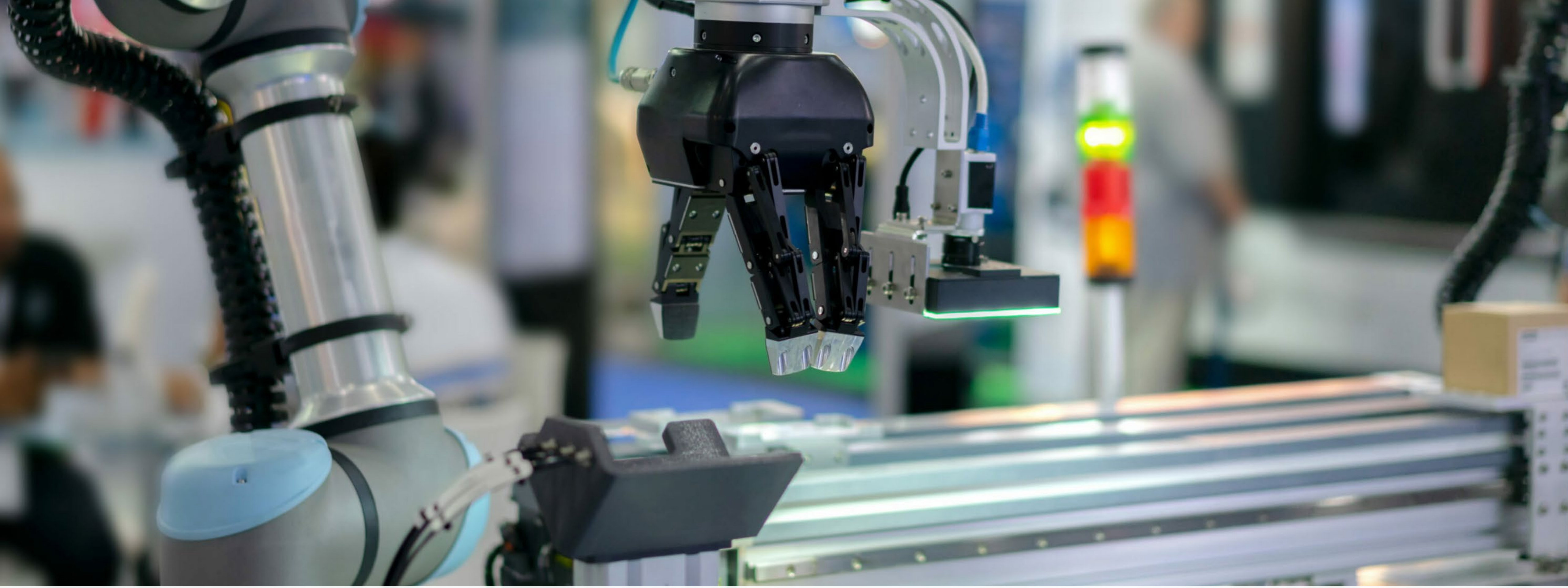


ISE 589-006: INTRODUCTION TO MODERN INDUSTRIAL AUTOMATION

LECTURE 002

Fred Livingston, PhD

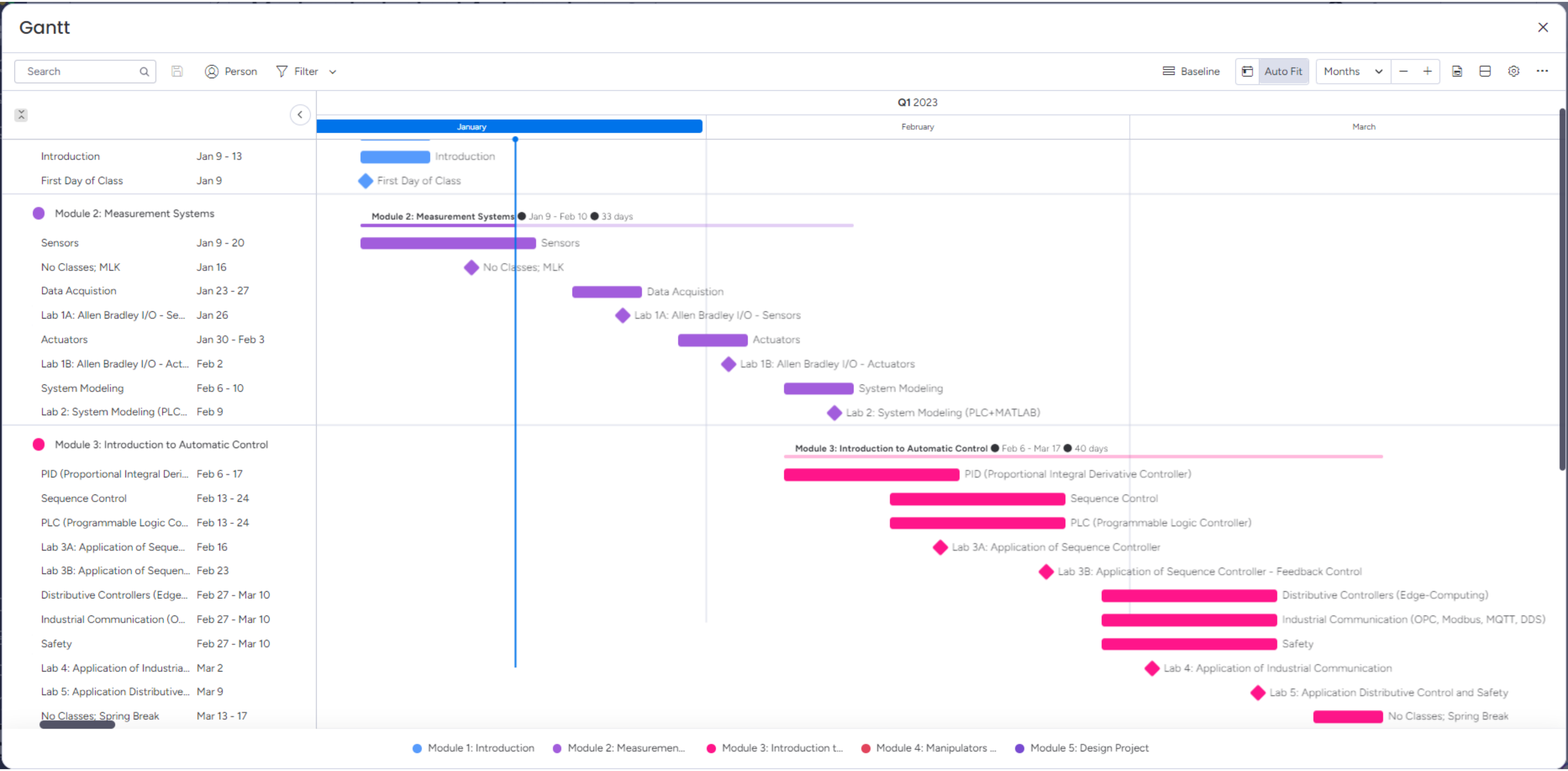
LECTURE 2: SENSORS 002

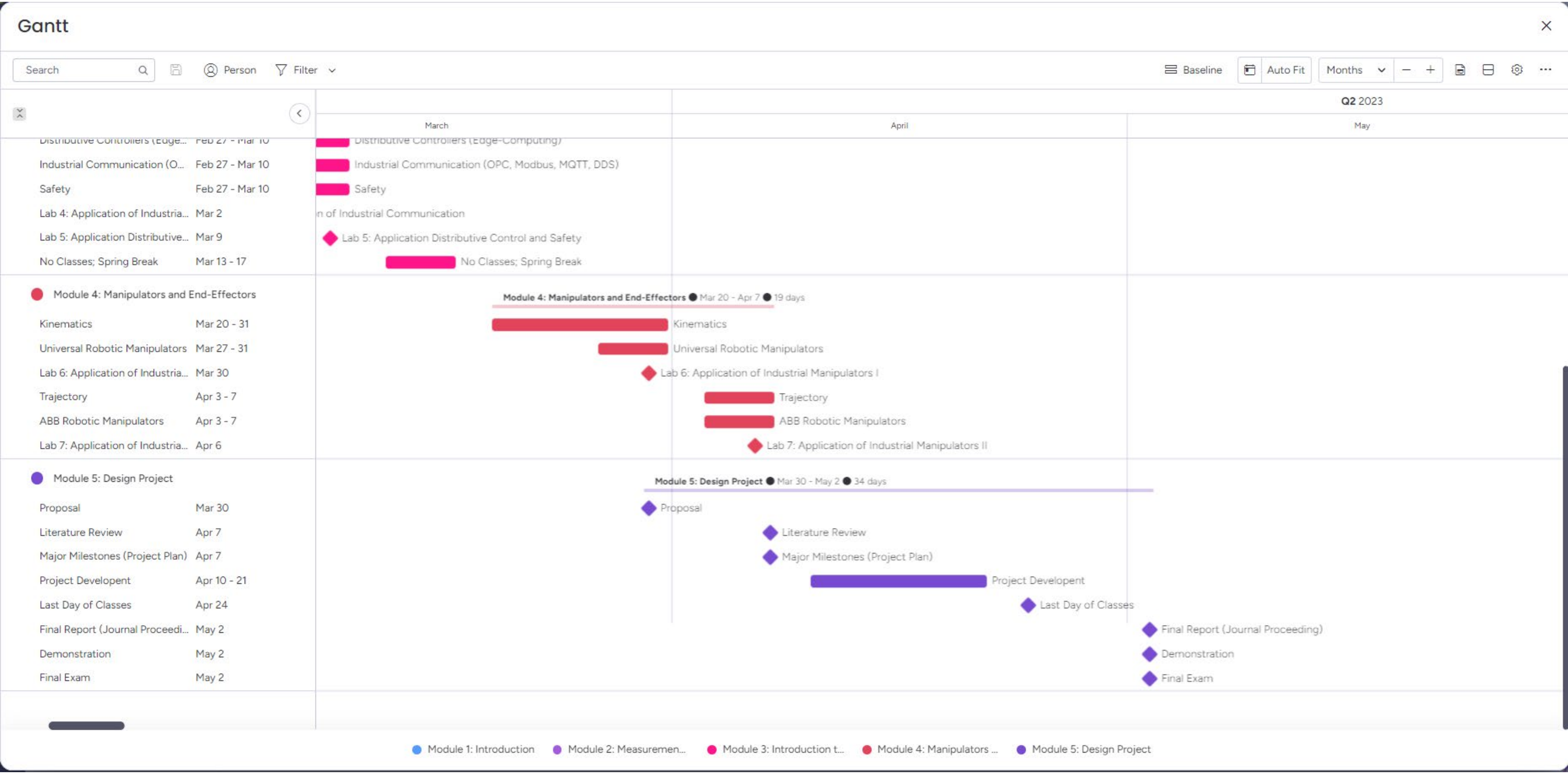
Course Updates

Performance Terminology

Sensors
- Traditional
- Modern

Design Problem


Gantt
Search
Person
Filter
Baseline
Auto Fit
Months
Q1 2023
January
February
March
Introduction Jan 9 - 13
First Day of Class Jan 9
Module 2: Measurement Systems
Sensors Jan 9 - 20
No Classes; MLK Jan 16
Data Acquistion Jan 23 - 27
Lab 1A: Allen Bradley I/O - Se... Jan 26
Actuators Jan 30 - Feb 3
Lab 1B: Allen Bradley I/O - Act... Feb 2
System Modeling Feb 6 - 10
Lab 2: System Modeling (PLC... Feb 9
Module 3: Introduction to Automatic Control
PID (Proportional Integral Deri... Feb 6 - 17
Sequence Control Feb 13 - 24
PLC (Programmable Logic Co... Feb 13 - 24
Lab 3A: Application of Seque... Feb 16
Lab 3B: Application of Sequen... Feb 23
Distributive Controllers (Edge... Feb 27 - Mar 10
Industrial Communication (O... Feb 27 - Mar 10
Safety Feb 27 - Mar 10
Lab 4: Application of Industria... Mar 2
Lab 5: Application Distributive... Mar 9
No Classes; Spring Break Mar 13 - 17
Introduction
First Day of Class
Module 2: Measurement Systems Jan 9 - Feb 10 33 days
Sensors
No Classes; MLK
Data Acquistion
Lab 1A: Allen Bradley I/O - Sensors
Actuators
Lab 1B: Allen Bradley I/O - Actuators
System Modeling
Lab 2: System Modeling (PLC+MATLAB)
Module 3: Introduction to Automatic Control Feb 6 - Mar 17 40 days
PID (Proportional Integral Derivative Controller)
Sequence Control
PLC (Programmable Logic Controller)
Lab 3A: Application of Sequence Controller
Lab 3B: Application of Sequence Controller - Feedback Control
Distributive Controllers (Edge-Computing)
Industrial Communication (OPC, Modbus, MQTT, DDS)
Safety
Lab 4: Application of Industrial Communication
Lab 5: Application Distributive Control and Safety
No Classes; Spring Break
Module 1: Introduction
Module 2: Measuremen...
Module 3: Introduction t...
Module 4: Manipulators ...
Module 5: Design Project


Gantt
Search
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Months
Q2 2023
March
April
May
Industrial Communication (O... Feb 27 - Mar 10
Safety Feb 27 - Mar 10
Lab 4: Application of Industria... Mar 2
Lab 5: Application Distributive... Mar 9
No Classes; Spring Break Mar 13 - 17
Module 4: Manipulators and End-Effectors
Kinematics Mar 20 - 31
Universal Robotic Manipulators Mar 27 - 31
Lab 6: Application of Industria... Mar 30
Trajectory Apr 3 - 7
ABB Robotic Manipulators Apr 3 - 7
Lab 7: Application of Industria... Apr 6
Module 5: Design Project
Proposal Mar 30
Literature Review Apr 7
Major Milestones (Project Plan) Apr 7
Project Developent Apr 10 - 21
Last Day of Classes Apr 24
Final Report (Journal Proceedi... May 2
Demonstration May 2
Final Exam May 2
Industrial Communication (OPC, Modbus, MQTT, DDS)
Safety
Lab 5: Application Distributive Control and Safety
No Classes; Spring Break
Module 4: Manipulators and End-Effectors Mar 20 - Apr 7 19 days
Kinematics
Universal Robotic Manipulators
Lab 6: Application of Industrial Manipulators I
Trajectory
ABB Robotic Manipulators
Lab 7: Application of Industrial Manipulators II
Module 5: Design Project Mar 30 - May 2 34 days
Proposal
Literature Review
Major Milestones (Project Plan)
Project Developent
Last Day of Classes
Final Report (Journal Proceeding)
Demonstration
Final Exam
Module 1: Introduction
Module 2: Measuremen...
Module 3: Introduction t...
Module 4: Manipulators ...
Module 5: Design Project

LABS

Lab 1A - Allen Bradley I/O – Sensors

Lab 1B – Allen Bradley I/O - Actuators

Lab 2 - System Modeling using Simulink

Lab 3A - Application of Sequence Controller

Lab 3B – Application of Sequence Controller (Feed Back Control)

Lab 4 - Application of Industrial Communication Protocol

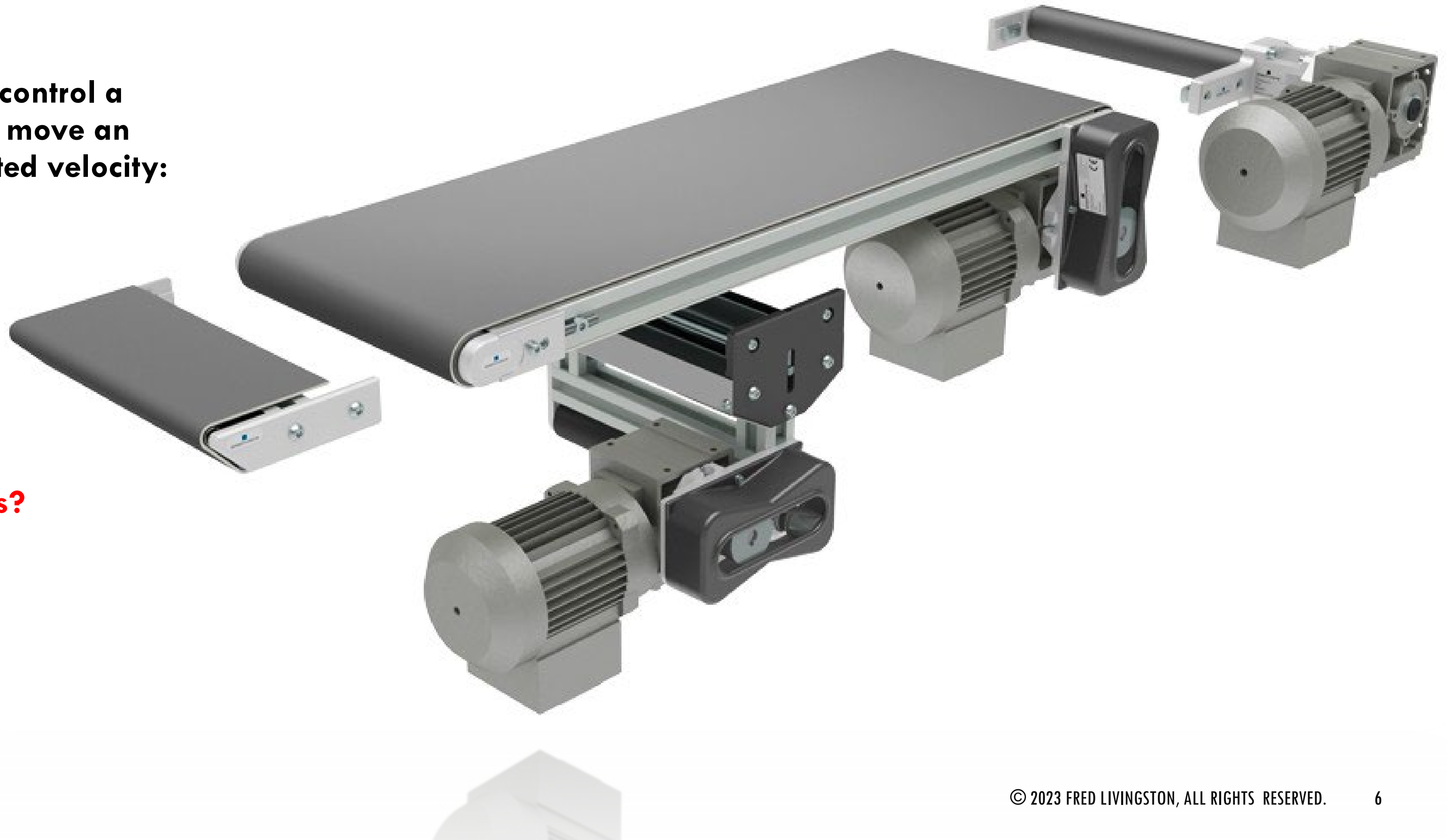
Lab 5 - Application of Disruptive Control and Safety

Lab 6 - Application of Industrial Manipulators I (UR Demo)

Lab 7 - Application of Industrial Manipulator II (ABB Demo)

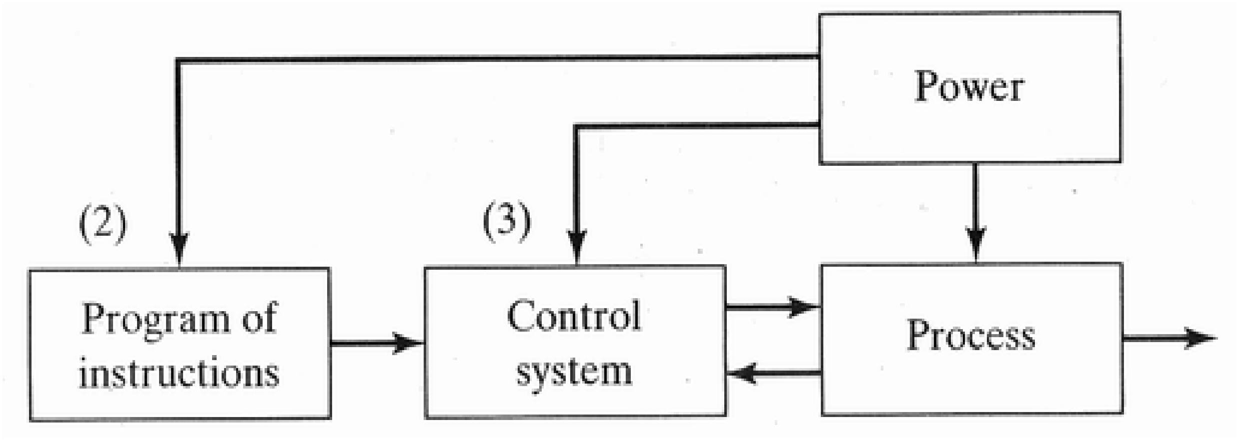
INDUSTRIAL AUTOMATION DESIGN PROBLEM

- **Task to design and control a conveyor system to move an object at user-selected velocity:**
- Power?
- Inputs?
- Outputs?
- Controls?
- **Performance Metrics?**



