

ENMC3361 Sensors and Instrumentation

Lecture #10

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



Commonly Used Sensors:

The following is an overview of commonly used sensors for detection and measurement of the following:

- Displacement, and position.
- Velocity and Acceleration.
- ➢ Force and Strain.
- Pressure.
- ► Flow.
- > Temperature.
- ➤ Humidity and moisture.
- Chemical and Biological agents



Displacement and position:

Position Sensors:

- \succ detect the position of a target referenced to some fixed point in space or to the sensor itself.
- > In sensing the position could be distance between two points or rotation (angle position).

Displacement:

 \succ is a shift of an object from one position to another for a specific distance or angle.

Proximity detectors:

 \succ indicate when a critical distance is reached.



Displacement and position:

Potentiometric Sensor:

- ➤ A displacement sensor can be constructed using a potentiometer.
- > A moving object is mechanically coupled to the pot wiper, whose movement causes the resistance change.
- ➢ In many practical circuits, a resistance measurement is replaced by a measurement of voltage drop.
- ➤ Advantage: low cost, low tech, easy to use.
- Disadvantage: wear due to moving parts, low accuracy, low repeatability, and limited frequency response.



STUDENTS-HUB.com



Displacement and position:

Potentiometric Sensor:

Voltage across the wiper of a linear pot is proportional to the displacement (d).

 $v = v_o \frac{d}{D}$

Where:

D: Is the full scale displacement.

 v_o : Is excitation voltage across the pot.





Displacement and position:

Potentiometric Sensor:

- A potentiometric sensor is used as part of a fuel tank level sensor in most cars.
- Recent addition of Ethanol alcohol in the fuel causes corrosion on the windings in older cars that have exposed winding.
- Wear caused by rapid movement of the wiper arm as the fuel splashes in the fuel tank







STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #10



Displacement and position:

Inductive Position Sensors:

- > These sensors are often referred to as LVDT (Linear Variable Differential Transformer).
- The sensor consists of a primary coil (can also be a trace on a PCB) and one or more sensing coils (also can be traces).
- The current generates Eddie currents in the metal target which will create a current in the secondary coils.



STUDENTS-HUB.com



Displacement and position:

Inductive Position Sensors:

- As the metal target moves across the two sensing coils the ratio of the current induced in the two sensing coils changes.
 This ratio can be calibrated to an exact target location.
- High accuracy of better than 0.1% is easily achieved in commercial inductive position sensors.







STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #10



Displacement and position:

Inductive Position Sensors:

Inductive angular sensors are very similar to linear position sensors but with the traces making a circular pathways.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #10



Displacement and position:

Inductive Position Sensors:

➤ Advantage:

- No moving parts and no contact makes this sensor extremely reliable.
- It has no temperature sensitivity.
- Since all sensing elements can be enclosed the sensor is able to operate in harsh environments.
- > Disadvantage:
 - Limited sensing range.
 - Target object must have the ferrous material machined into it or attached to it.



Displacement and position:

Laser range sensor:

- The most common form of laser rangefinder operates on the time of flight principle by sending a laser pulse in a narrow beam towards the object and measuring the time taken by the pulse to be reflected off the target and returned to the sender.
- > Due to the high speed of light, this technique is not appropriate for high precision sub millimeter measurements.
- It is possible to use Doppler effect techniques to judge the speed as well as the position of the object.
- The precision of the instrument is determined by the rise or fall time of the laser pulse and the speed of the receiver.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #10



Displacement and position:

Laser range sensor:

- ➤ Laser range sensors could also be used for precise displacement sensing.
- ➤ A laser hits the target, light reflected off of the target is concentrated through the receiving lens and is focused onto the light receiving element.
- If the distance from the sensor to the target changes, the angle of the reflected light changes causing the position of the received light to change on the light receiving element.
- > This change is proportional to the movement amount of the target.



