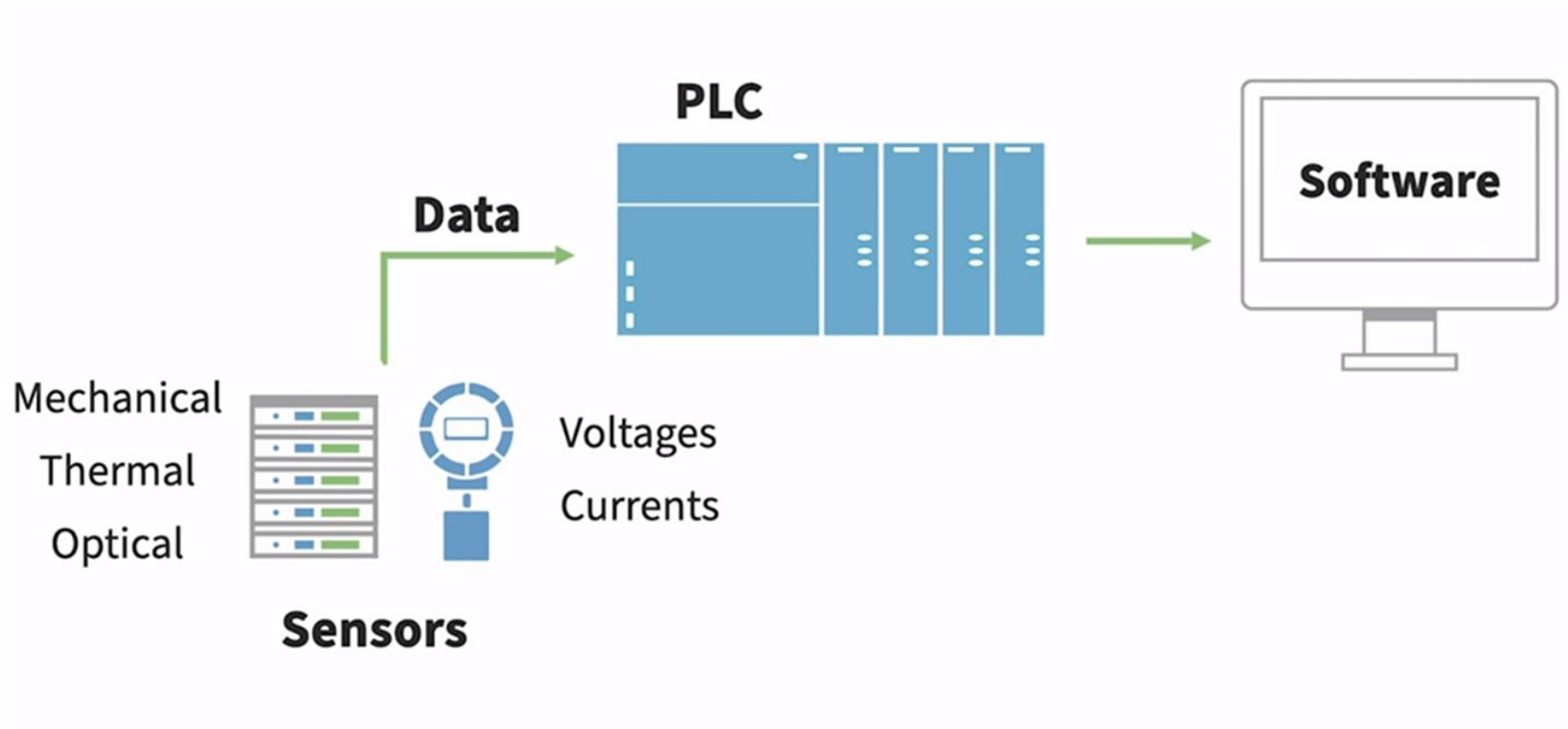
ROBOTICS and AUTOMATIONS

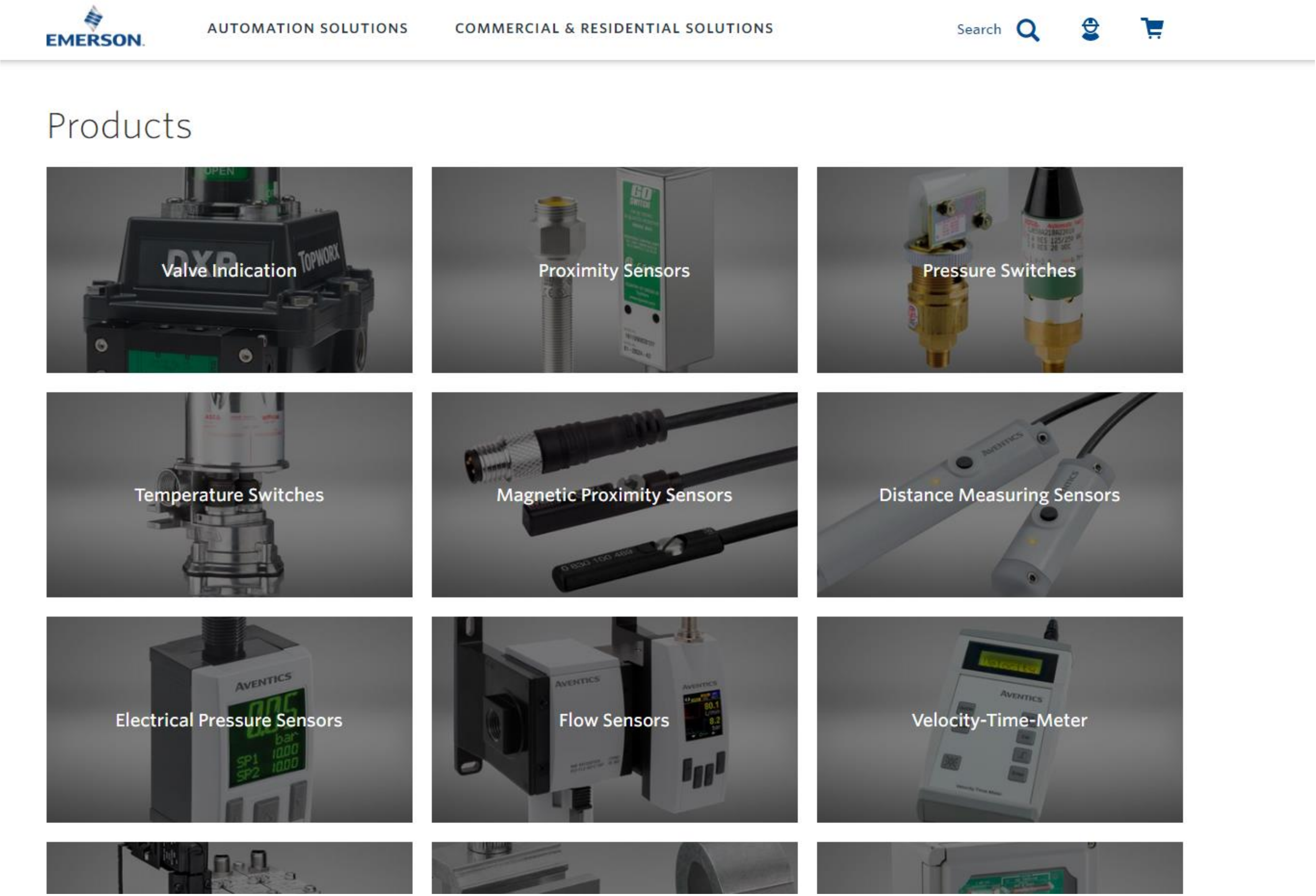
Forward Kinematics

Week 7

Sensors in Industrial Automation

Sensors


PLC
Data
Software
Mechanical
Thermal
Optical
Voltages
Currents
Sensors



https://www.emerson.cn/en-cn/automation/fluid-control-pneumatics/sensors-controls