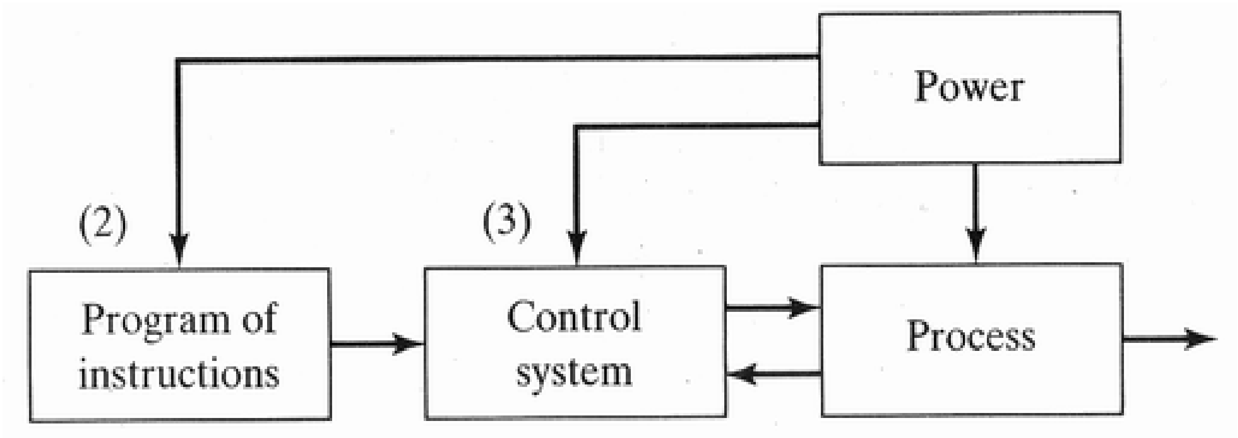
ELEMENTS OF AUTOMATION

- **Power** to accomplish the process and operate the system
- **Program of Instruction** to direct the process
- **Control Systems** to actuate the instructions

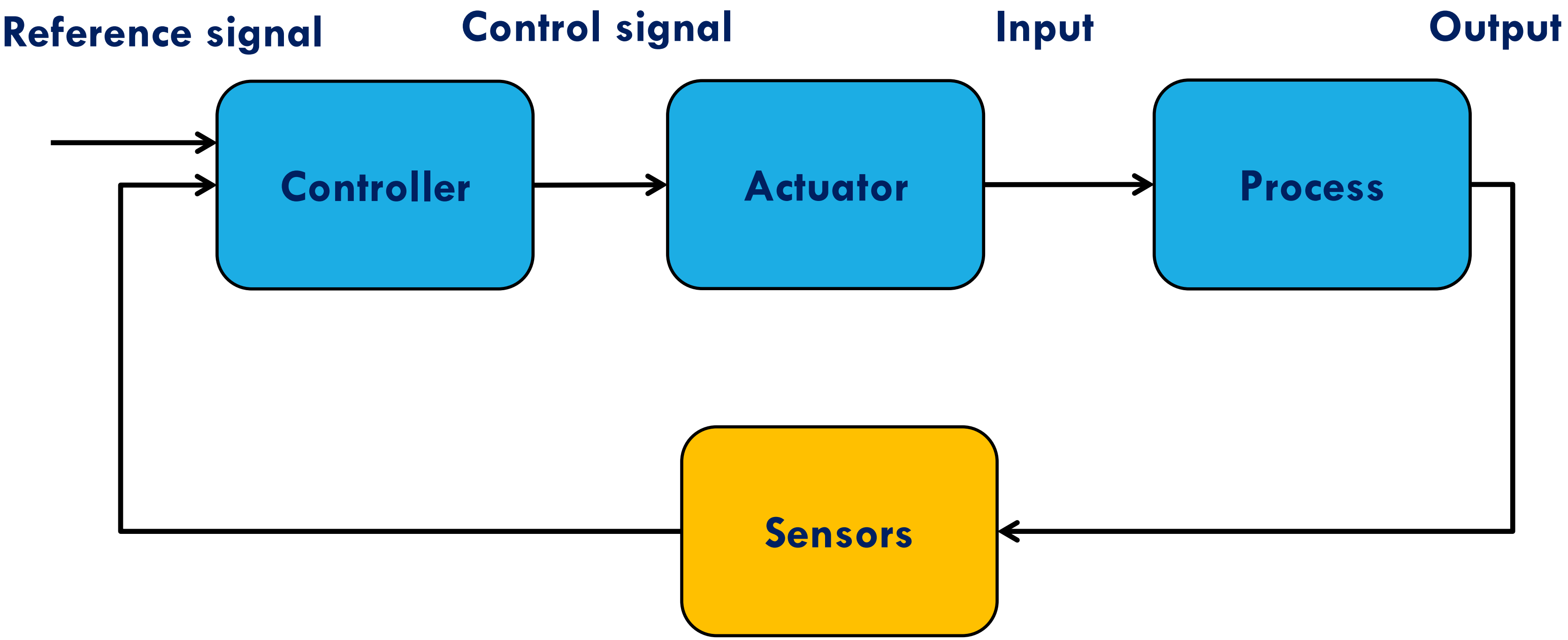


SENSOR, CONTROLLER, AND ACTUATOR

- **Sensor** is used to measure the output variable
- **Controller** compares the output with the input and makes the required adjustments
- **Actuators,** hardware devices that physically carry out the control actions



CLOSED-LOOP CONTROL SYSTEMS



PERFORMANCE TERMINOLOGY FOR AUTOMATION SYSTEMS

1. **Range**
   - The limits between which the input can vary.
2. **Error**
   - The deviation of measurements from actual values
3. **Accuracy**
   - The extent to which the value indicated by a measurement system might be wrong
4. **Sensitivity**
   - The relationship indicating how much output there is per unit input.
5. **Non-linearity error**
   - A non-linear input-output relation deviated from a linear system relation
6. **Resolution**
   - The smallest change in the input value that will produce an observable change in the output
7. **Deadband**
   - The range of input values for which there is no output

RANGE

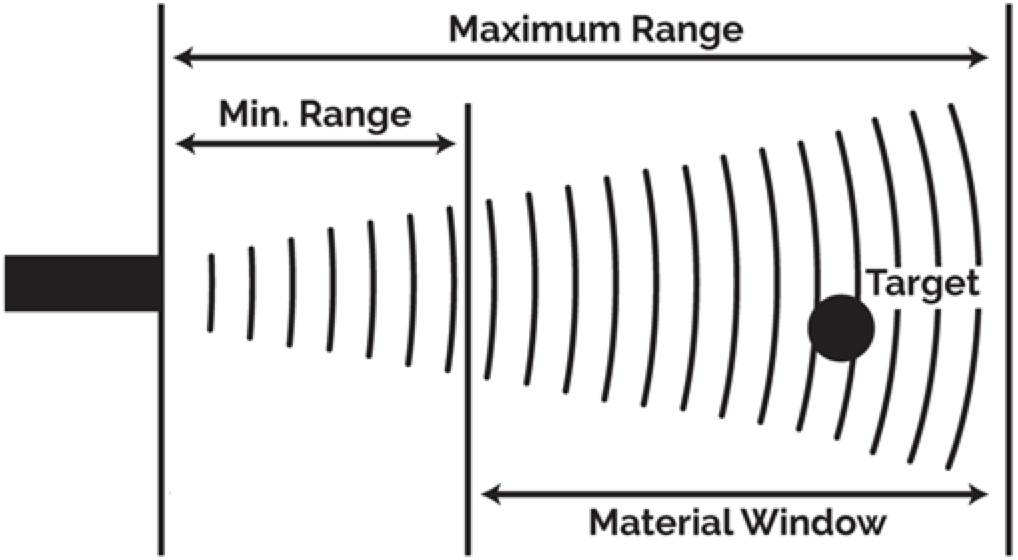
- The limits between which the input can vary.

RANGE

The full scale range defines the maximum and minimum values of the measured property

Range of lidar sensor:

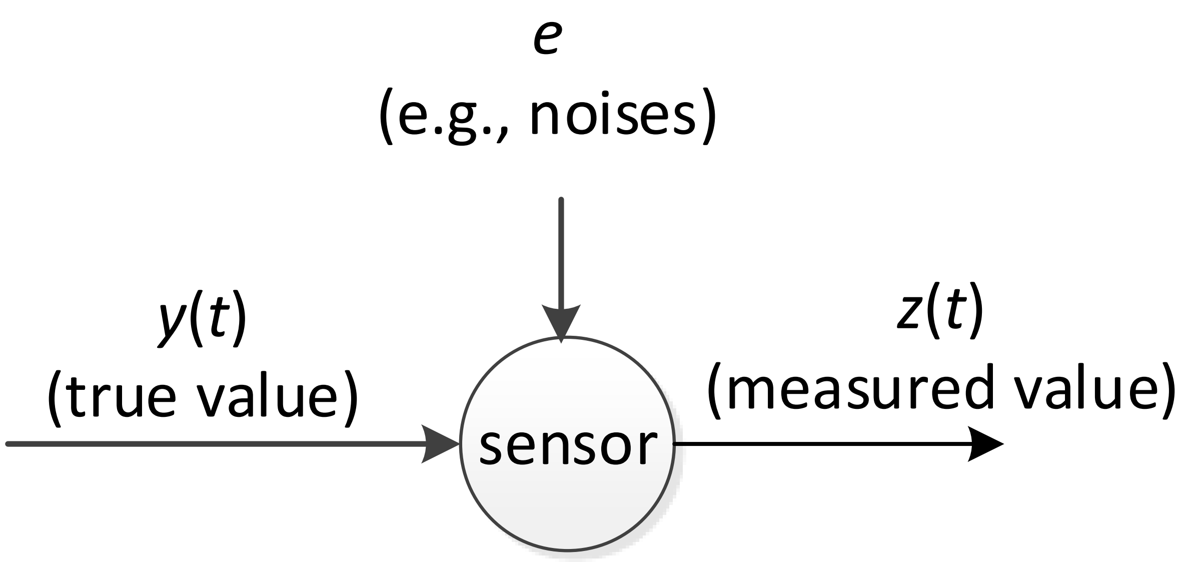
- Minimal range: around 3 cm
- Maximal range: 255 cm



ERROR

The deviation of measurements from actual values

ERROR



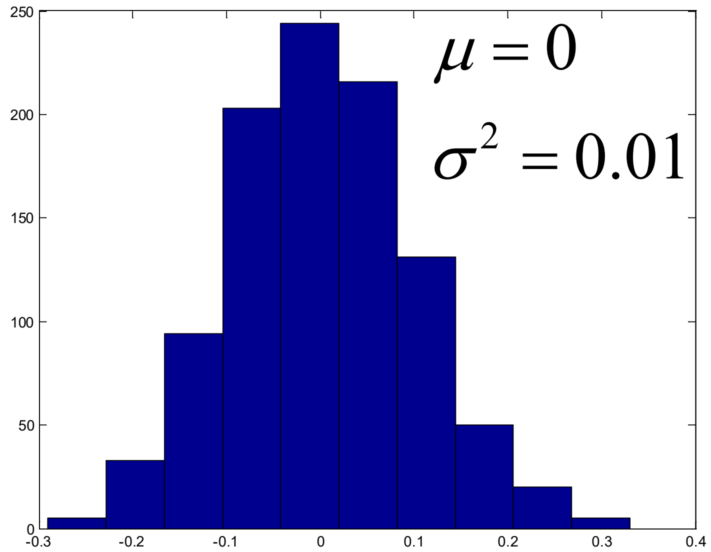
$$\boldsymbol{z} = \boldsymbol{y} + \boldsymbol{e},$$

or $$\boldsymbol{e} = \boldsymbol{z} - \boldsymbol{y}.$$

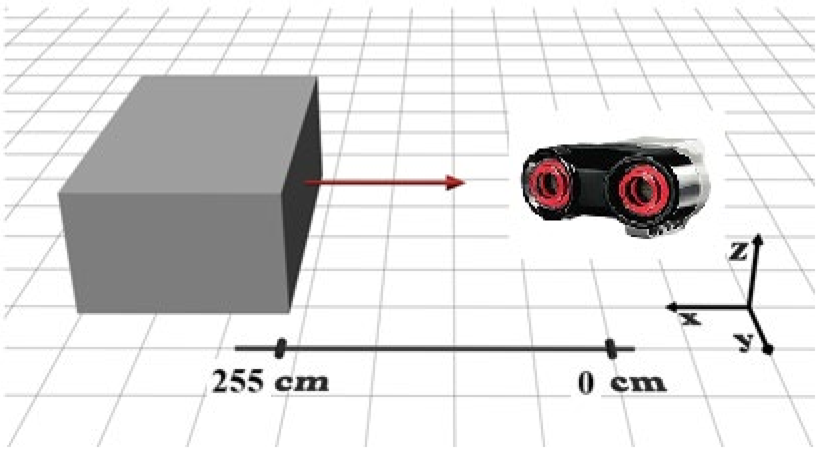
Typical measurement noise assumptions (can vary subjected to applications)

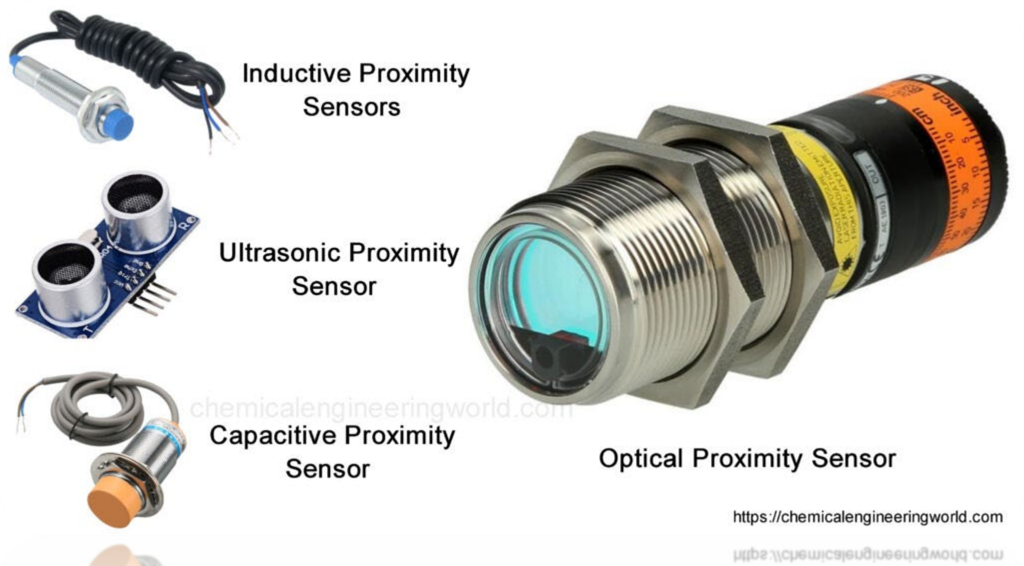
$$e \in G(\mu, \sigma^2)$$

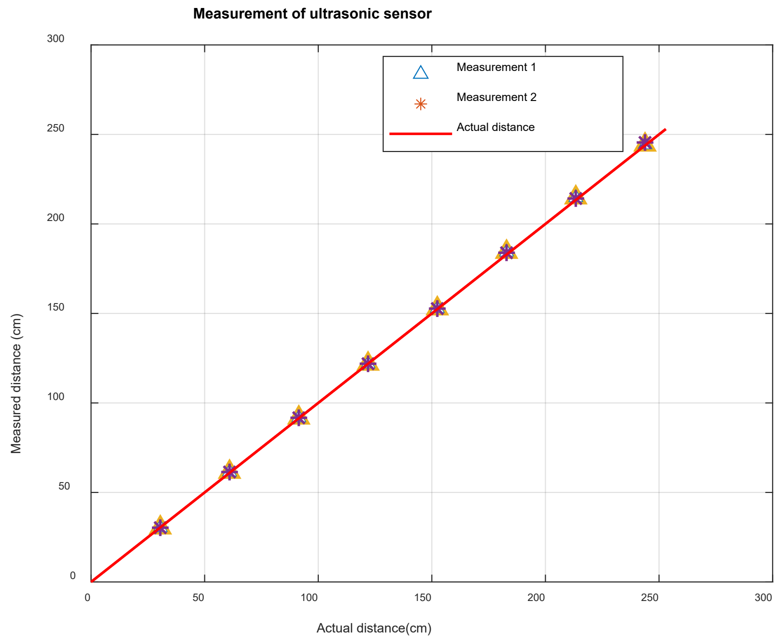
a Gaussian noise with mean μ and variance σ^2



EXAMPLE: PROXIMITY SENSOR MEASUREMENTS





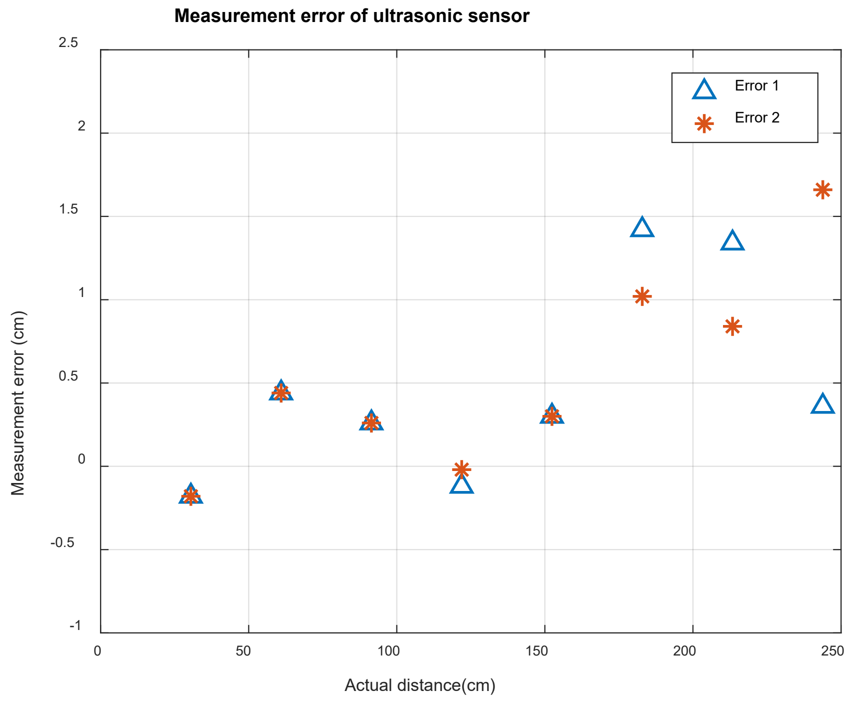


Input (u, feet/cm)	Output (y_1, cm)	Output (y_2, cm)
1 ft (30.48 cm)	30.3	30.3
2 ft (60.96 cm)	61.4	61.4
3 ft (91.44 cm)	91.7	91.7
4 ft (121.92 cm)	121.8	121.9
5 ft (152.40 cm)	152.7	152.7
6 ft (182.88 cm)	184.3	183.9
7 ft (213.36 cm)	214.7	214.2
8 ft (243.84 cm)	244.2	245.5

SENSOR MEASUREMENT

Based on the data from the previous slide, calculate the measurement error of the data

Input (u, feet/cm)	Error 1 (e_1, cm)	Error 2 (e_2, cm)
1 ft (30.48 cm)	−0.18	−0.18
2 ft (60.96 cm)	0.44	0.44
3 ft (91.44 cm)	0.26	0.26
4 ft (121.92 cm)	−0.12	−0.02
5 ft (152.40 cm)	0.3	0.30
6 ft (182.88 cm)	1.42	1.02
7 ft (213.36 cm)	1.34	0.84
8 ft (243.84 cm)	0.36	1.66



Question: What observations do you have from the data?