STUDENTS-HUB.com

The End of Lecture #10

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #11

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



Displacement and position:

Laser range sensor:

- Two dimensional light sensor can be used to get profile of objects.
- Advantage: High resolution, speed and accuracy as well as non contact reliability.
- Disadvantage: not all objects work based on reflectance and surface roughness. Expensive, limited range.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11



Displacement and position:

Ultrasonic Range sensor:

- Ultrasonic displacement sensors emit ultrasonic waves from the sensor head and receive the waves reflected off the target object.
- ➤ A piezoelectric transducer is used for both emitter and receiver.
- The distance is measured by detecting and calculating the time from the emission to receipt of the ultrasonic wave.
- If the detected distance is expressed as (L), the time from the emission of ultrasonic to the receipt as (T), and the speed of sound as (C), the detected distance can be calculated:

$$L = \frac{1}{2} \times T \times C$$





STUDENTS-HUB.com



Displacement and position:

Ultrasonic Range sensor:

- ➢ Industrial.
 - determine liquid levels.
 - motion detector systems.
 - non destructive testing
- ➢ Biomedical.
 - detect micromotion at bone implant interface.
 - measure other internal tissue displacements.
 - quantify external movement during daily activities



STUDENTS-HUB.com



Displacement and position:

Incremental Encoder:

- Output is a series of square wave pulses generated by a photocell arrangement and a coded disk with evenly spaced transparent and dark.
- Incremental encoders have two separate outputs called "quadrature outputs". These two outputs are displaced at 90° out of phase from each other with the direction of rotation of the shaft being determined from the output sequence.
- Incremental encoders only provide displacement.
- Incremental encoders have many applications including conveyor belts, escalators, CNC machines, robots, etc.



STUDENTS-HUB.com



Displacement and position:

Incremental Encoder:

- Incremental encoders only provide displacement.
- Incremental encoders have many applications including conveyor belts, escalators, CNC machines, robots, etc.
- They provide in expensive yet accurate displacement measurements that is not effected by EMF, temperature, or humidity.





Displacement and position:

Absolute Encoder:

- provide a unique output code for every single position of rotation indicating both position and direction..
- Their coded disk consists of multiple concentric "tracks" of light and dark.
- The number of tracks on the disk corresponds to the binary "bit" resolution of the encoder so a 12 bit absolute encoder would have 12 tracks and the same coded value only appears once per revolution.
- > Absolute encoders provide position rather than displacement.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11



Displacement and position:

Absolute Encoder:

- Typical application of absolute position encoders are in computer hard drives and CD/DVD drives were the absolute position of the drives read/write heads are monitored.
- Another common example is printers/plotters to accurately position the printing heads over the paper.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11



Velocity and Acceleration:

- ➢ For some applications, velocity and acceleration can be derived using the position sensors "covered previously".
- ▶ In other applications, the velocity or acceleration of an object must be self measured.
- > In these applications, velocity is often derived from measured acceleration.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11



Velocity and Acceleration:

- Inertia Linear Accelerometer.
- Inertia Rotary Accelerometer.
- > Thermal Accelerometer.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11



Velocity and Acceleration:

Inertia Linear Accelerometers work by:

- 1. A "Proof mass" is held by a system of springs and allowed to move.
- 2. Acceleration will exert a force on the mass moving it from its rest position.
- 3. The shift in position is directly proportional to the acceleration on the proof mass.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #11

The End of Lecture #11

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #12

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



Velocity and Acceleration:

Inertia Linear Accelerometers work by:

- MEMS (micro electro mechanical system) based accelerometers are widely used for many applications.
- The most common type is a capacitive accelerometer.
- The proof mass movement will change the distance between two set of conductive plates.





Velocity and Acceleration:

Inertia Linear Accelerometers work by:

- A typical mems accelerometer will have a separate sensor for each axis of motion.
- Proof mass, springs and even capacitive plates are fabricated from silicone.