Major industrial Sensors

- Temperature sensors

- Proximity sensors

- Pressure sensors

- Level measurements

- Flow sensors

Contact and Non-contact Sensors

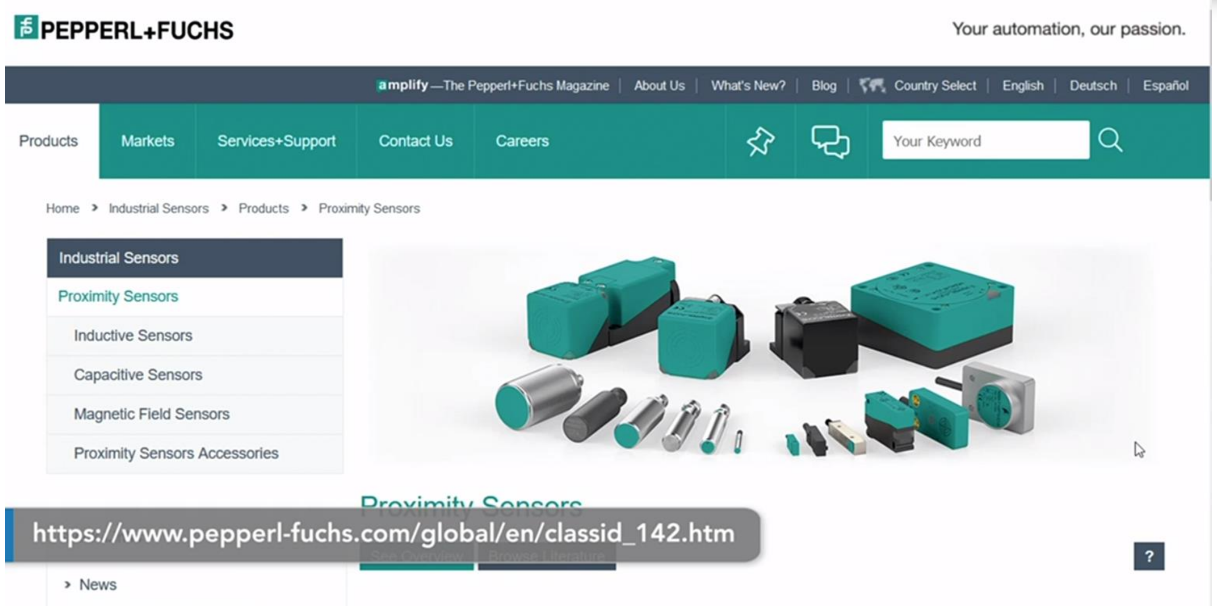
- Contact sensors must physically touch an object to sense it
- Non-contact sensors can sense without physically touching an object

