to leakage.
- Strain gauge
- Capacitive

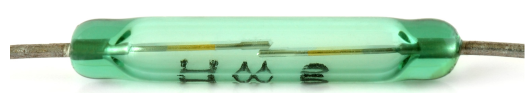
# Hall Effect

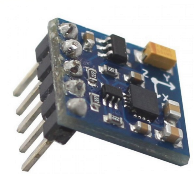
- External magnetic field causes a voltage in the sensor
  - Current sensors
  - Magnetic field sensors
- Very high dynamics
- Robust sensors since no contact
  - Integrated into one chip
- Also magnetoresistivity
  - Change in external magnetic field induces a change in material's electrical resistivity

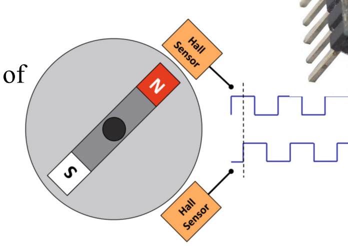



# Magnetic Sensors

- Magnetic switch
  - Mechanical or electrical
  - Magnetic field intensity
  - On/off
    - Motor commutation
- Magnetometer
  - Senses magnitude and direction of external magnetic field
  - Electric compass

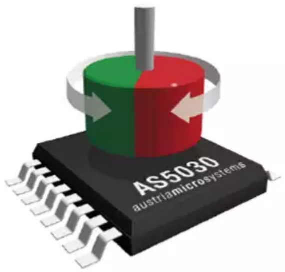


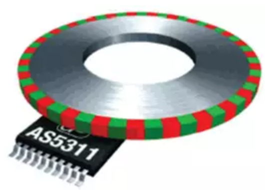


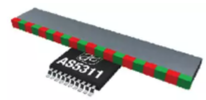


# Magnetic Encoders

- Hall sensors sense the direction of the magnetic field

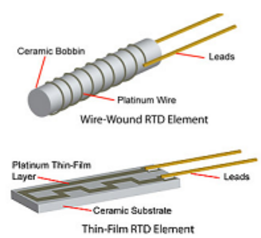







# Temperature

- Thermocouple
  - Change in voltage, a few µV per C°
  - Temperature up to 2000°C, fast response
- Resistance temperature sensors
  - Change in resistance (Pt100 100 ohm at 0 C °)
  - High accuracy, linear response
  - Usually for temperatures below 600 C °
- Thermistor
  - Resistance changes. Exponential response -> limited range
  - Temperature up to 1700°C



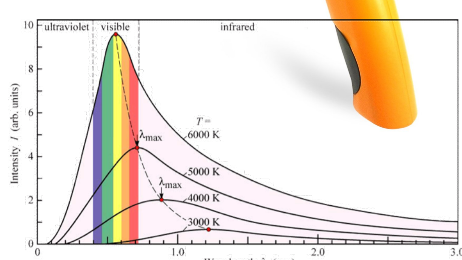

http://sensorwiki.org/doku.php/sensors/temperature

# Pyroelectricity

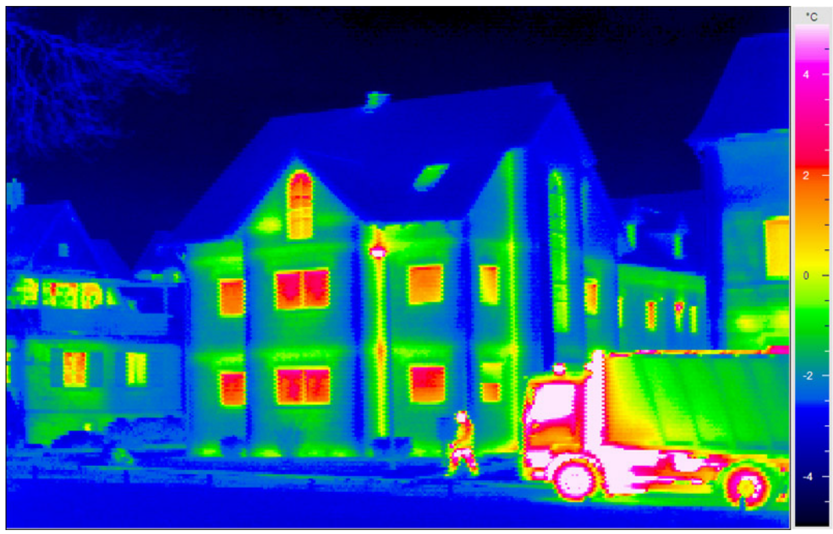
- Change in temperature causes voltage difference in crystal
- Application: Passive Infrared (PIR) motion sensors