Velocity and Acceleration:

Inertia Linear Accelerometers work by:

- A piezoelectric accelerometer uses a piezoelectric ceramic and an attached proof mass.
- The compression of the piezoelectric transducer produces a voltage that can be converted to acceleration.
- Piezoelectric accelerometers are ac accelerometers and can only be used for measuring vibration.
- The inherent high pass filter means that the accelerometer wont measure constant acceleration such as gravity.
- Used in Seismic monitoring and machine vibration.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #12



Velocity and Acceleration:

Inertia Linear Accelerometers work by:

- Another type of piezoelectric accelerometer uses a proof weight attached to a cantilever with a piezoelectric ceramic on the surface.
- The compression of the piezoelectric transducer due to deflection of the cantilever produces a voltage that can be converted to acceleration.
- The adjustment of weight and stiffness of the cantilever member will create a sensor for different frequency ranges and sensitivities.
- The sensor will produce non linear response near it's resonance frequency.





STUDENTS-HUB.com



Velocity and Acceleration:

Thermal Inertial Accelerometer:

A MEMS based accelerometer based on natural convection of fluid.

- 1. Resistive heater in center of a cavity.
- 2. Temperature sensors surrounding the heater.
- 3. Heat will create a thermal bubble surrounding the heater.
- 4. The heat bubble will shift based on acceleration creating a difference in temperature reading between the sensors.



STUDENTS-HUB.com



Force and Strain:

There are two types of force sensors:

1. Indirect where sensors measure displacement cased by the force rather than the force directly.

These sensors are a combination of a force to displacement transducer and displacement sensor that converts displacement to electrical output.

2. Direct where the force is measured directly without requiring a displacement measurement.



Force and Strain:

The most common indirect force sensor utilizes a spring and a displacement sensor.

Using the formula:

F = K.x

Where: "K" is the spring coefficient and "x" is the displacement measured.



STUDENTS-HUB.com



Force and Strain:

LVDT force sensor uses an inductive displacement sensor with a spring with a known spring coefficient.

Using the formula:

F = K.x

Where: "K" is the spring coefficient and "x" is the displacement measured.

A common application of this type of force sensor is on aircrafts, where the force sensors are used on landing gears to determine aircraft weight to be inputted into the flight computer.





STUDENTS-HUB.com



Force and Strain:

Pressure based force Sensor

- A similar sensor can be constructed with other types of springs and pressure sensors.
- For example: a pressure sensor is combined with a fluid filled bellows which is subjected to force.
- The bellows functions as a force to pressure converter (transducer) by distributing a localized force at its input over the sensing membrane of a pressure sensor, that, in turn, comprises another displacement transducer for converting the membrane motion to an electrical output.





Force and Strain:

Strain gauges

- Force transducers based on strain gauges have a so called spring element or loaded member where the forces to be measured are applied.
- The spring element deforms, and strain is produced on the surface.
- A strain gauge converts this strain into an electrical signal.



STUDENTS-HUB.com
The End of Lecture #12

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #13

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



Pressure:

Pressure sensors

- Pressure sensors are used for control and monitoring in thousands of everyday applications.
- Pressure sensors can also be used to indirectly measure other variables such as fluid/gas flow, speed, fluid level, and altitude.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #13



Pressure:

Types Pressure Sensors

- 1. Absolute pressure sensor: Measures pressure relative to perfect vacuum.
- 2. Gauge pressure sensor: Measures pressure relative to atmospheric pressure.



Pressure greater than atmospheric pressure

- 3. Vacuum pressure sensor: Measures pressures below atmospheric pressure.
- 4. *Differential pressure sensor*: Measures the difference between two pressures, one connected to each side of the sensor.
- 5. *Sealed pressure sensor*: pressure relative to some fixed pressure rather than the ambient atmospheric pressure (which varies according to the location and the weather).