Contact temperature sensor

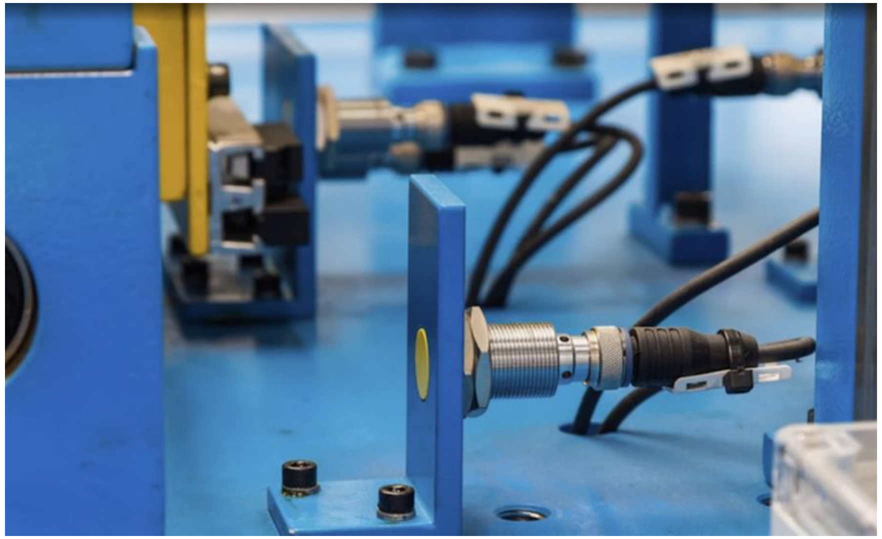
Non-contact temperature sensor

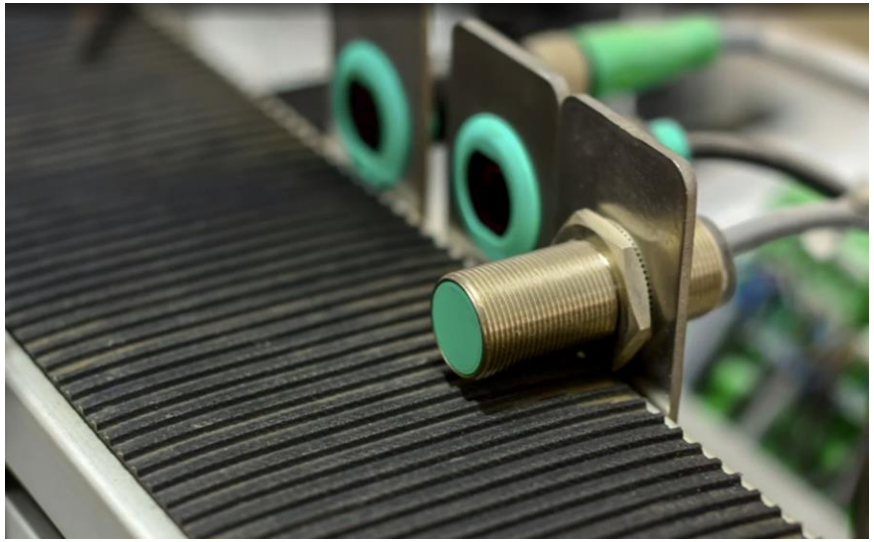
Proximity Sensor

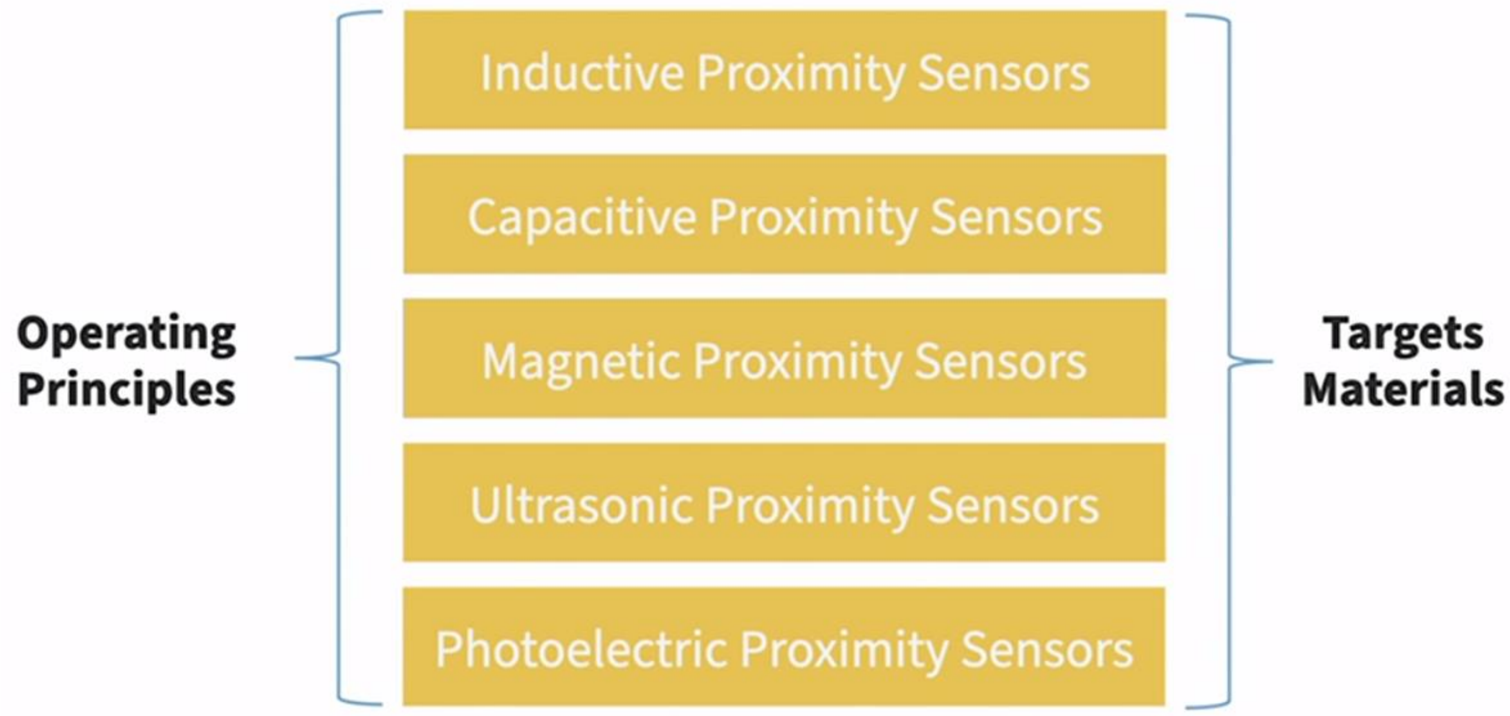
Detect a presence of an object without physical contact and then convert the signal into a electrical signal



Proximity Sensor







Different types of Proximity Sensor

Proximity Sensor

Sensors must be protected from harsh industrial environments.