# Contactless Temperature Measurement

- All objects emit black body radiation
- Benefits from contactless sensing
  - Moving objects
  - Short response time
  - Temperatures over 1300°C

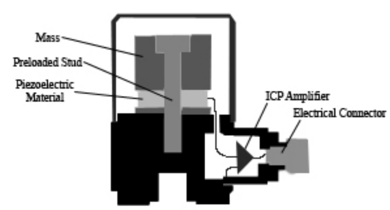


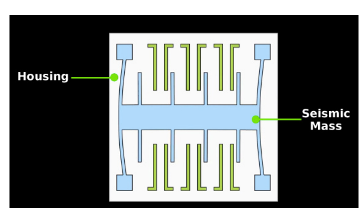
# Thermal Imaging




# Acceleration Sensors

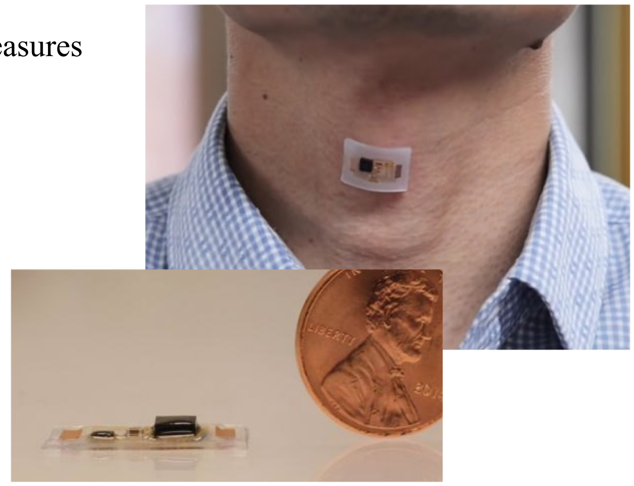
- Navigation, inclination, vibration, input devices, screen orientation
- Based on
  - Piezoelectricity
  - Piezoresistivity
  - Capacitive sensing



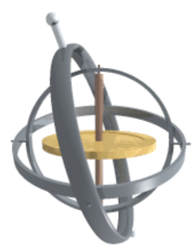



# Example: Wearable Sensor

- Accelerometer measures body vibrations
  - Heart rate
  - Voice



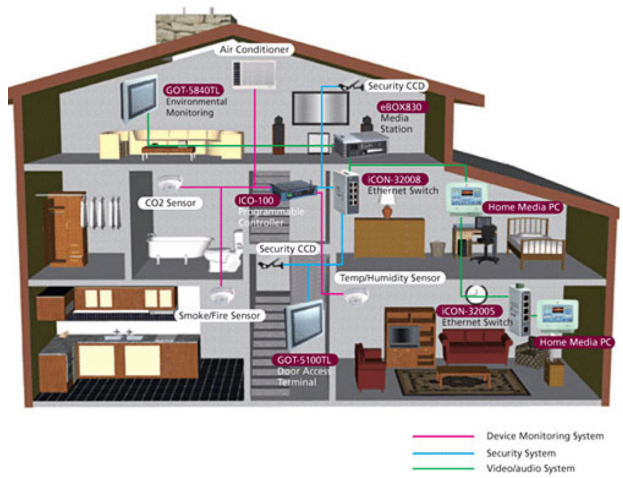
# Gyroscope



- Measures rate of angular rotation
  - Bias stability (drift), maximum rate of change
- Navigation, platform stabilization
- Principles
  - Mechanical – complex, expensive, very accurate
  - MEMS – low cost & power, often not very accurate (drift >10 deg/h)
  - Optical – accurate, medium cost, shock tolerant

# Building Automation

- Humidity
- Temperature
- Light intensity
- Carbon dioxide
- Air speed
- Radiation
- Smoke detector

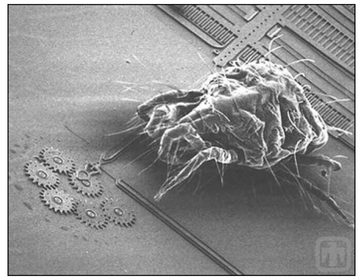


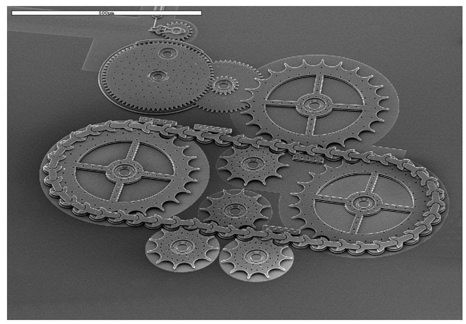

# Other Sensors

- Electrical – voltage, current
- Light – intensity, spectrum
- Material concentration – pH, gas detectors etc.
- Flow – air or liquid
- Radiation – geiger counter
- Acoustic