Pressure:

Types Pressure Sensors

- Pressure sensing is mostly done using force collection.
- These types of electronic pressure sensors generally use a force collector (such a diaphragm, piston, bourdon tube, or bellows) to measure strain (or deflection) due to applied force over an area (pressure).
- The strain is measured by a transducer.



Pressure:

Piezoresistive Pressure Sensors

- Uses the piezoresistive effect of bonded or formed strain gauges to detect strain due to applied pressure, resistance increasing as pressure deforms the material.
- Advantage:
 - Excellent linearity and low hysteresis.
 - High Sensitivity.
 - Low cost MEMS solutions.
- Disadvantage.
 - Temperature dependent



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #13



Pressure:

Capacitive Pressure Sensors

- Uses a capacitive transducer to measure the strain in a diaphragm or bellow.
- The stiffness and strength of the material can be chosen to provide a range of sensitivities and operating pressures.
- By choosing materials for the capacitor plates that have a low coefficient of thermal expansion, it's possible to make sensors with very low sensitivity to temperature change.





Pressure:

Capacitive Pressure Sensors

- The change in capacitance can be measured by connecting the sensor in a frequency dependent circuit such as an oscillator.
- Advantage:
 - ✓ Excellent linearity and low hysteresis.
 - ✓ High Sensitivity.
 - ✓ Low cost MEMS solutions.
 - ✓ Less Temperature dependent than Piezoresistive.
- Disadvantage:
 - ✓ Requires more sophisticated circuitry
 - \checkmark Non linear response.



Pressure:

Inductive pressure sensors

- Inductive pressure sensors measure the strain of the diaphragm by means of LVDT or Hall Effect.
- Not commonly used due to the high manufacturing cost and marginal improvement in accuracy over simpler capacitive and resistive sensors.
- Advantage:
 - ✓ High Sensitivity.
 - ✓ Minimal Temperature dependent.
- Disadvantage:
 - \checkmark More expensive.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #13



Pressure:

Optoelectronic pressure sensors

- Optoelectronic pressure sensors used when high electromagnetic noise is present..
- An optical position sensor similar to those covered are used to measure deflection of a diaphragm.
- Advantage:
 - ✓ High Sensitivity.
 - ✓ Minimal Temperature dependent.
 - ✓ Minimal EMF sensitivity.
- Disadvantage:
 - ✓ Expensive.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #13



Pressure:

Vacuum Sensors:

- When measuring vacuum close to absolute using a capacitive or resistive sensor will not provide the required accuracy.
- Other properties such as heat transfer of the gas are used to indirectly measure the absolute pressure.
- A Pirani gauge works by using two heated thermistors.
- The heat loss in air at atmosphere vs the heat loss of the air in the sensing chamber is proportional to the pressure being measured.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #13

The End of Lecture #13

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #14

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



STUDENTS-HUB.com



- The common types of flowmeters with industrial applications are:
 - Pressure flow meters
 - Thermal low meters
 - Ultrasonic
 - Variable area flow meters
 - Electromagnetic
 - Cantilever
 - Mass flowmeter (Coriolis force).
 - Mechanical flow meters



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



- Pressure Based flow meters measure pressure change as the fluid is passed through an obstruction.
- These sensors are ideally used for non-viscous incompressible medium.





Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



 Velocity across a restrictor can be measured using Bernuolli's equation

 $\Delta p = p_1 - p_2 = \frac{\rho}{2} (v_2^2 - v_1^2)$

- The pressure difference is a function of the difference in square of the speeds.
- MEMS based flow meters can also be created using a capacitive sensor and a flexible membrane.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



- Another method of measuring speed based on pressure differential is by using a pitot tube.
- A pitot tube has a port facing the flow and one perpendicular to the flow.
- The pressure difference created by the flow velocity follows Bernoulli's equation.
- Pitot tubes are used in many applications including airspeed of an aircraft, air flow in stacks and chimneys.
- Pitot tubes provide point measurement and can be used to determine flow profile.