ACCURACY

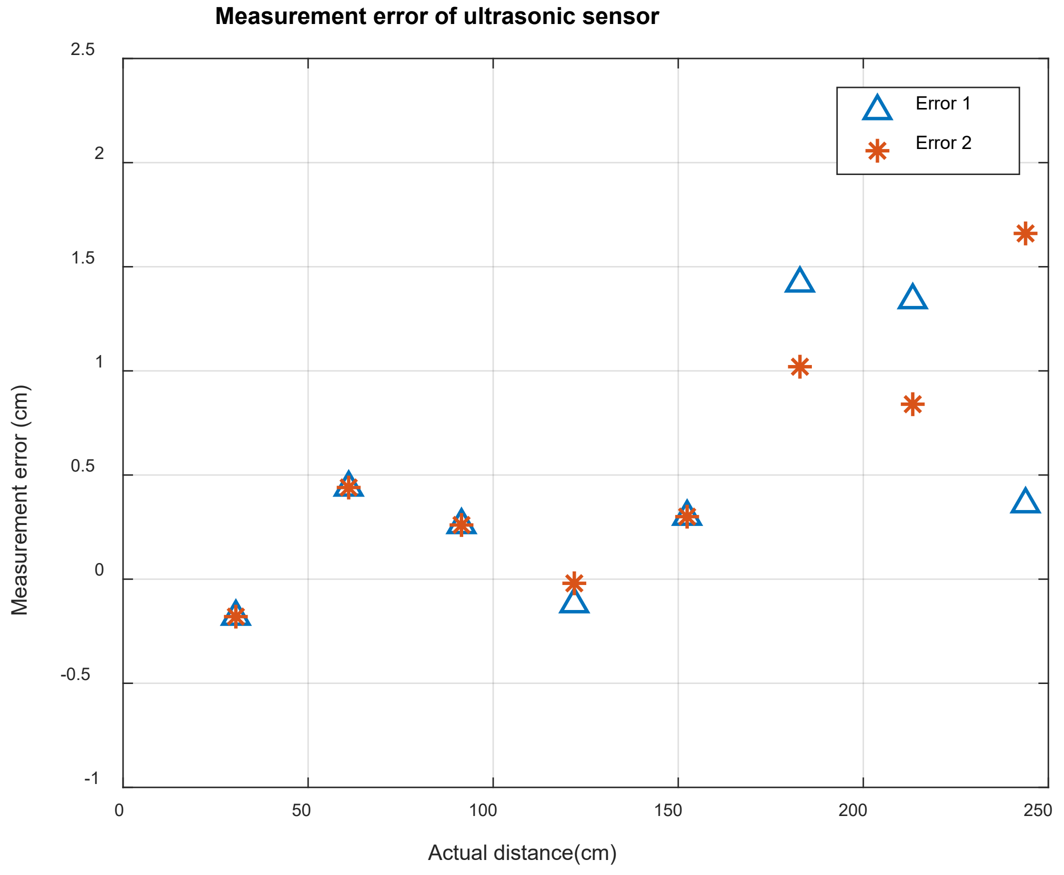
Sensor accuracy is a degree of conformity of a measured quantity to its actual value.

Example

- The ultrasonic sensors are specified to have the accuracy of ± 1 cm.
- Is the previous measurement example of ultrasonic sensor within the accuracy specification range?

Answer: No! (Assuming the measurement is exactly correct)

- The maximal error for y1 is 1.42 cm$\notin$[-1, 1] cm.
- The maximal error for y2 is 1.66 cm$\notin$[-1, 1] cm.



SENSITIVITY

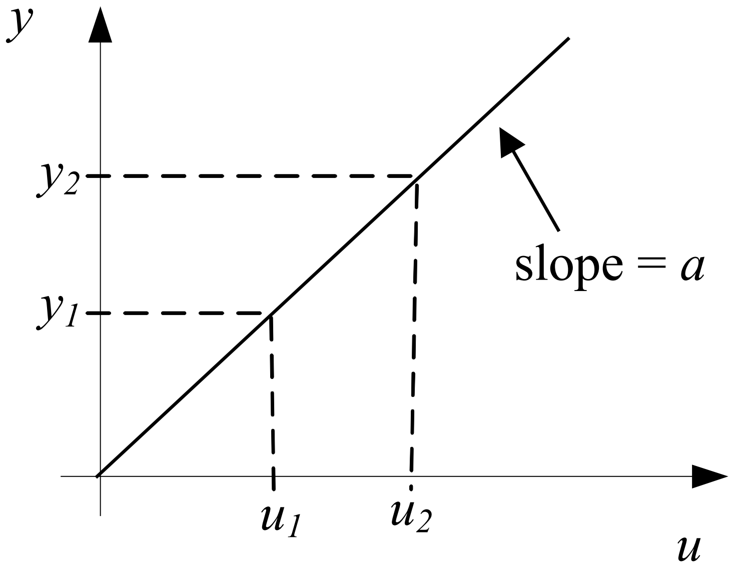
- The relationship indicating how much output there is per unit input.

SENSITIVITY

$$S\left(u^n\right) = \left.\frac{\Delta y}{\Delta u}\right|_{u^n}$$

Linear systems $y = au$

$$S = \frac{\Delta y}{\Delta u} = \frac{dy}{du} = a$$

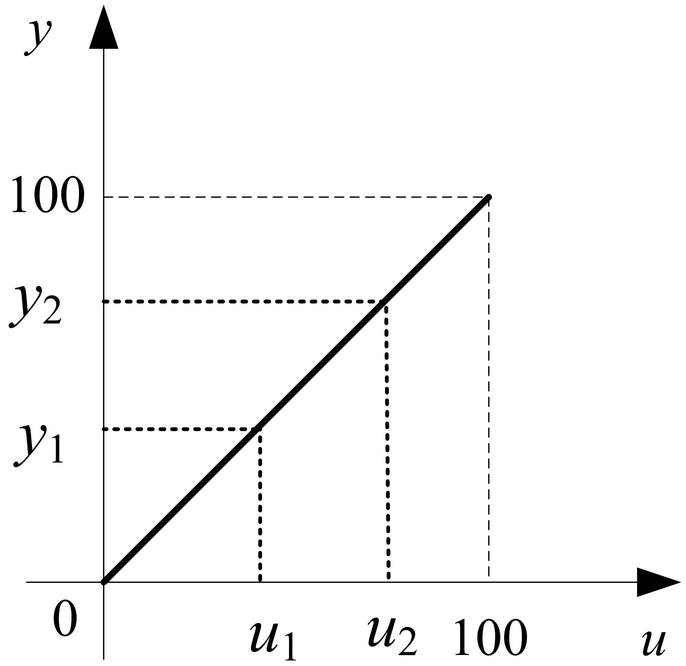


NON-LINEAR ERROR

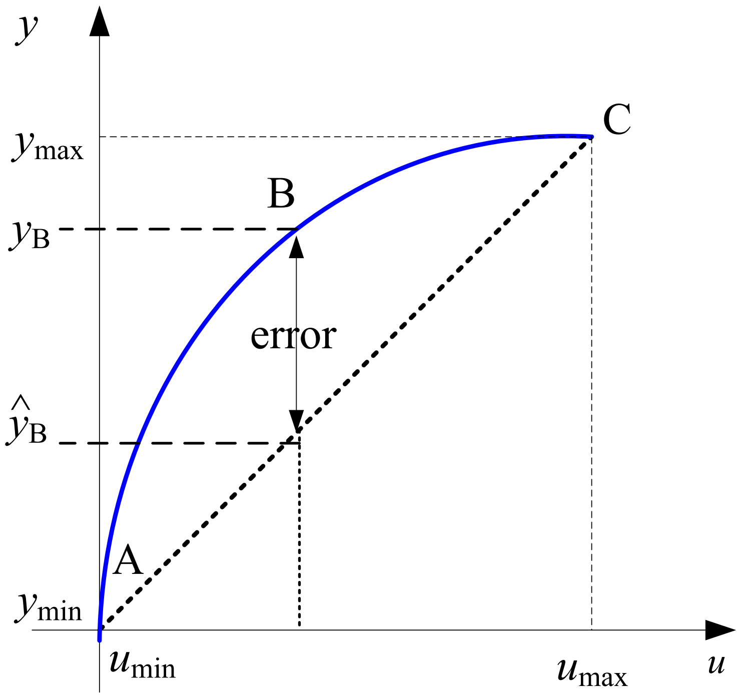
- A non-linear input-output relation deviated from a linear system relation

NON-LINEARITY ERROR

The input-output relation of a linear system.

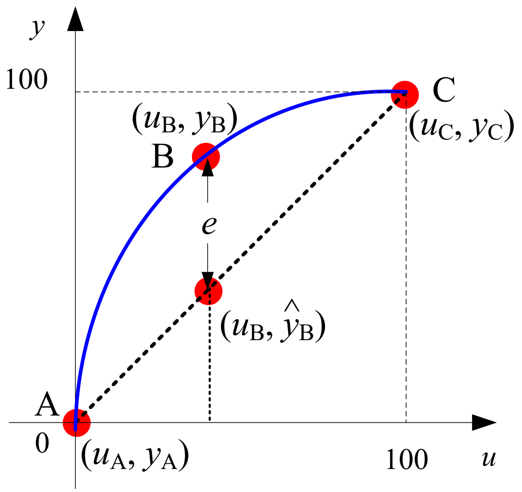


A nonlinear input-output relation deviated from a linear system relation

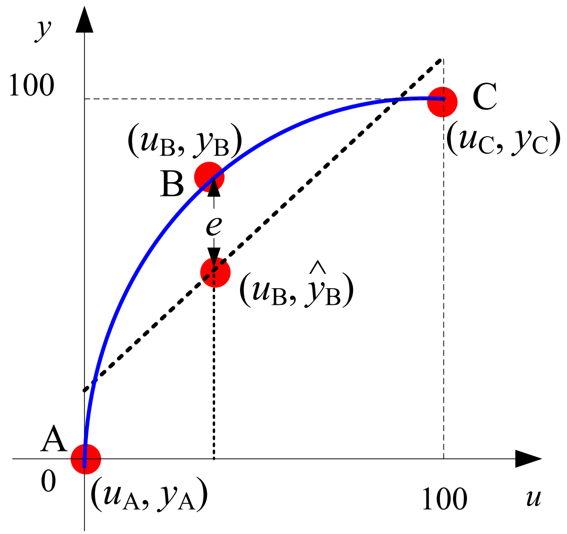


THREE NON-LINEARITY ERROR MEASURES

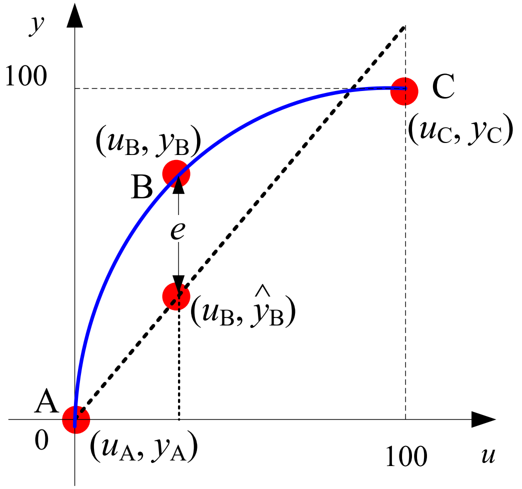
End-to-end linear interpolation



Least-square-fit

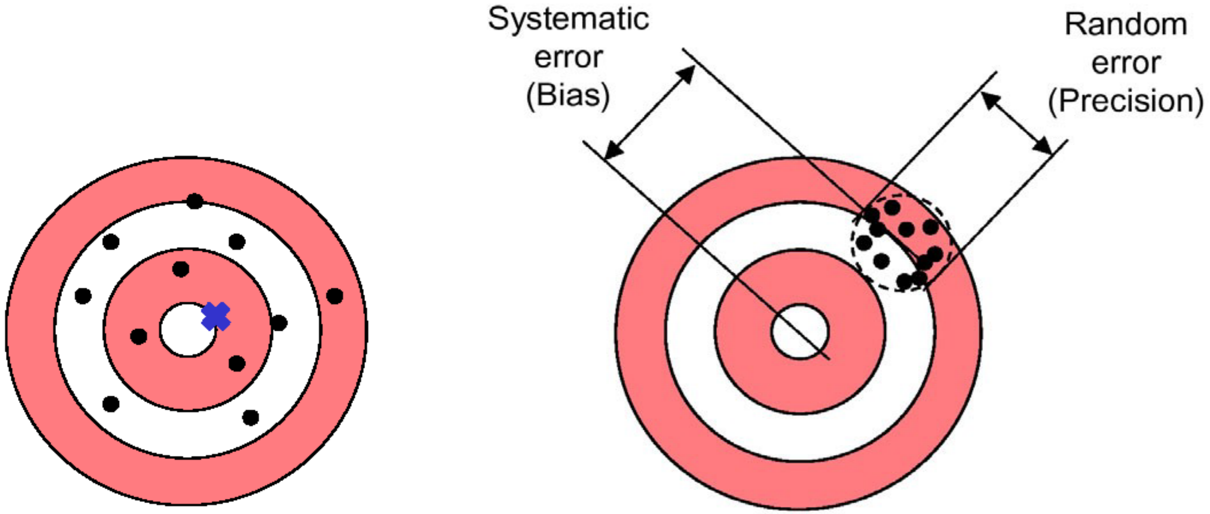


Least-square-fit with specific operating constraints



END OF REVIEW

SENSORS FEATURES



- For above two sensors' output, which one gives better accuracy?
- Which one gives better precision?

WORKED EXAMPLE (FUTURE LAB)

The table below gives two sets of measurements (y1 and y2) of sensors. The sensors needs to detect an object withing 122 cm.

Input (u, feet/cm)	Output (y_1, cm)	Output (y_2, cm)
1 *ft* (30.48 cm)	30.3	30.3
2 *ft* (60.96 cm)	61.4	61.4
3 *ft* (91.44 cm)	91.7	91.7
4 *ft* (121.92 cm)	121.8	121.9
5 *ft* (152.40 cm)	152.7	152.7
6 *ft* (182.88 cm)	184.3	183.9
7 *ft* (213.36 cm)		214.2
8 *ft* (243.84 cm)		245.5

1. What is the maximal error of measurement set 1 and the corresponding actual distance?
2. What is the maximal error of measurement set 2 and the corresponding actual distance?
3. What is the range of each sensor?
4. Are these sensor linear?
5. What is the best sensor for this application based on performance?

WORKED EXAMPLE (FUTURE LAB)

Input (u, feet/cm)	Output (y_1, cm)	Output (y_2, cm)
1 *ft* (30.48 cm)	30.3	30.3
2 *ft* (60.96 cm)	61.4	61.4
3 *ft* (91.44 cm)	91.7	91.7
4 *ft* (121.92 cm)	121.8	121.9
5 *ft* (152.40 cm)	152.7	152.7
6 *ft* (182.88 cm)	184.3	183.9
7 *ft* (213.36 cm)	184.3	214.2
8 *ft* (243.84 cm)	184.3	245.5

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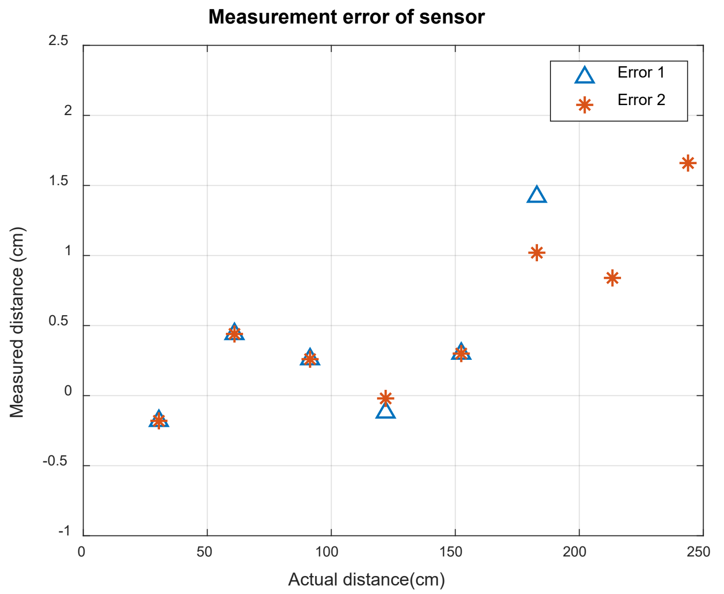
sensor_nonlinear_error.m

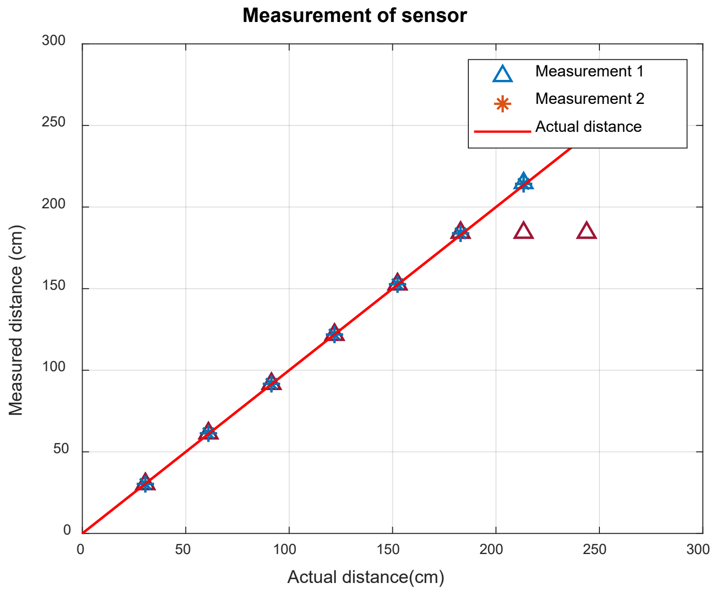
```
% ISE 589 range sensor measurement
% Fred Livingston, January 19, 2022

% range sensor, nonlinearity error
u =30.48*[1:8];
y1 = [30.3 61.4 91.7 121.8 152.7 184.3 184.3 184.3];
y2 = [30.3 61.4 91.7 121.9 152.7 183.9 214.2 245.5];
e1 = y1 - u;
e2 = y2 - u;


figure(1)       % error information
plot(u, e1, '^', u, e2, '*', 'MarkerSize',8, 'Linewidth',1.2);
ylim([-1, 2.5]);
grid on;
xlabel('Actual distance(cm)', 'fontsize', 12.5);
ylabel('Measured distance (cm)', 'fontsize', 12.5);
title('Measurement error of sensor','fontsize', 14);
h1 = legend('Error 1', 'Error 2' );
set(h1, 'fontsize', 11);

figure(2)
plot(u, y1, '^', u, y2, '*', 'MarkerSize',8, 'Linewidth',1.2)
hold on;
u0 = 30.48*[0:0.1:8.37];
y0 = u0;
plot(u0, y0, 'r', 'MarkerSize',8, 'Linewidth',1.2);
grid on;
xlabel('Actual distance(cm)', 'fontsize', 12.5);
ylabel('Measured distance (cm)', 'fontsize', 12.5);
title('Measurement of sensor','fontsize', 14);
h2 = legend('Measurement 1', 'Measurement 2', 'Actual distance' );
set(h2, 'fontsize', 11);
```

WORKED EXAMPLE (FUTURE LAB)

The table below gives two sets of measurements (y1 and y2) of sensors. The sensors needs to detect an object withing 122 cm.

1. What is the maximal error of measurement set 1 and the corresponding actual distance?
2. What is the maximal error of measurement set 2 and the corresponding actual distance?
3. What is the range of each sensor?
4. Are these sensor linear?
5. What is the best sensor for this application based on performance?