## MEMS

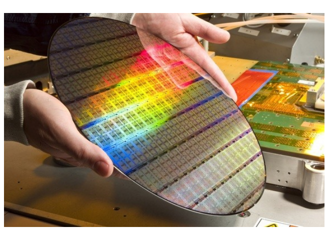
- Microelectromechanical system
  - Part dimensions 1-100 µm
- Low power
- Produced like electronic circuits
  - Mass manufacturing -> cheap

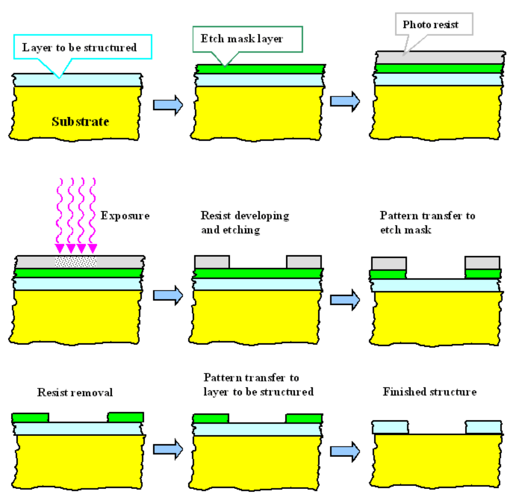




## Lithography

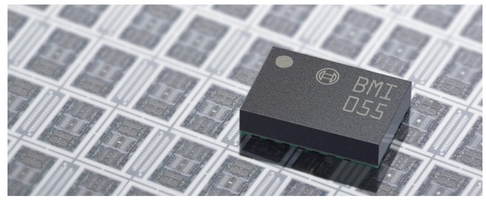
- Depositing
- Masking
- Etching

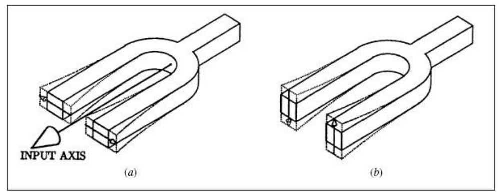




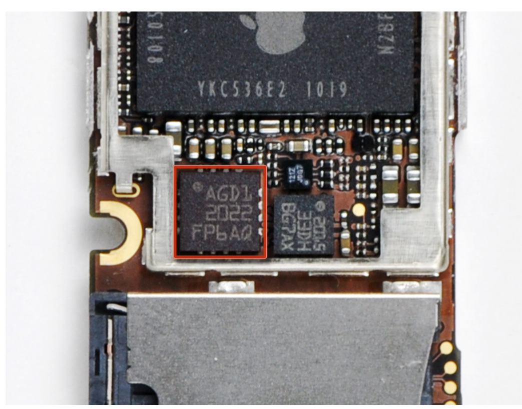
## MEMS Gyroscopes

- Cheap, small, low power
- Drift 1-1000°/h
- Sensitive to shocks

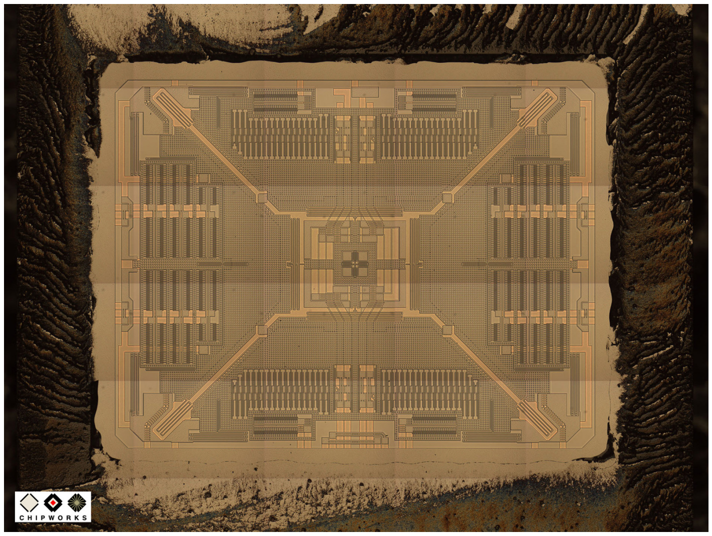


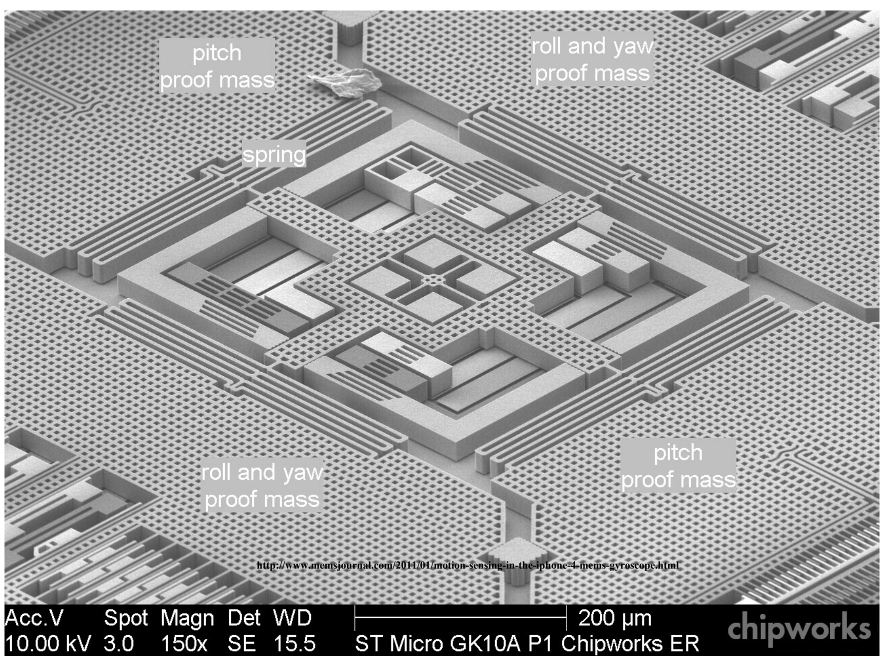




## MEMS Example - Iphone 4 Gyroscope



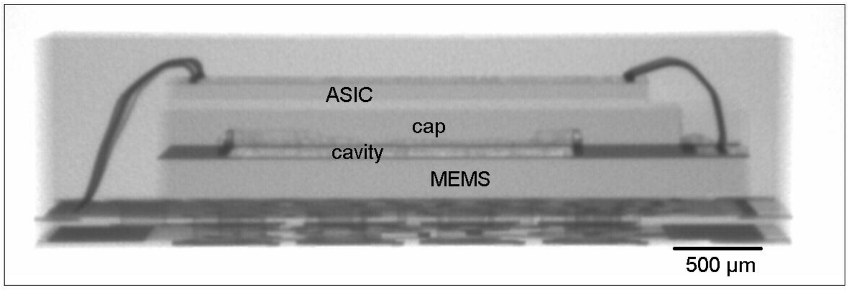
# MEMS Example - Iphone 4 Gyroscope




http://www.memsjournal.com/2011/01/motion-sensing-in-the-iphone-4-mems-gyroscope.html

# MEMS example - Iphone 4 Gyroscope




# Sensor Fusion

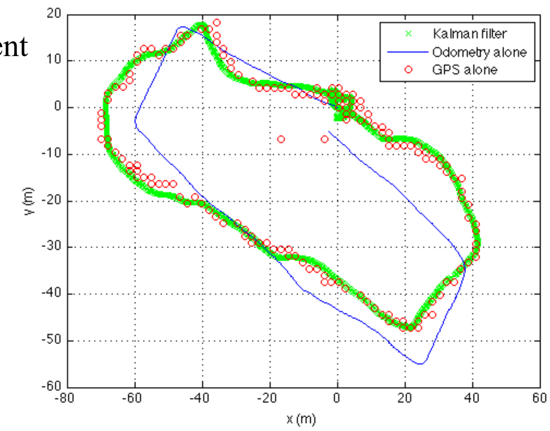
- Combine several sensors to increase precision

**Table 1: Summary Sensor Advantages and Issues**

| Sensor Type | Advantages | Issues |
|---|---|---|
| Accelerometer | • Fast.<br>• Absolute for "down". | • Cannot measure heading/yaw.<br>• Accumulated error due to jitter and noise, etc. |
| Gyroscope | • Fast.<br>• Measures relative orientation on all 3 axes. | • No absolute references.<br>• Long-term bias change, which leads to heading drift. |
| Geomagnetic Sensor | • Absolute for "heading". | • Magnetic anomaly distorts heading. |

## Sensor Fusion for Positioning

- Absolute measurement vs incremental




## Indirect Measurements

- Strain -> Pressure
- Pressure ->Hydraulic force
- Force -> Mass
- Acceleration -> Position/velocity
- Pressure -> Fluid velocity
- Back emf voltage -> Motor speed

# Summary

- Anything that can be converted to voltage can be measured
- Absolute vs incremental sensors
- MEMs are getting cheaper and more accurate
- Sensor fusion
- Indirect measurements