STUDENTS-HUB.com



V=(2∆P/)^{1/2}

Where ρ is the density of the fluid

For air

 $\rho_{\rm dry}$ = P/RT

Where

"P" is static pressure "R" is specific gas constant = 287 j/kg.K "T" is the Temperature in K





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



- A "variable area meter" measures fluid flow by allowing the cross-sectional area of the device to vary in response to the flow, causing some measurable effect that indicates the rate.
- A rotameter is an example of a variable area meter, where a weighted "float" rises in a tapered tube as the flow rate increases
- The float stops rising when area between float and tube is large enough that the weight of the float is balanced by the drag of fluid flow.
- Rotameters can be equipped with inductive sensors to detect flow limits.



STUDENTS-HUB.com



- Thermal mass flowmeters generally use combinations of heated elements and temperature sensors to measure the difference between static and flowing heat transfer to a fluid.
- Flow calculations requires fluid density and specific heat capacity.
- This type of flow meter can provide mass flow reading without any pressure and temperature compensation.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



- Hotwire anemometer is another formal thermal flow meter that uses heat loss to detect air velocity.
- A fine wire is electrically heated to some temperature above the ambient.
- The wire is cooled by the air flowing past it.
- Measuring resistance of the wire provides this temperature indirectly.
- A relationship can be obtained between the resistance of the wire and the flow speed.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



• What could cause an error in the reading?





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14



- Ultrasonic anemometers measure wind speed based on the time of flight of sonic pulses between pairs of piezoelectric transducers.
- 2 or even 3-dimensional wind measurements are possible using pairs of transducers.
- The fast response of ultrasonic anemometers makes them ideally suited for measuring turbulent flow.
- Same principle can be used to measure flow in a pipe.







STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #14

The End of Lecture #14

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #15

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com



- Vortex flow meters use an obstacle (called a shredder bar) in the path of the fluid to create vortices.
- The frequency at which these vortices switch sides is proportional to the fluid flow.
- A piezoelectric element is used to measure the pressure after the shredder bar.
- Sensor does not register low flow (laminar flow)-Why?
- The equation governing this type of sensor is:

f=SV/L Where:

- f is the frequency of oscillation,
- V is the fluid velocity,
- L is the length of the shedder bar, and
- **S** is a Struhaul number which is constant for a body shape and is derived in calibration.

STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15





Department of Mechanical and Mechatronics Engineering

FLOW

- Electromagnetic flow meters are non-contact non-obstructive flow meters ideally suited for a conductive fluid.
- The principle of operation is:
 - Two coils or permanent magnets generate a magnetic flux through the tube.
 - Two electrodes are placed perpendicular to the tube
 - The magnetic flux separates positive and negative charged particles in the fluid creating a voltage between the electrodes (E) as: "Faraday's Law"

E = K B D V

- where K is a constant derived in calibration
 - **B** Magnetic field Strength
 - D distance between electrodes
 - V fluid velocity





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15



- What would be a good application of this sensor?
 - * Conductive flow, or water based
 - * Waste water, or any dirty liquid which is conductive or water based
- What are some of the limitations?
 - * The case material







- Coriolis flow meter provides a measure of mass flow rather than volume flow or velocity.
- Coriolis effect is a force that acts on an object that are in motion within a moving frame of reference.
- Coriolis force $F=2m(\omega.v)$ where " ω " is the angular velocity and "v" is the relative velocity.
- Imagine having a hose filled with water that is not moving. Swinging a hose filled with water that is not moving will not twist.
- When water is flowing through the tube the hose will twist due to the inertia of the water.