STATIC AND DYNAMIC CHARACTERISTICS

Response time of different thermometers

Infrared thermometer

- Fluke 561 Infrared Thermometer
- Response time: <500 milliseconds
- Resolution: 0.1 °C
- Cost: $199.00

https://www.coleparmer.com/i/fluke-561-infrared-thermometer-hvac-pro-model/3563941?PubID=UX&persist=true&ip=no&gclid=Cj0KCQjwv_fKBRCGARIsAL6R6eigQ9nzpWPPFuCwITG9FzwhNY73mLAn06d8K3b3si-78pWAI47CRGwaArSuEALw_wcB

Analog thermometer

- Fridge / Freezer Thermometer
- Response time: ~ 60 seconds
- Resolution: 1 °C
- Cost: $4.00

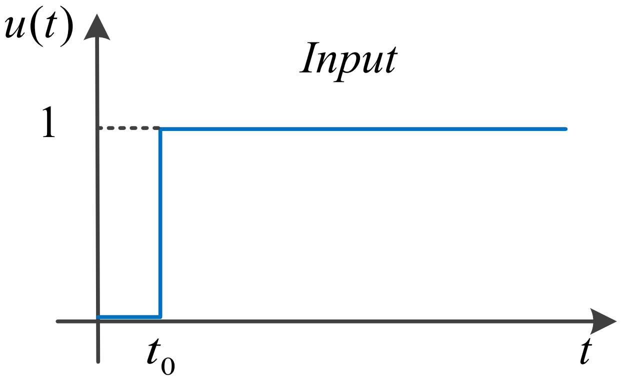
https://www.atp-instrumentation.co.uk/analogue-fridge-freezer-thermometer-with-hook.html

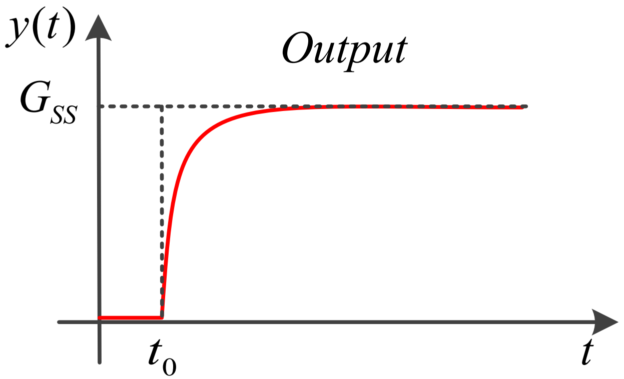
TIME RESPONSE OF A SENSOR

The first order differential equation is:

$$a_1 \frac{dy(t)}{dt} + a_0 y(t) = b_1 u(t)$$

Where u(t) is the input, y(t) is the output of the system.





$$u(t) = \begin{cases} 1, & t \geq t_0 \\ 0, & 0 \leq t < t_0 \end{cases}$$

$$y(t) = \frac{b_1}{a_0}\left(1 - e^{-\frac{t}{\tau}}\right), t \geq t_0$$

Steady State Gain $G_{ss} = \frac{b_1}{a_0}$,

Time Constant $\tau = \frac{a_1}{a_0}$

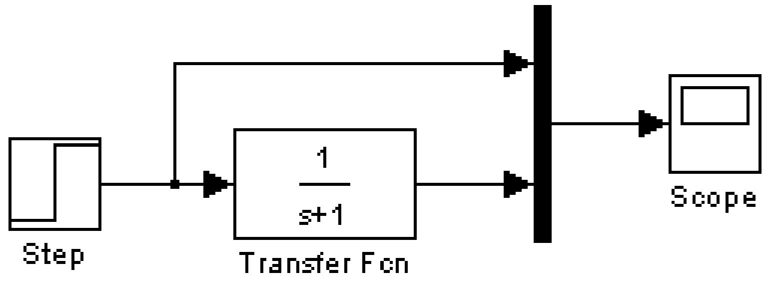
TIME MEASURES

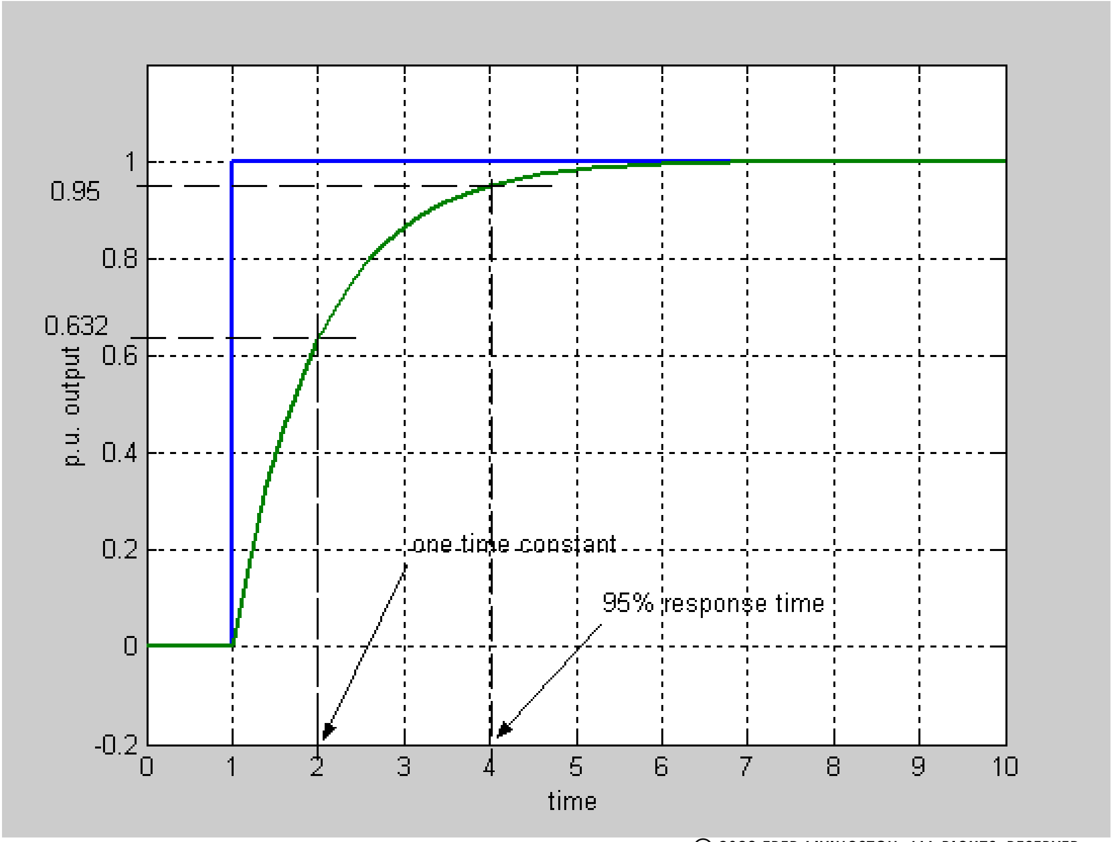
Time Constant

Response Time

Rise Time

Settling Time

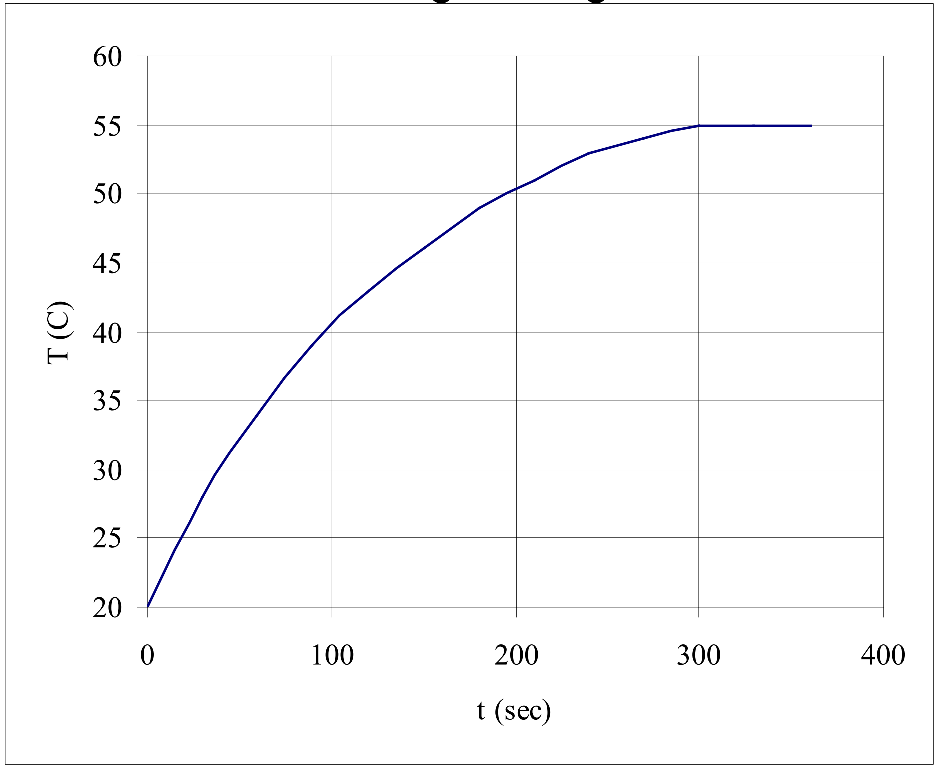




WORKED EXAMPLE: TIME MEASURE

Time (s)	0	30	60	90	120	150	180	210	240	270	300	330	360
Temp (°C)	20	28	34	39	43	46	49	51	53	54	55	55	55

Consider the following data which indicates how a thermometer reading changed with time by plunging into a liquid at time t = 0.



What is the 95% response time?

WORKED EXAMPLE: TIME MEASURE

Time (s)	0	30	60	90	120	150	180	210	240	270	300	330	360
Temp (°C)	20	28	34	39	43	46	49	51	53	54	55	55	55

Consider the following data which indicates how a thermometer reading changed with time by plunging into a liquid at time t = 0.

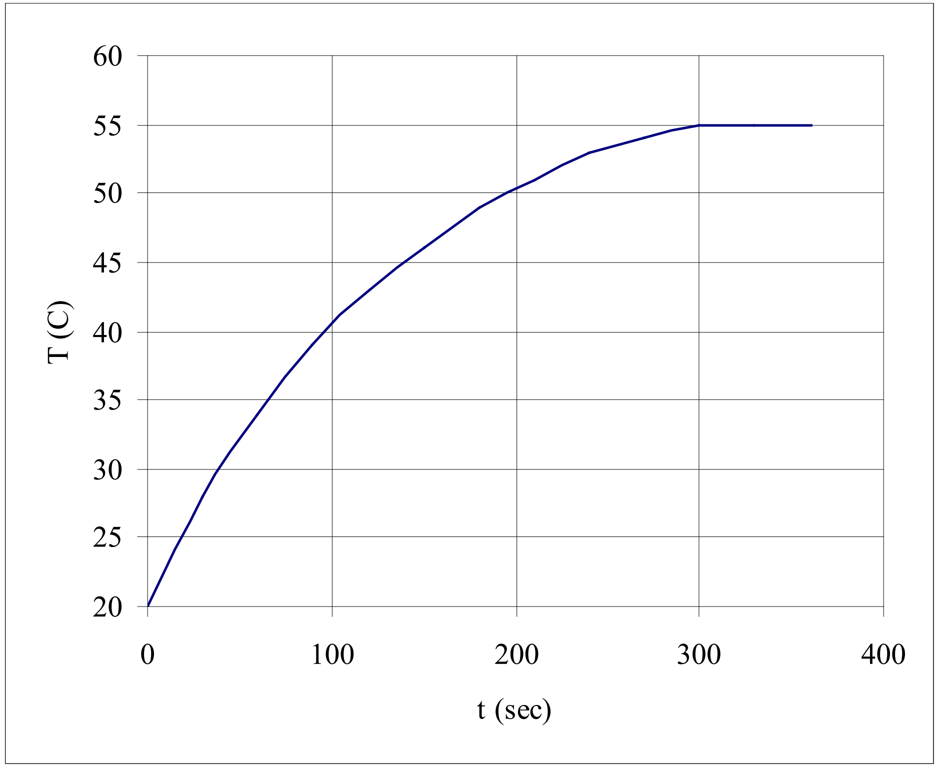
- What is the 95% response time?

The steady-state value is 55°C and so, since 95% of 55 is 53.25°C:

Answer:

$$T_{0.95} = 20 + 0.95 \times (55 - 20) = 53.25$$

the 95% estimated response time is about 247.5 s.

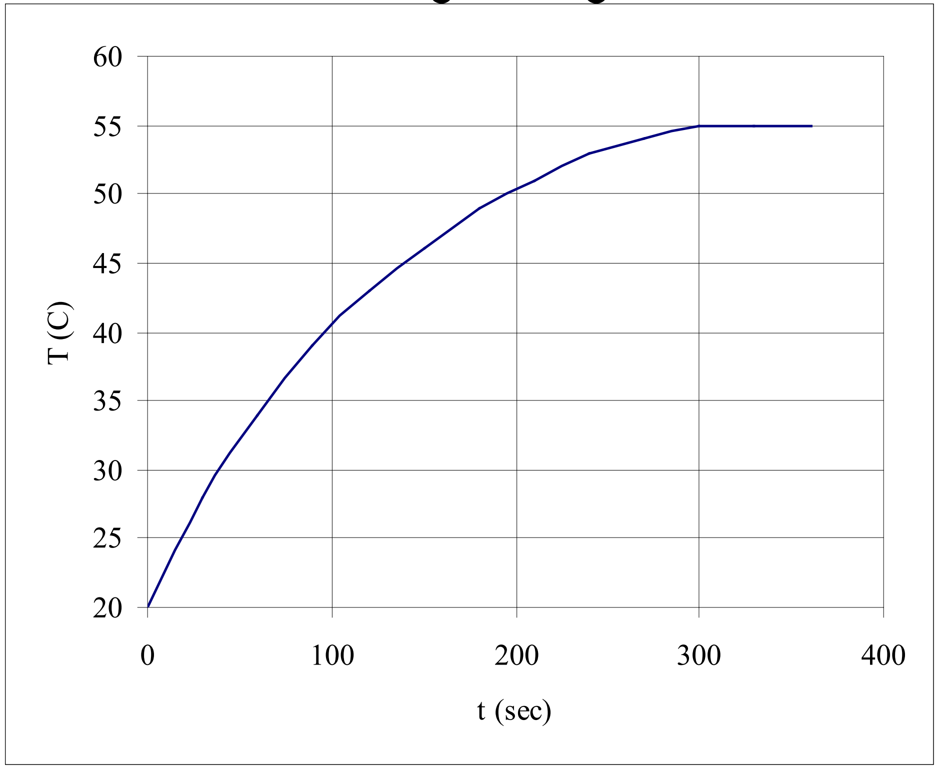


WORKED EXAMPLE: TIME MEASURE

Time (s)	0	30	60	90	120	150	180	210	240	270	300	330	360
Temp (°C)	20	28	34	39	43	46	49	51	53	54	55	55	55

Consider the following data which indicates how a thermometer reading changed with time by plunging into a liquid at time t = 0.

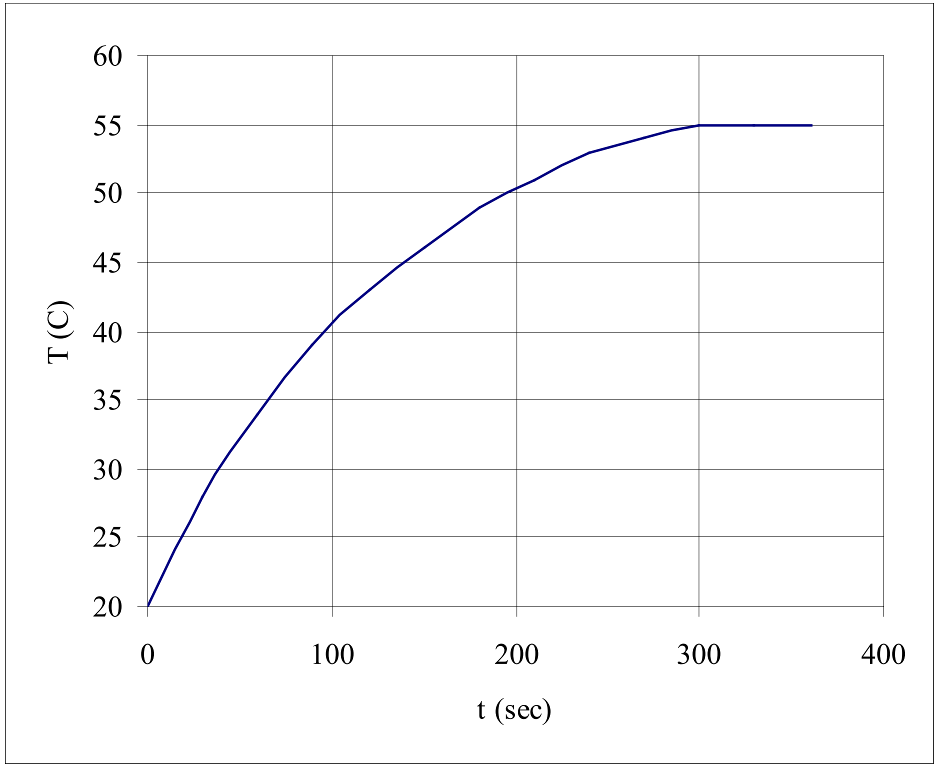
What is the 63.2% response time?



WORKED EXAMPLE: TIME MEASURE

Time (s)	0	30	60	90	120	150	180	210	240	270	300	330	360
Temp (°C)	20	28	34	39	43	46	49	51	53	54	55	55	55

Consider the following data which indicates how a thermometer reading changed with time by plunging into a liquid at time t = 0.



- What is the 95% response time?

The steady-state value is 55°C and so, since 63.2% of 55 is 42.225°C:

Answer:

$$T_{0.632} = 20 + 0.632 \times (55 - 20) = 42.225$$

the 63.2% estimated response time is about 42.12 s.

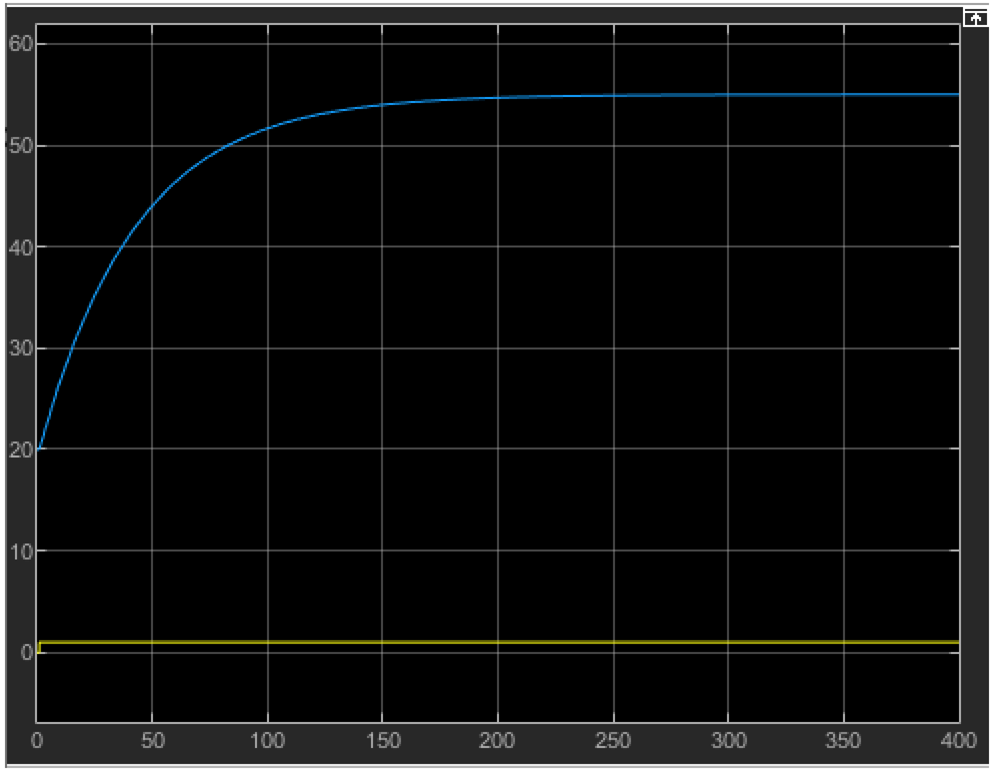
1ST ORDER SYSTEM RESPONCE

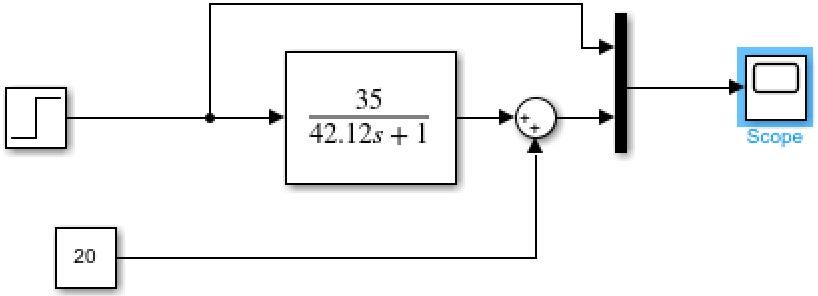
Useful for mathematical modeling a real-system response

Applications

Developing Control Algorithms

Estimate/Predicting Output





RESOLUTION

Definition

- The smallest change in the input value that will produce an observable change in the output.

RESOLUTION

Definition

- The smallest change in the input value that will produce an observable change in the output.

Example – (light) sensor

- The output voltage from (light) sensor can be digitized to have a value between 0-1023
- For a sensor giving a digital output the smallest change in output is N bits. Then the resolution is generally expressed as
- Resolution = OutputRange/2^N.
-

DEADBAND/DEADTIME

Deadband

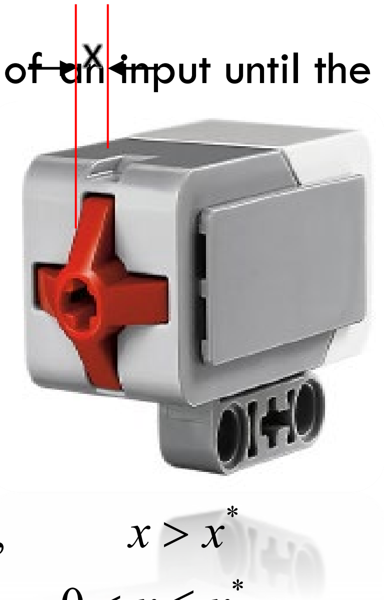
- The range of input values for which there is no output

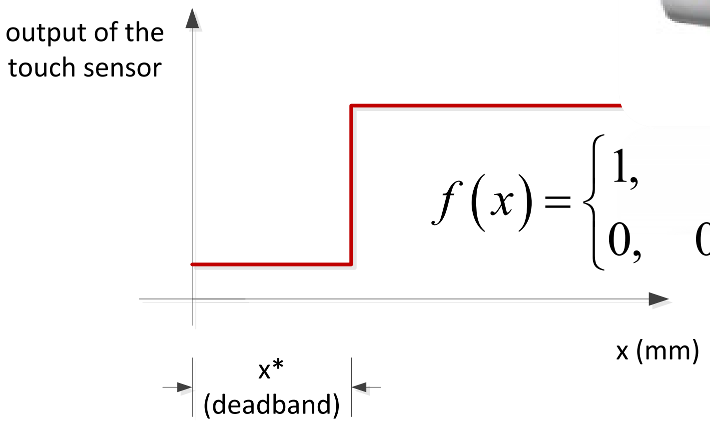
Deadtime

- The length of time from the application of an input until the output to respond and change

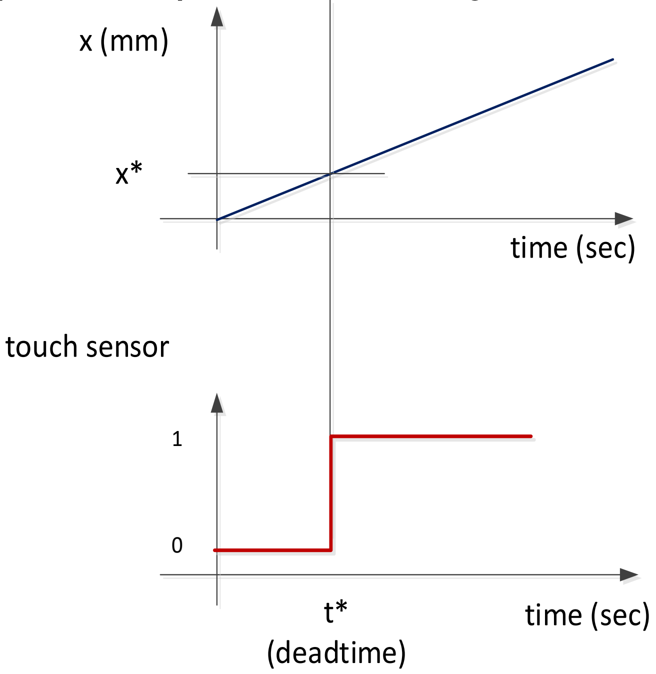
Example:

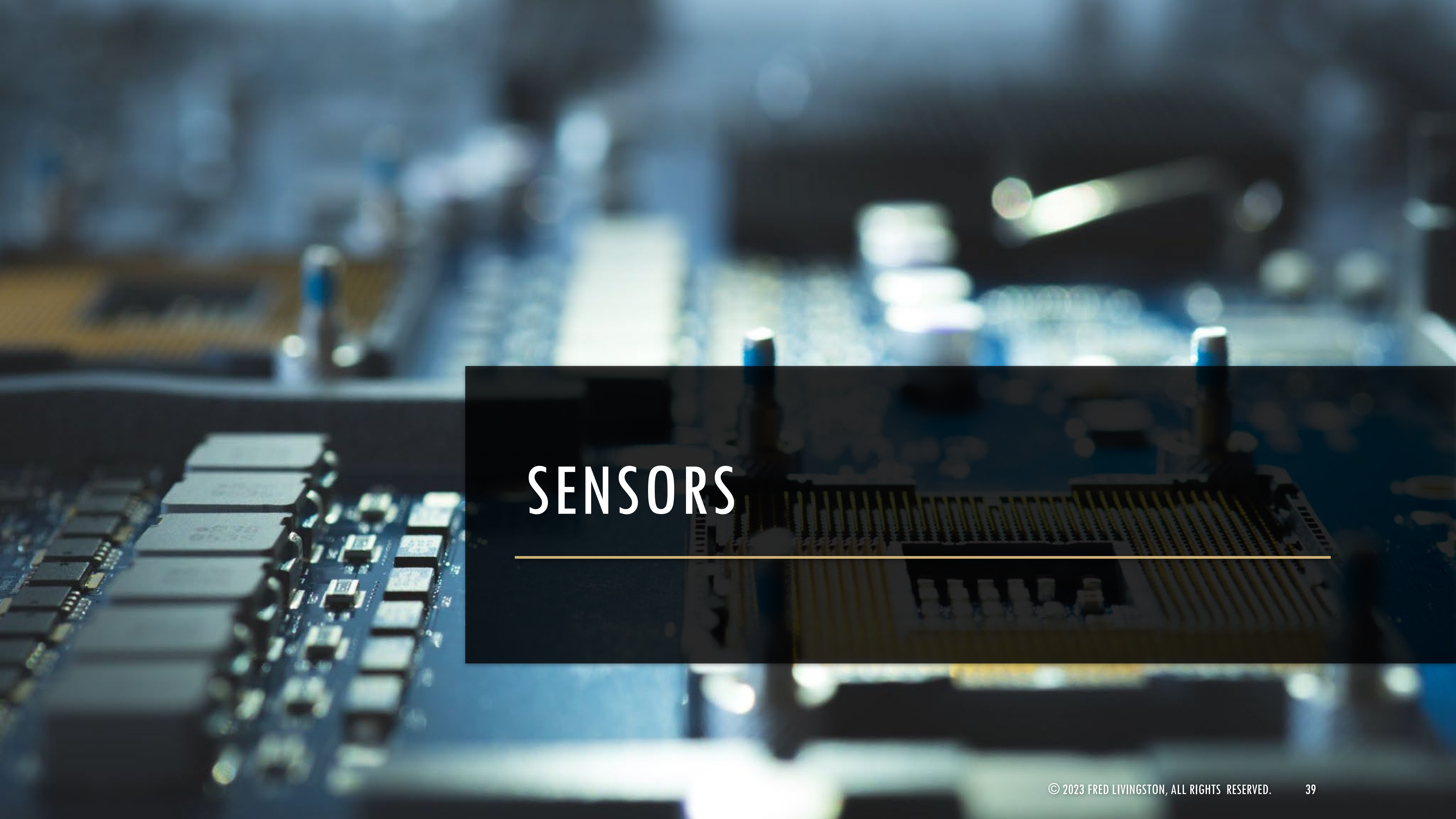
- Touch sensor





$$f(x)=\begin{cases}1, & x>x^{*}\\ 0, & 0<x\le x^{*}\end{cases}$$

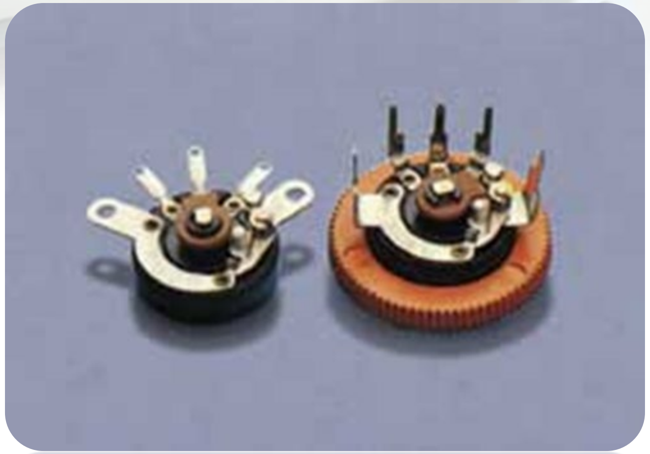


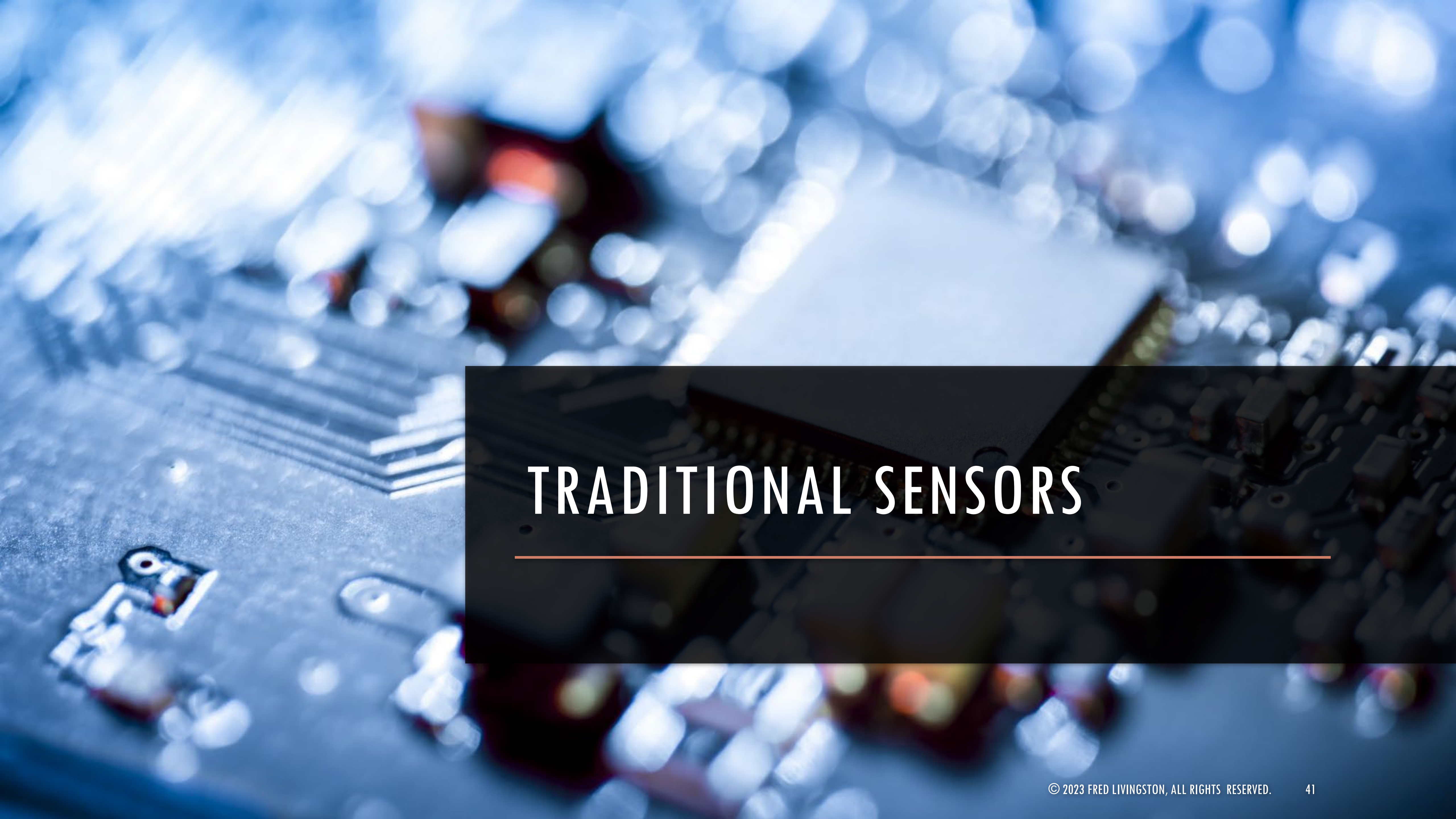


SENSORS

CLASSIFICATION OF SENSORS

- Based on converted signal types
  - Analog
  - Digital
- Based on method of detection
  - Contact
  - Non-contact
  - Process
- Important information of a sensor:
  - Signal type: Analog, Digital
  - Measure and basic sensing principle
  - Performance Characteristics





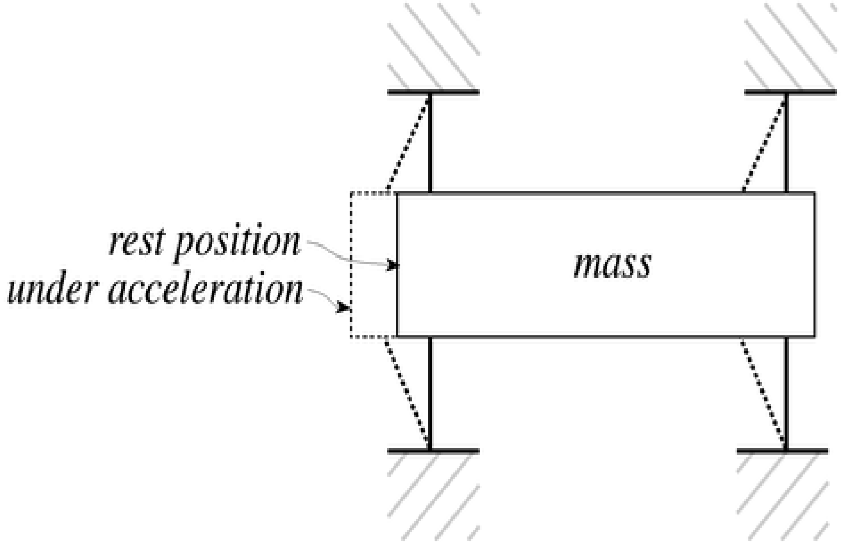
TRADITIONAL SENSORS

DIFFERENT TYPES OF SENSORS

- Accelerometer
- Bimetallic switch
- DC tachometer
- Float transducer
- Limit switch (mechanical)
- Photoelectric sensor
- Potentiometer
- Strain gage
- Thermocouple
- Ammeter
- Manometer
- Optical encoder
- Piezoelectric transducer
- Proximity switch
- Photoelectric sensor
- Ultrasonic range sensor

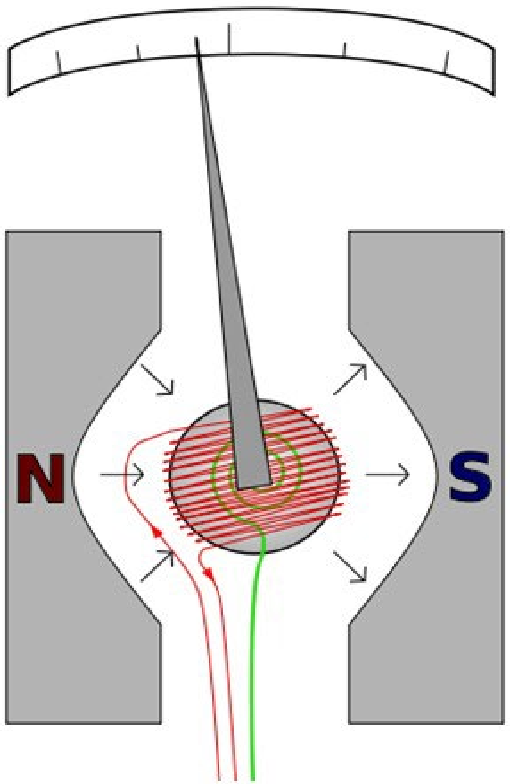
ACCELEROMETER

- An analog device used to measure vibration and shock.



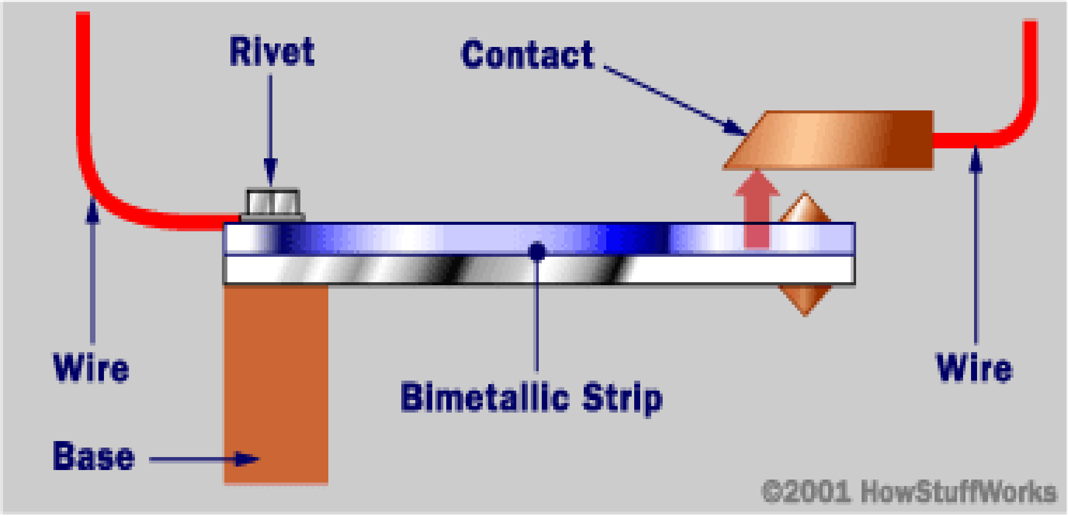
AMMETER

- An analog device that measures the strenath of an electrical current



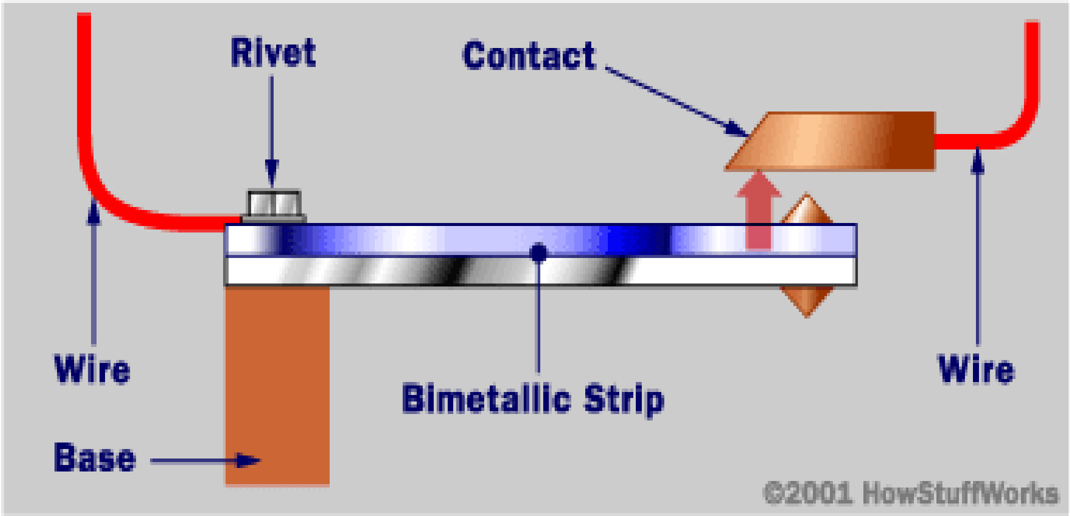
BIMETALLIC SWITCH

- A binary switch that uses bimetallic coil to open and close electrical contact as a result of temperature change
- Bimetallic coil consists of town metal strips of different thermal expansion coefficients bonded together



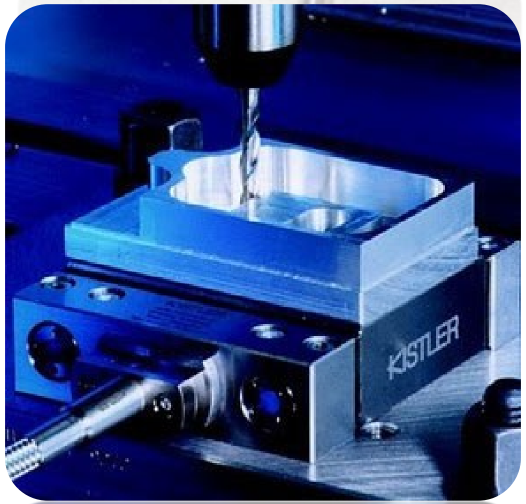
BIMETALLIC SWITCH

- Different metals expand at different rates as they warm up



DC TACHOMETER AND DYNAMOMETER

- DC Tachometer
  - An analog device consisting of dc generator that produces electrical voltage proportional to rotational speed
- Dynamometer
  - An analog device used to measure force, power, or torque. Can be based on various physical phenomena (e.g., strain gage, piezoelectric effect)