STUDENTS-HUB.com



- Coriolis flow meter has two parallel tubes that carry partially or the entirety of the flow.
- A pair of electromagnets create excitation of the two tubes at the resonant frequency of the system.
- Two inductive or optical sensors measure the distance at each end of the tube.
- The phase shift between the two sensors is directly related to the mass flow rate through the tubes.
- The frequency response of the tube in response to excitation is proportional to density of the fluid.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15



- Advantage of Coriolis flow meters are:
 - Direct mass and density reading
 - Same system can measure mass flow of different gases and liquids
 - Non-contact sensing
- Disadvantage of Coriolis flow meters
 - Require fluid of a minimum density or flow rate.
 - Expensive



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15



- Ultrasonic Flow meters use two piezoelectric sensors up and down stream of each other.
- Each sensor will emit and receive an ultrasonic signal.
- The delay in transmission of signal between the upstream and downstream signal will be proportional to the fluid flow.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15



• Ultrasonic Flow meters



No Flow > **Slow wave**



Flow > fast wave in the flow direction



Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #15

The End of Lecture #15

STUDENTS-HUB.com



ENMC3361 Sensors and Instrumentation

Lecture #16

Ihab Abu Ajamieh, PhD.

STUDENTS-HUB.com


STUDENTS-HUB.com



Thermocouple Temperature Sensor

- Use thermoelectric effect to create a voltage across two dissimilar metals proportional to the temperature gradient across them.
- The measured temperature is relative between the two junctions.



Uploaded By: anonymous

STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #16



Thermocouple Temperature Sensor

- First uses of thermocouples used an ice/water bath to set the cold junction at 0°C.
- Modern thermocouple-based instruments use a cold junction compensation system.
- This consists of a:
 - copper junction on each line
 - A thermistor or RTD is required to measure the absolute temperature of the cold junction.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #16



Thermocouple Temperature Sensor

- Advantages:
 - Self-powered, no necessity for an external power source.
 - Simple and Robust.
 - Inexpensive.
 - Wide Temperature Range.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #16



Resistive Temperature Sensor (RTD)

- Thermoresistive properties of metal alloys are used to measure absolute temperature.
- RTDs can be:
 - Thin film RTDs are often fabricated of thin platinum or its alloys and deposited on a suitable substrate (e.g. silicon).
 - Wire-wound RTDs, where the platinum winding is partially supported by a high temperature glass adhesive inside a ceramic tube.
- RTDs have the highest accuracy (0.025°C) of any common temperature sensor.
- Temperature range -50 to 850°C or up to 1600 for specialized Platinum/Lead.



STUDENTS-HUB.com



Resistive Temperature Sensor (RTD)

- RTDs have the highest accuracy (0.025°C) of any common temperature sensor.
- Inaccuracy due to lead wire connections can be compensated using a 3-wire or 4-wire connection.
- Lead resistance is measured using a secondary wire and subtracted from the reading.
- This requires all lead resistances to be equal.
- A Wheatstone bridge is used to compensate for the lead resistances.





STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #16



Thermistor

- Thermistors are another type of resistor with strong thermoresistive properties.
- Most commonly thermistors are made of powdered metal oxides.
- Accuracy of ±0.05
- Temperature range -55 to 80°C but up to 300C using glass-body.
- Inexpensive and widely used on a electronic devices.



STUDENTS-HUB.com

Asst. Prof. Ihab Ajamieh - ENMC3361 Lecture #16



Infrared Thermometer

- Infrared thermometers use a photoelectric pyrometer.
- Sensor turns blackbody IR radiation to a measurable signal.
- A laser beam is included to help aim the thermometer.
- Temperature range 0-600°C
- Accuracy ±3°C
- A sensor array of photoelectric pyrometers will produce an IR camera.





STUDENTS-HUB.com



Acoustic Sensor

- Alternative approach is to use an acoustic temperature senor.
- Uses the principle that temperature of a media affects the speed of sound through it.
- For dry air, the speed of sound is:



$$v \approx 331.5 \sqrt{\frac{T}{273.15}}$$

STUDENTS-HUB.com

The End of Lecture #16

STUDENTS-HUB.com