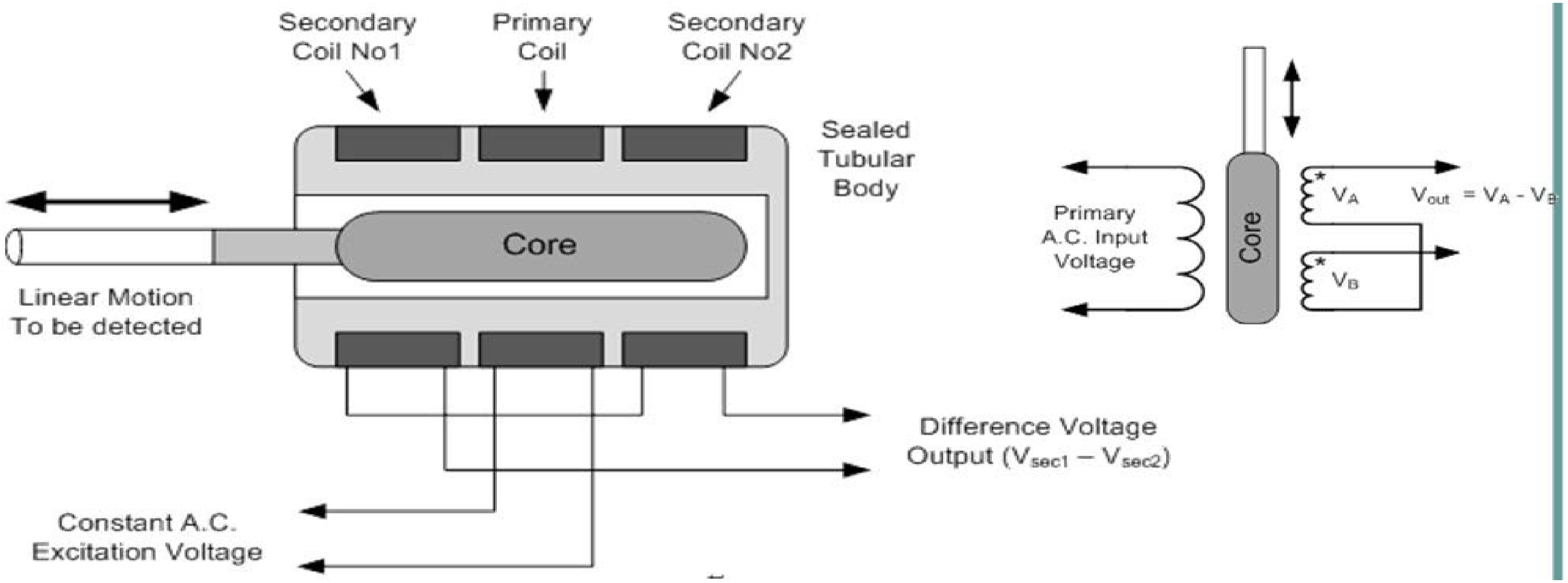


LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

- An analog position sensor consisting of primary coil opposite to two secondary coils separated by a magnetic core. When primary coil is energized, induced voltage in secondary coil is a function of core position. Can also be adapted to measure force or pressure when connected with a spring

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

- When the iron core slides through the transformer, a certain number of coil windings are affected by the proximity of the sliding core and thus generate a unique voltage output



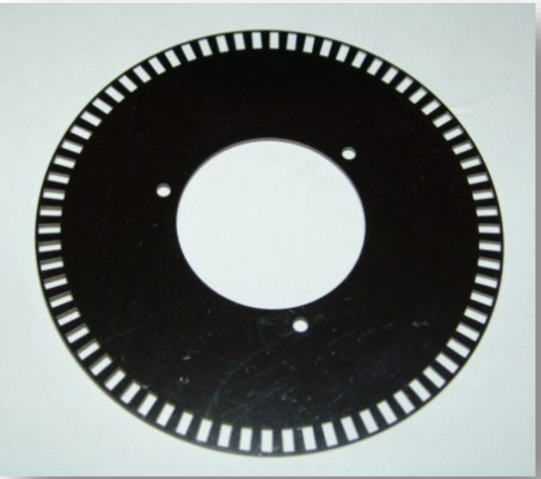
LIMIT SWITCH

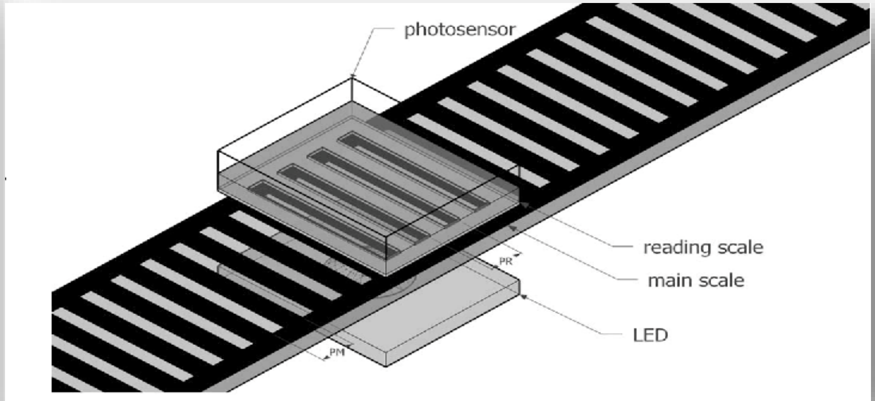
- A binary contact sensor in which lever arm or pushbutton closes (or opens) an electrical contact

ENCODERS

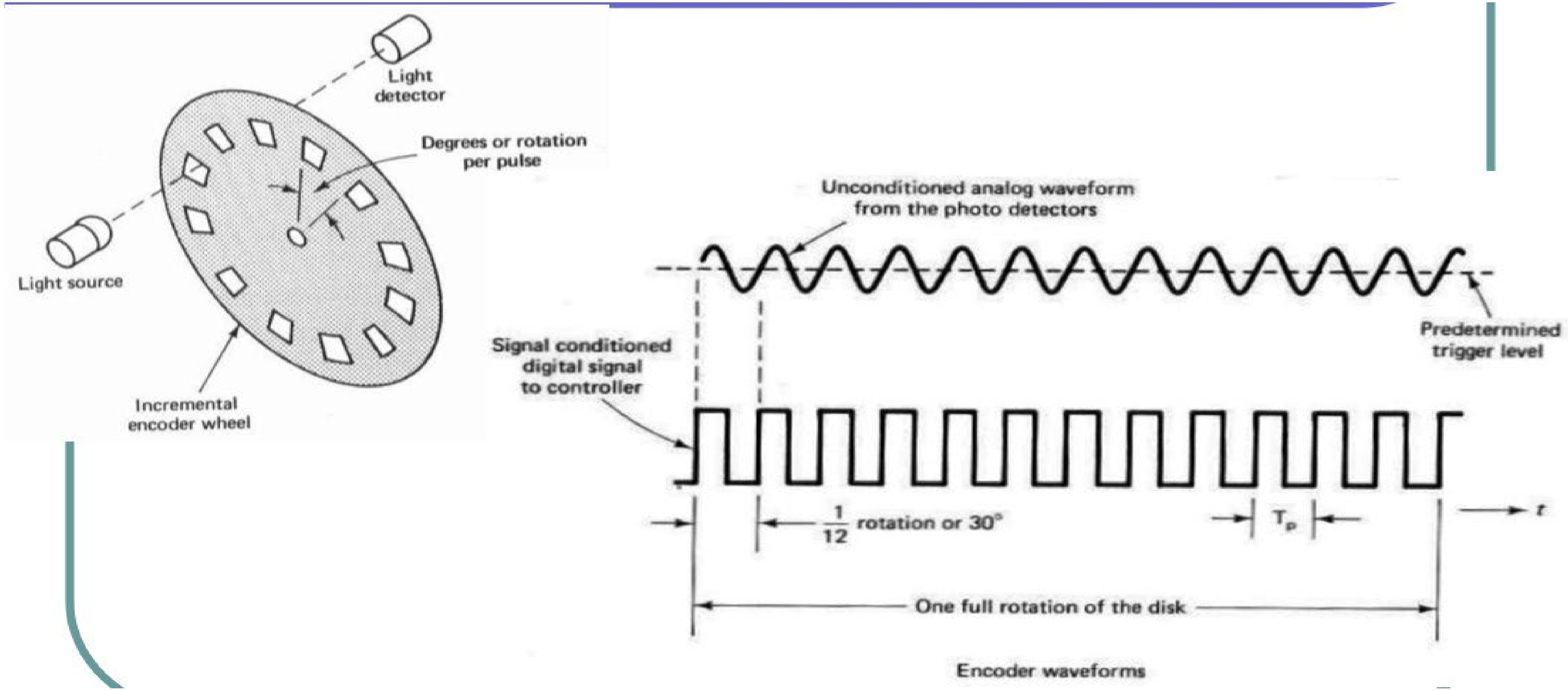
OPTICAL ENCODER

- A digital device used to measure position or speed
- It consists of a slotted disk separating a light source from a photocell. As disk rotates, photocell senses light through slots as a series of pulses
- Number and frequency of pulses are proportional to position and speed of shat connected to disk
- Can be adapted for linear or rotational measurements





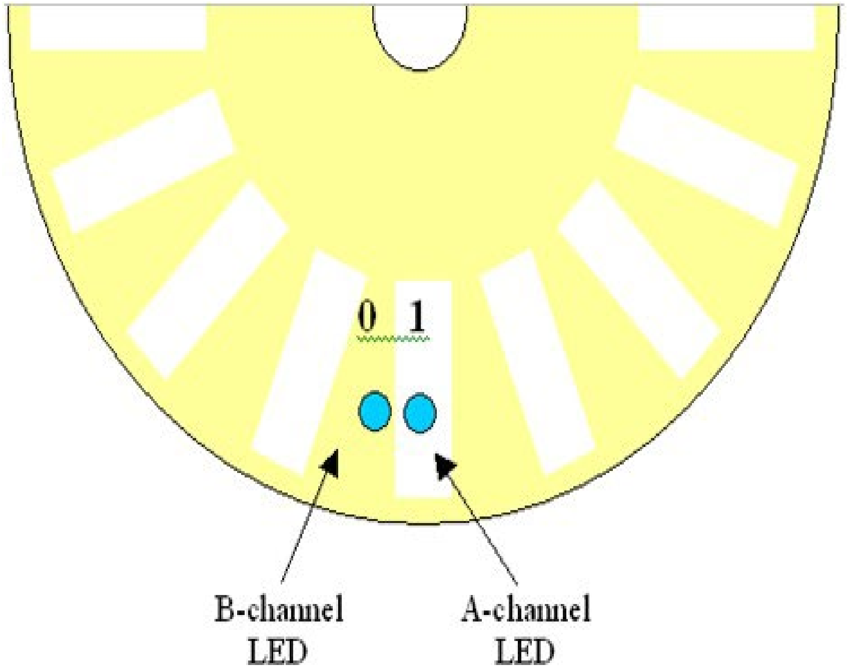
INCREMENTAL ENCODER

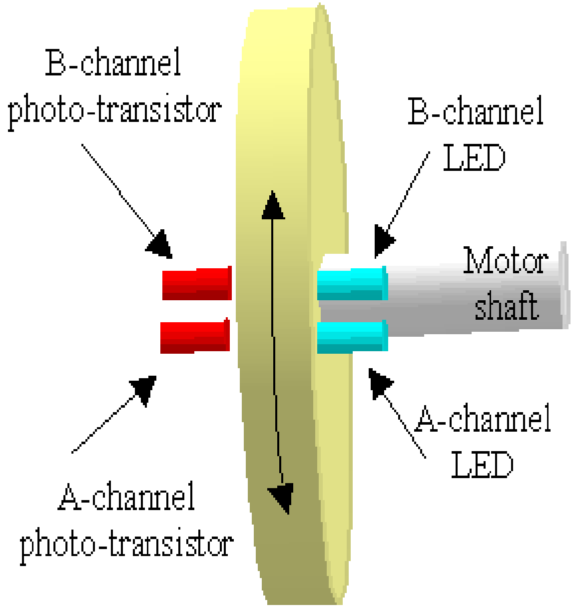


- Can this setup detect rotational direction?

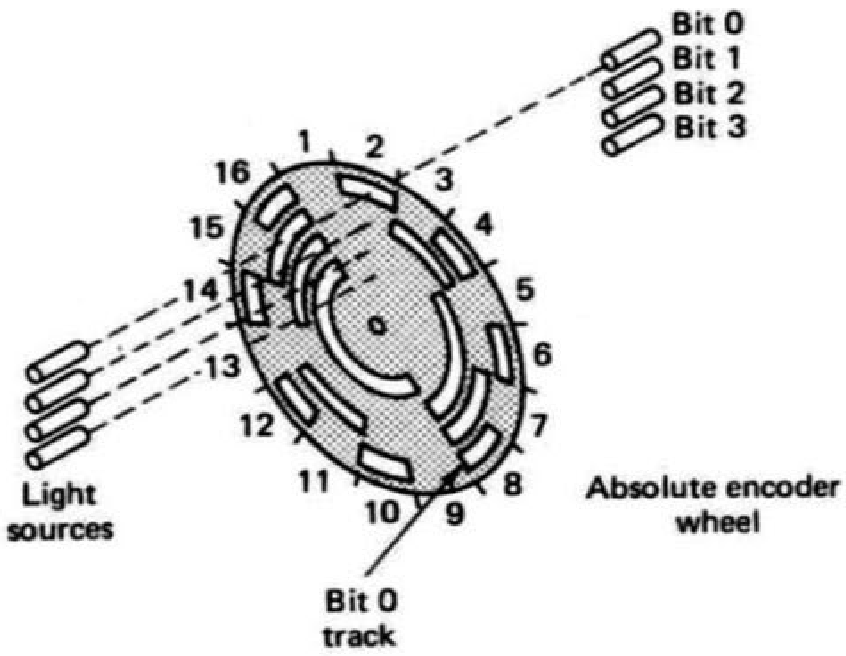
TWO CHANNEL OPTICAL ENCODERS

- The phase of the signals from two channels senses the direction of the motion





ABSOLUTE ENCODER

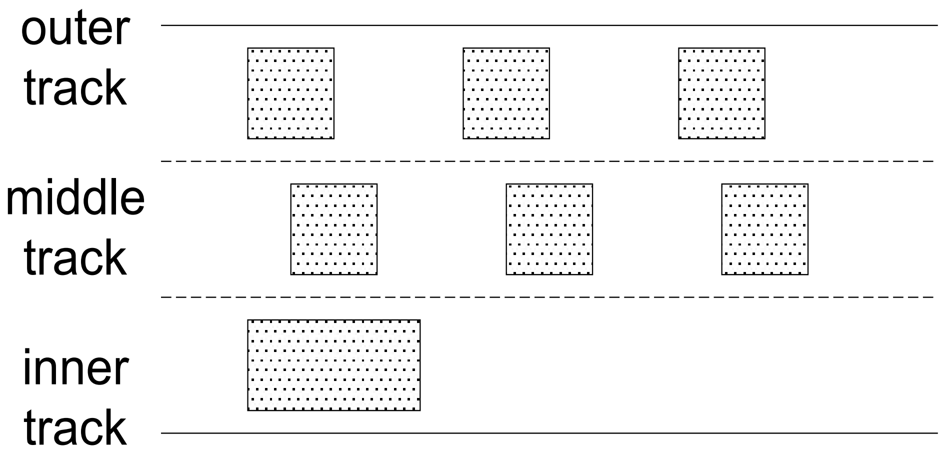


Code chart

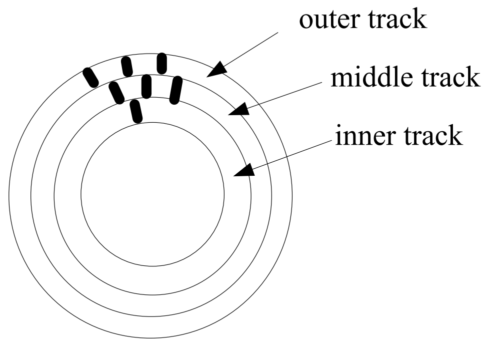
Segment	Bit pattern			
	Bit 0	Bit 1	Bit 2	Bit 3
1	Off	Off	Off	Off
2	On	Off	Off	Off
3	Off	On	Off	Off
4	On	On	Off	Off
5	Off	Off	On	Off
6	On	Off	On	Off
7	Off	On	On	Off
8	On	On	On	Off
9	Off	Off	Off	On
10	On	Off	Off	On
11	Off	On	Off	On
12	On	On	Off	On
13	Off	Off	On	On
14	On	Off	On	On
15	Off	On	On	On
16	On	On	On	On

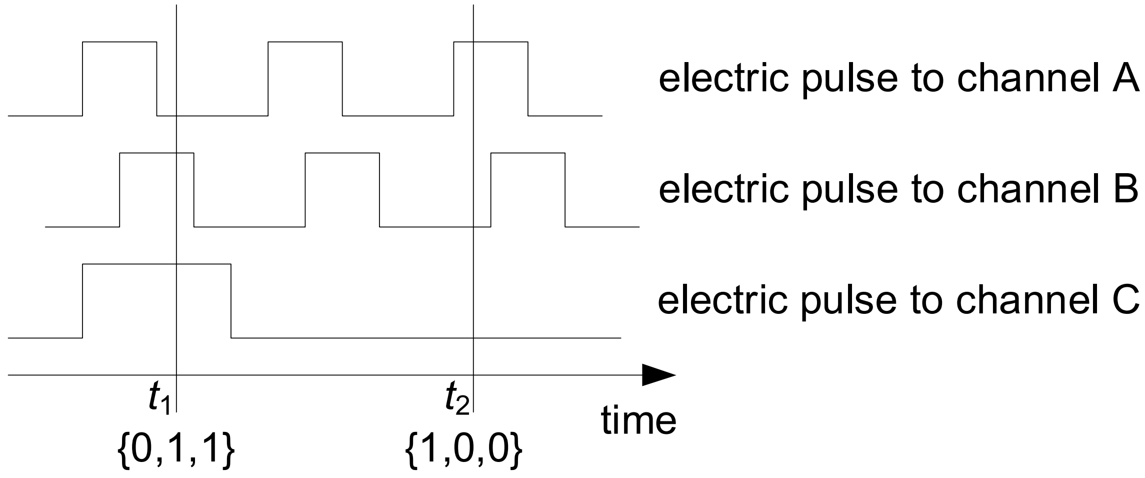
Figure 4-15 Absolute Encoder with Code

INCREMENTAL ENCODER IMPLEMENTATION



mechanical
construction





RESOLUTION

The resolution is determined by the number of slots on the disc. With 60 slots occurring with 1 revolution then, since 1 revolution is a rotation of 360°, the resolution is $360/60 = 6°$.

WORKED EXAMPLE

Question

- A shaft encoder is to be used with a 100 mm radius tracking wheel to monitor linear displacement. If the encoder produces 512 pulses per revolution, what will be the number of pulses produced by a linear displacement of 500 mm.

WORKED EXAMPLE

Question

- A shaft encoder is to be used with a 100 mm radius tracking wheel to monitor linear displacement. If the encoder produces 512 pulses per revolution, what will be the number of pulses produced by a linear displacement of 500 mm.

Answer

- The total length, L, of the encoder per revolution with radius r is:
- $L = 2\pi r = 2\pi\ 100 = 200\pi$
- With N_P (=512) pulses per revolution, the length, L_P, cover by every pulse of the encoder is:
- $$L_P = \frac{L}{N_P} = \frac{200\pi}{512} = 1.227\text{mm/pulse}$$

EXAMPLE – CONT'

The total number, N500mm, of pulse for 500 mm has two possible cases:

- Pass the counting edge (ceiling operator)

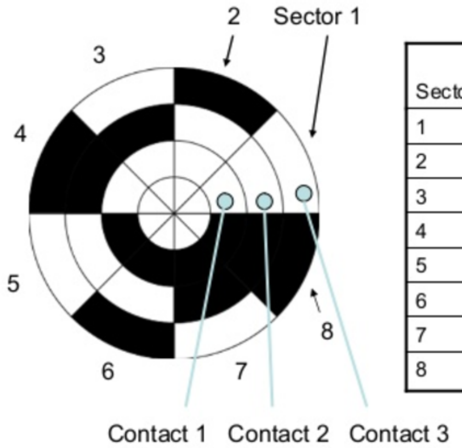
$$N_{500mm} = \left\lceil \frac{500}{1.227} \right\rceil = \lceil 407.43 \rceil = 408 \text{ pulses}$$

- Not pass the counting edge yet (floor operator)

$$N_{500mm} = \left\lfloor \frac{500}{1.227} \right\rfloor = \lfloor 407.43 \rfloor = 407 \text{ pulses}$$

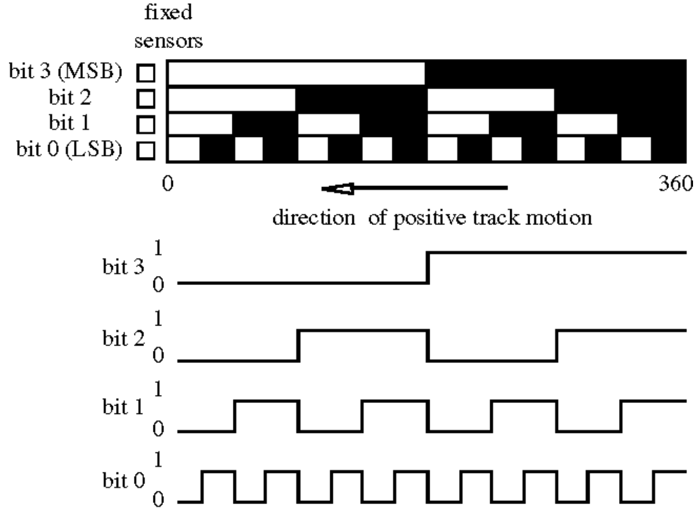
ABSOLUTE ENCODER

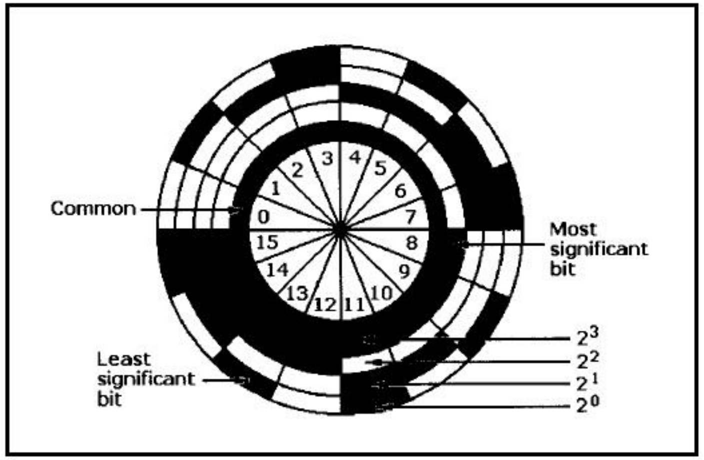
3-bit absolute encoder



Sector	Con-tact 1	Con-tact 2	Con-tact 3	Angle
1	off	off	off	0° - 45°
2	off	off	ON	45° - 90°
3	off	ON	off	90° - 135°
4	off	ON	ON	135° - 180°
5	ON	off	off	180° - 225°
6	ON	off	ON	225° - 270°
7	ON	ON	off	270° - 315°
8	ON	ON	ON	315° - 360°

4-bit absolute encoder





Binary-code disk for an absolute optical rotary encoder. Opaque sectors represent a binary value of 1, and the transparent sectors represent binary 0. This four-bit binary-code disk can count from 0 to 15.

GRAY CODE

	normal binary	gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

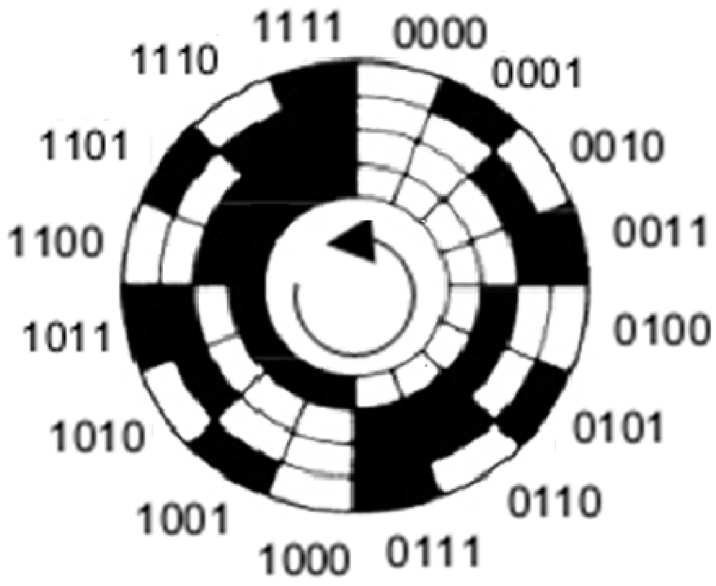
Decimal code	Rotation range (°)
0	0–22.5
1	22.5–45
2	45–67.5
3	67.5–90
4	90–112.5
5	112.5–135
6	135–157.5
7	157.5–180
8	180–202.5
9	202.5–225
10	225–247.5
11	247.5–270
12	270–292.5
13	292.5–315
14	315–337.5
15	337.5–360

A binary numeral system where two successive values differ in only one digit, ⇒ only one bit changes in moving from one number to the next.

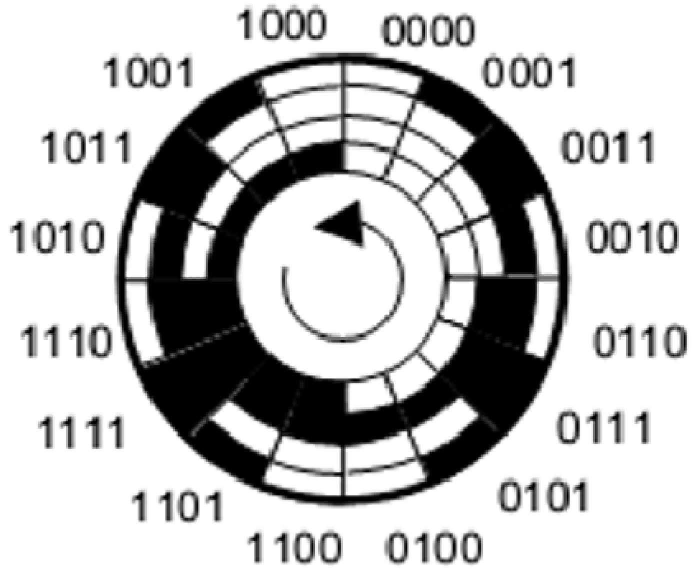
The reflected binary code was originally designed to prevent spurious output from electromechanical switches. Today, Gray codes are widely used to facilitate error correction in digital communications, etc.

[ref]: http://en.wikipedia.org/wiki/Gray_code.

Binary code and Gray code



Binary code



Gray code

PHOTOELECTRIC SENSOR

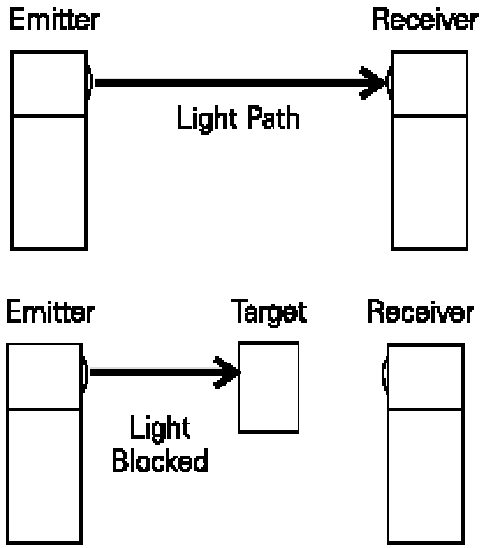
- A binary non-contact sensor (switch) is used to detect the absence, or presence of an object
- It is consisting of emitter (light source) and receiver (photocell) triggered by interruption of light beam.

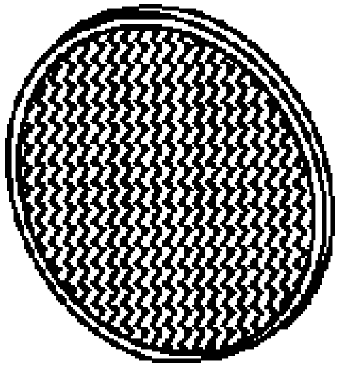
- Two common types:

1. Transmitted type, in which object blocks light beam between emitter and receiver
2. Retro reflective type, in which emitter and receiver are located in one device and beam is reflected off remote reflector except when object breaks the reflected light beam

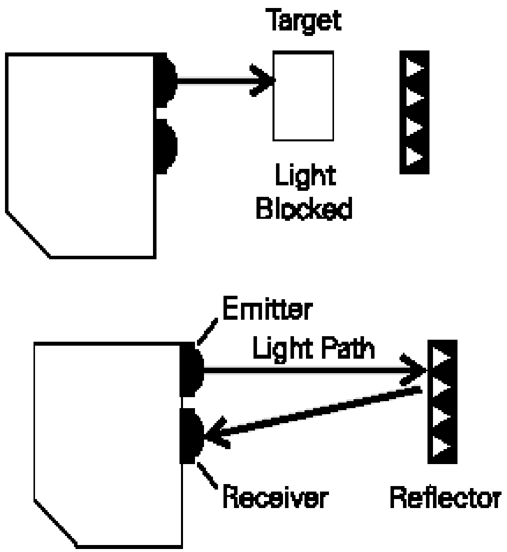
PHOTOELECTRIC SENSOR

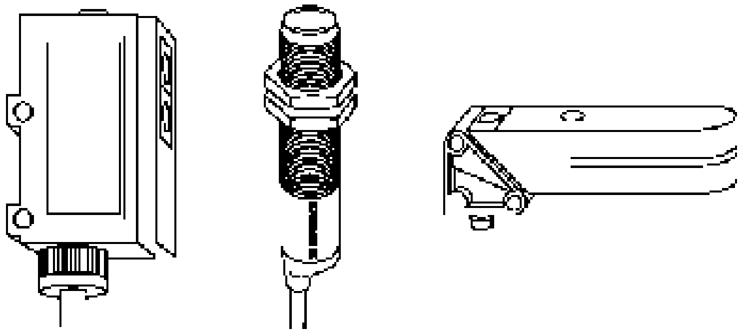
Transmitted Type

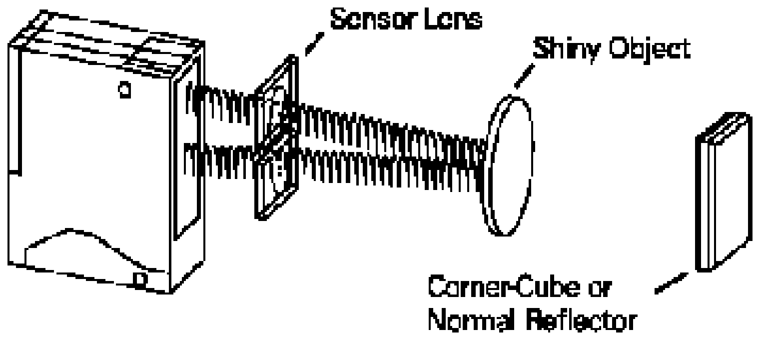




Retro Reflective Type





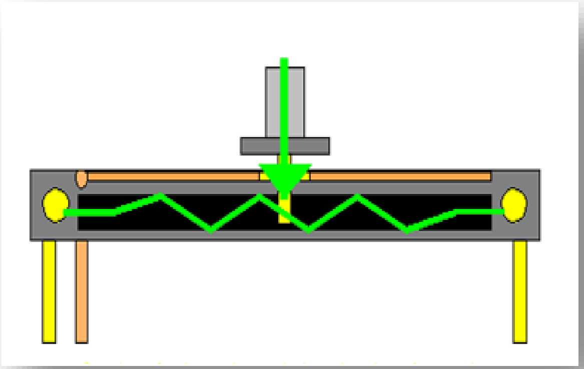


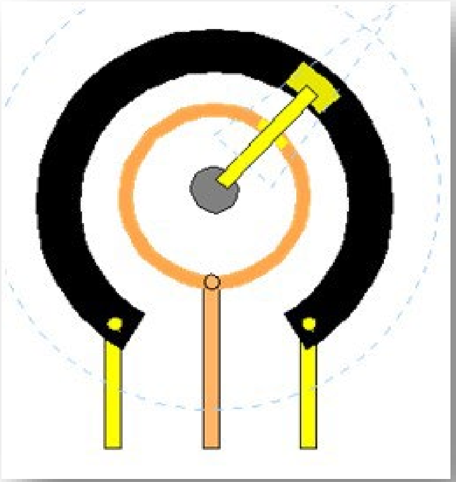
PIEZOELECTRIC TRANSDUCER

- An analog device based on piezoelectric effect of certain materials (e.g. quartz) in which an electrical charge is produced when the material is deformed.
- Electrical charge can be measured and is proportional to deformation
- Can be used to measure force, pressure, and acceleration

POTENTIOMETER

- An analog position sensor consisting of resistor and contact slider. Position of slider on resistor determines measured resistance. Available for both linear and rotational (angular) measurements.



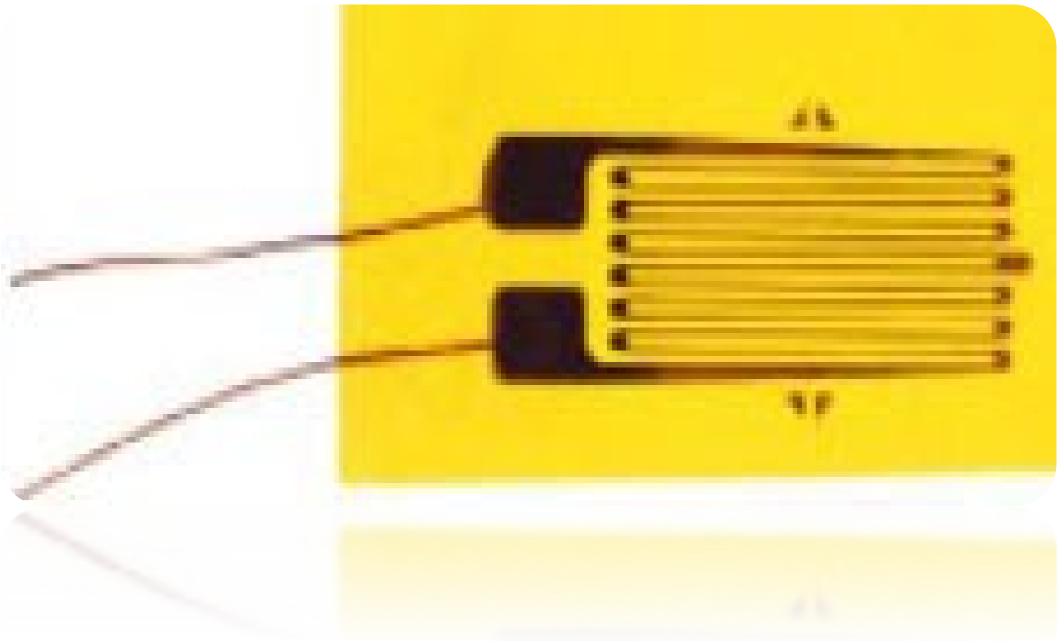


PROXIMITY SWITCH

- A binary non-contact sensor is to detect the presence of nearby objects which induce changes in electromagnetic field
- Major types:
  - Inductive, for metal targets
  - Capacitive
  - Ultrasonics
  - Optics, Photoelectric Sensors

STRAIN GAGE

- A widely used analog sensor to measure strain, force, torque, or pressure
- Based on change in electrical resistance resulting from strain of a conducting material.



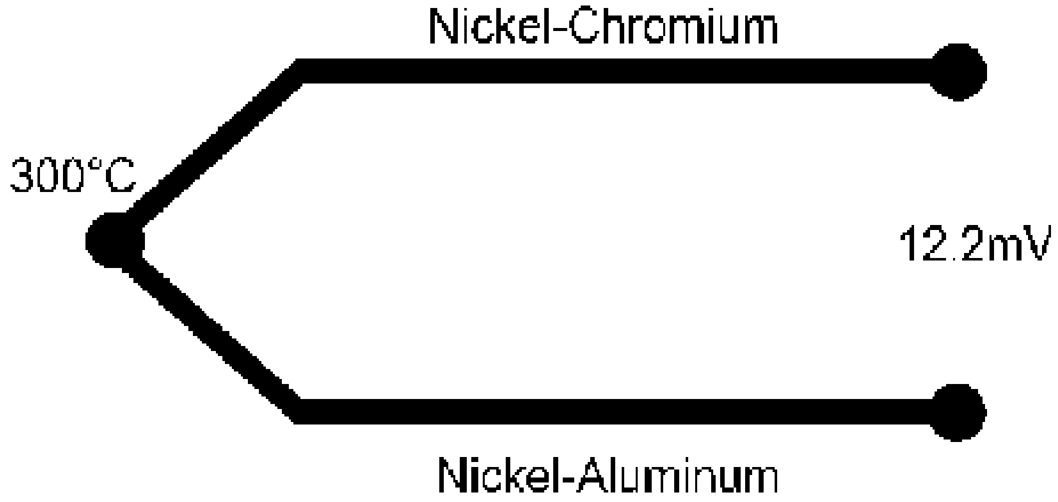
TEMPERATURE SENSORS

- Resistance-temperature detector:
  - An analog temperature-measuring device based on increase in electrical resistance of a **metallic material** as temperature is increased

- Thermistor:
  - An analog temperature-measuring device based on decrease in electrical resistance of a **semiconductor material** as temperature is increased

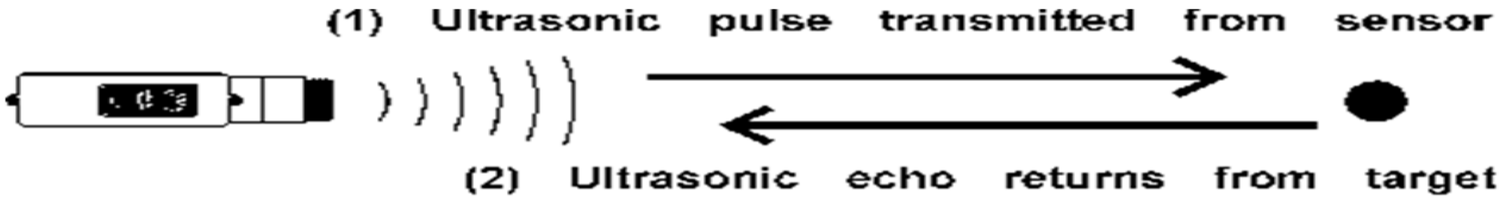
THERMOCOUPLE

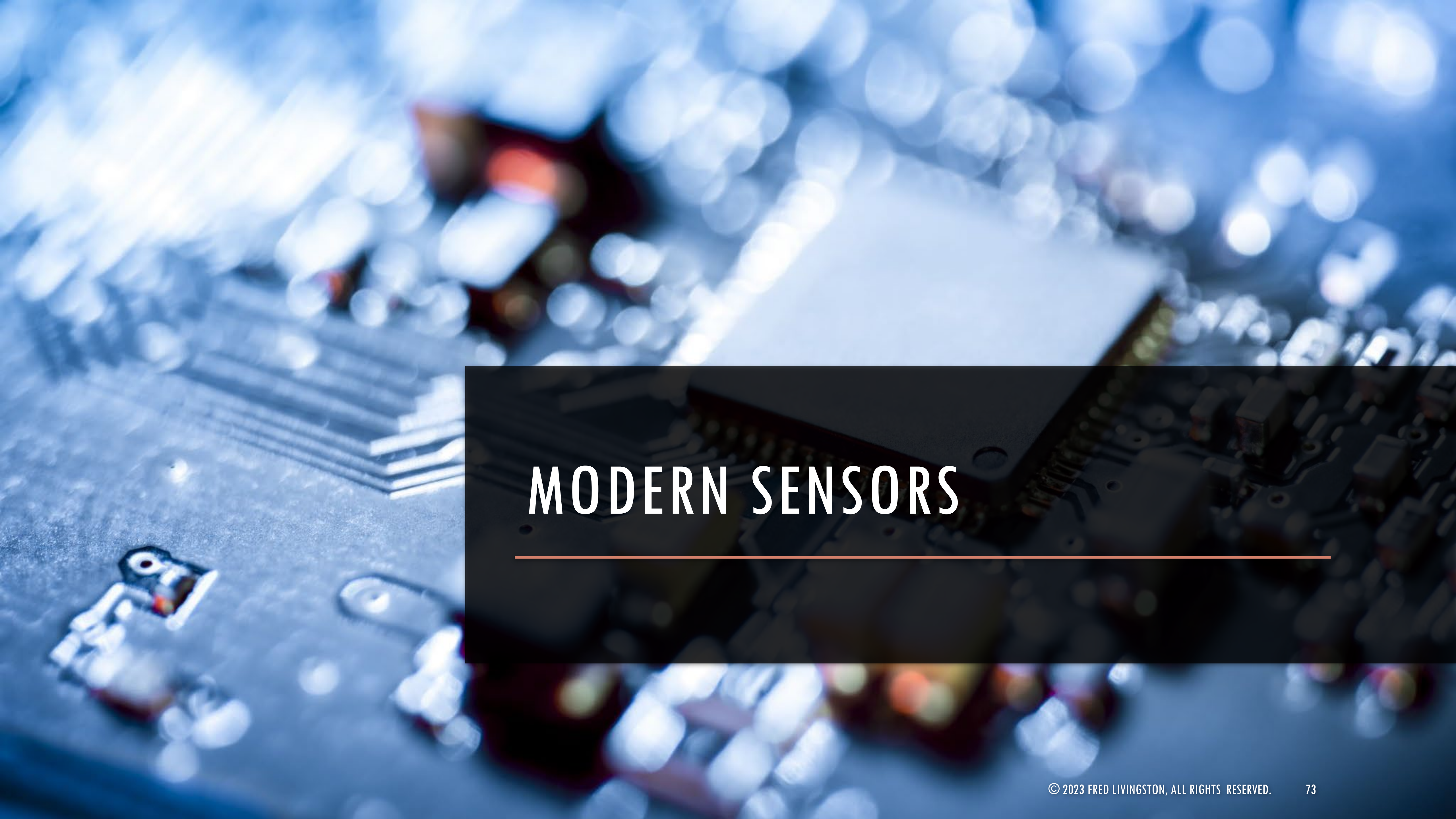
- An analog temperature- measuring device based on thermoelectric effect, in which a junction between two different metals produces a voltage related to a temperature difference



ULTRASONIC RANGE SENSOR

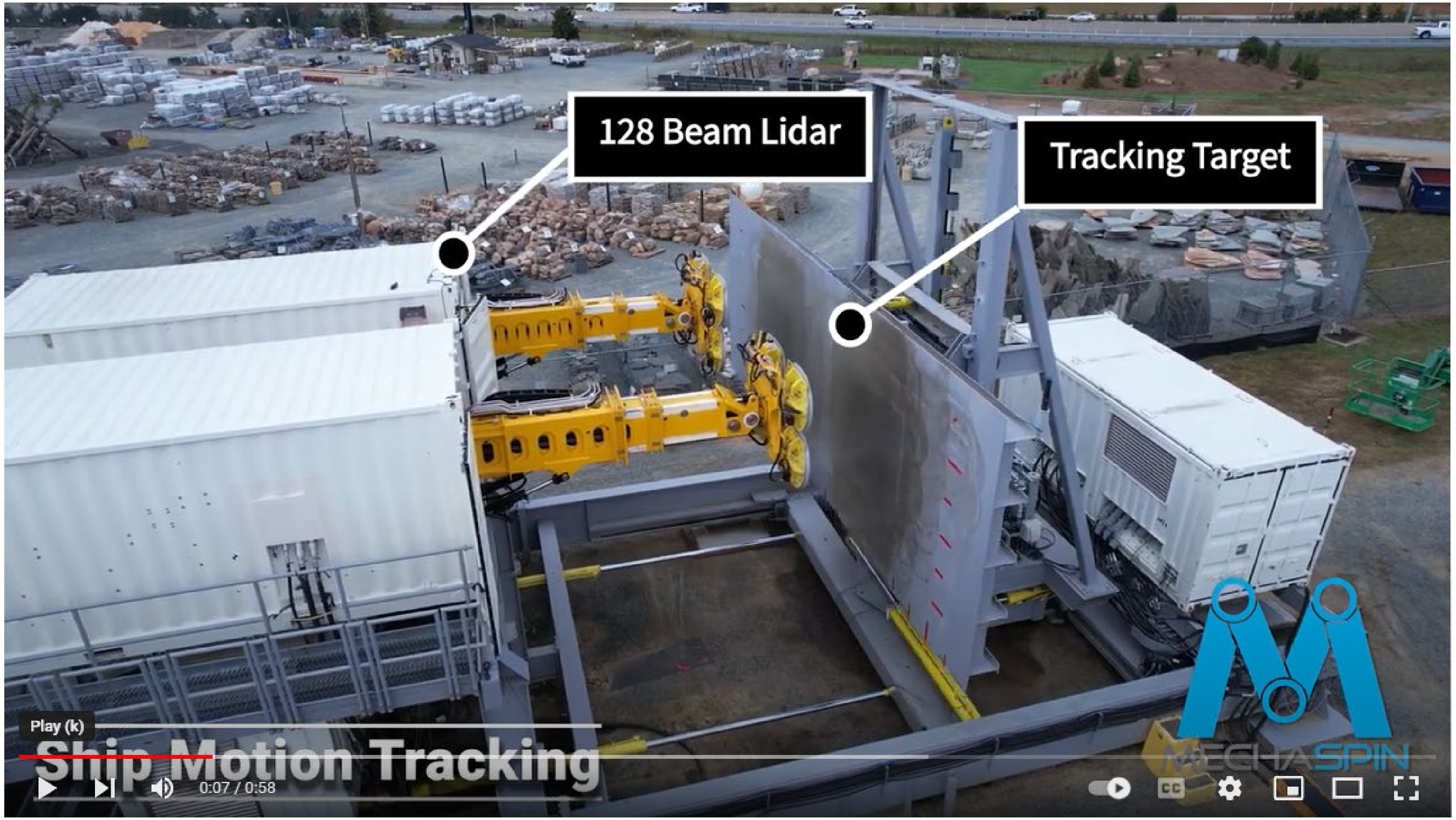
- Measures by reflected ultrasound
- Time lapse between emission and reelection (from object) of high-frequency sound pulses is measured
- Can be used to measure distance or simply indicate presence of object





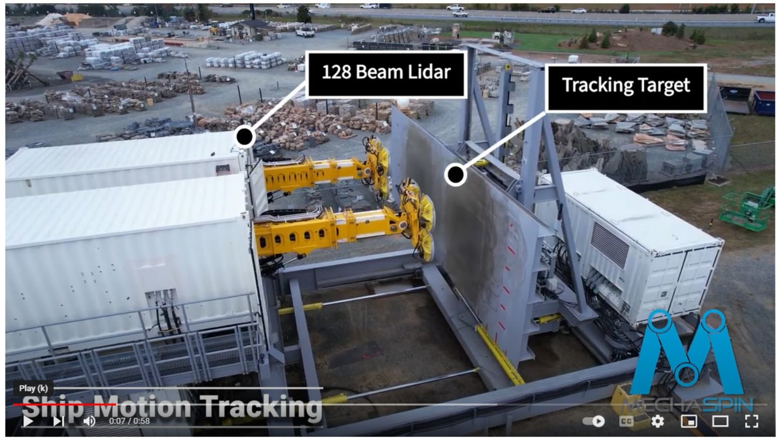
MODERN SENSORS

SENSOR SELECTION APPLICATION



- **Traditional**
  - LVDT (can)
  - Limit Switches (PLC)
  - Pressure Transducer (PLC)
  - Torque (PLC)
  - Proximity (PLC)
- **Modern**
  - 128 beam Lidar (Xavier)
  - 64 beam Lidar (Xavier)
  - IMU (Xavier)

SENSOR CONSIDERATIONS



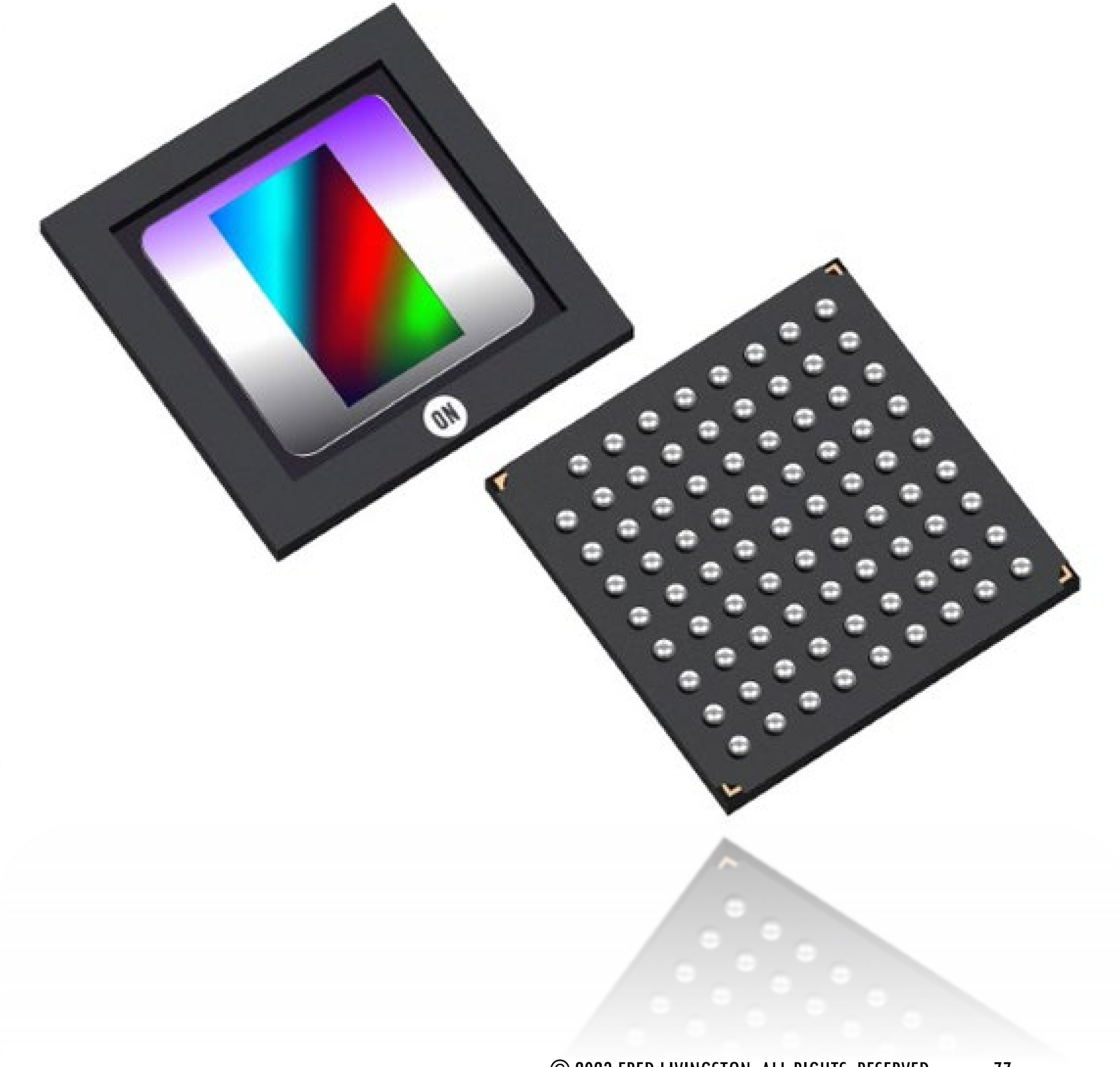
- Noise
  - PLC: Filter Algorithms
  - Xavier: Kalman Filter
- Loss of Signal
- Data Priorities
- Data Transfer

IMU

An electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometime magnetometers.

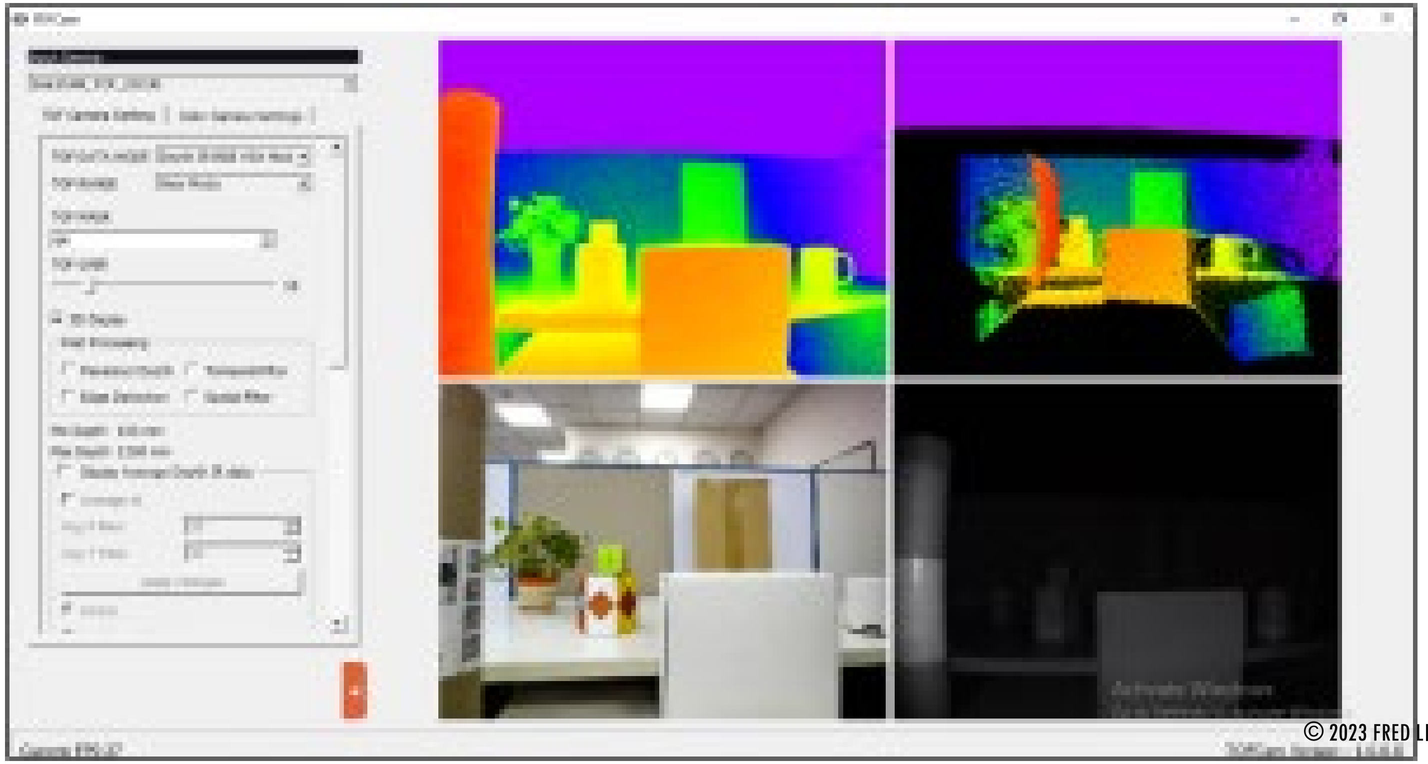
2D CAMERA (RGB)

- A visible camera sensor is an imager that collects visible light (400~700nm) and converts that to an electrical signal.



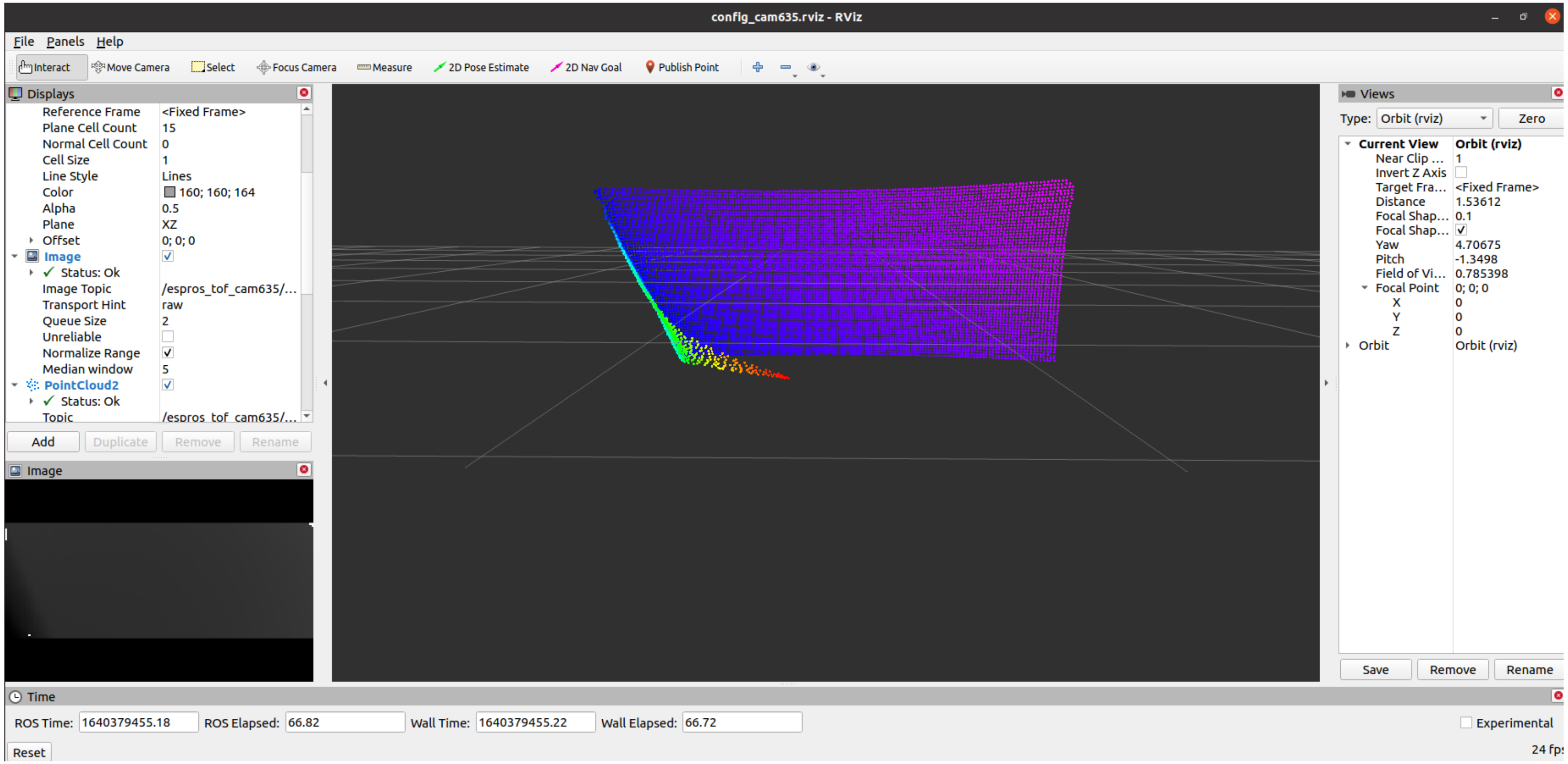
3D CAMERA (RGBD)

An RGBD camera is a type of depth camera that provides both depth (D) and color (RBG) data as the output in real-time. Depth information is retrievable through a depth map/image which is created by a 3D depth sensor such as a stereo sensor or time of flight sensor



ESPROS DEMO

https://bitbucket.org/livingston_ai/espros_notes/src/master/espros_demo.ipynb



2D/3D PERCEPTION ALGORITHMS

- Point Cloud Library
- https://pointclouds.org/

- OpenCV
- https://opencv.org/

- Open3D
- http://www.open3d.org/

- Deep Learning
  - Convolutional neural networks (CNN)
  - VoxelNet (3D Object Detection) https://arxiv.org/abs/1711.06396
  - PointNet2 (3D Object Detection) http://stanford.edu/~rqi/pointnet2/

BIN PICKING FOR SHIP-BUILDING LOGISTICS USING PERCEPTION AND GRASPING SYSTEMS

- Cordeiro, A., Souza, J. P., Costa, C. M., Filipe, V., Rocha, L. F., & Silva, M. F. (2023). Bin Picking for Ship-Building Logistics Using Perception and Grasping Systems. *Robotics*, *12*(1), 15. https://doi.org/10.3390/robotics12010015

HW 1 (PREVIEW) SENSOR DESIGN PROBLEM

Q1. Given a desired task: List possible sensors for each of the follow robot manipulator task

1. Part presence
2. Part location and orientation
3. Moving speed

Q2.
This robot contains a numbers of sensors for detecting an object. Given the following data, determine the best sensor suitable for the task.

Q3.
Using Sensor A, derive a system model from the response time.

END OF LECTURE 002