Application of Proximity Sensor

When rapid response and high switching rates are needed

When the object has to be sensed through metallic or non-metallic barrier

When the object is too small, light weight or soft

Proximity Sensor

Figure 39 - Machine Tools

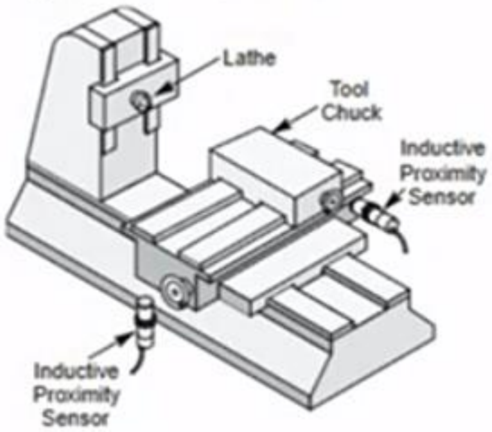


Figure 40 - Plating Line

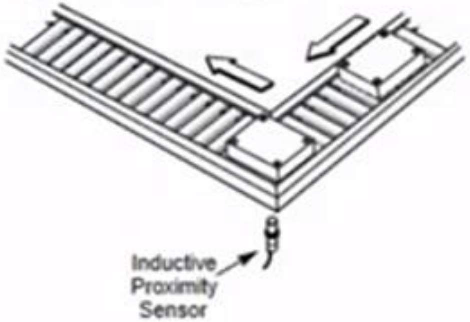


Figure 41 - Plating Line

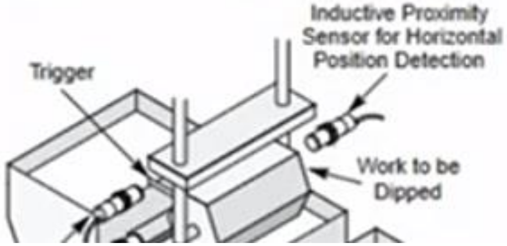


Figure 43 - Wood Industry

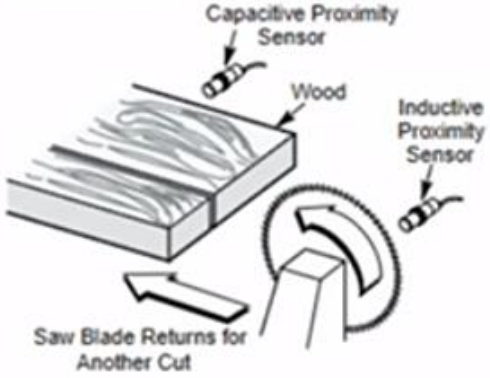


Figure 44 - Conveyor Belts

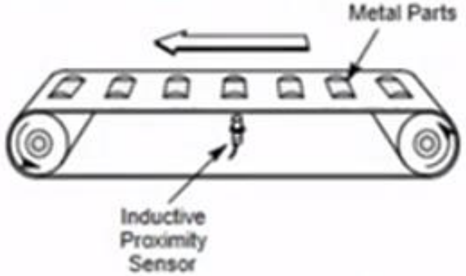


Figure 45 - Petroleum Industry – Valve Position

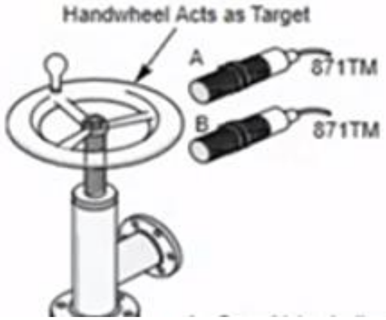


Figure 47 - Can Tops

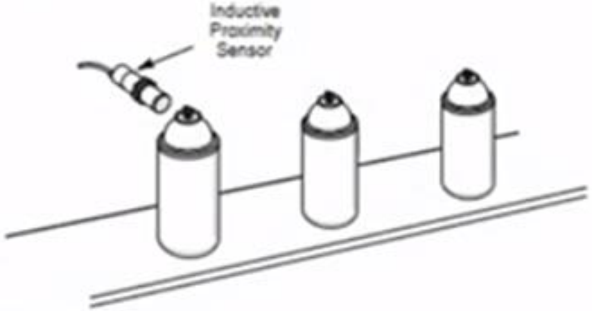


Figure 48 - Food Industry

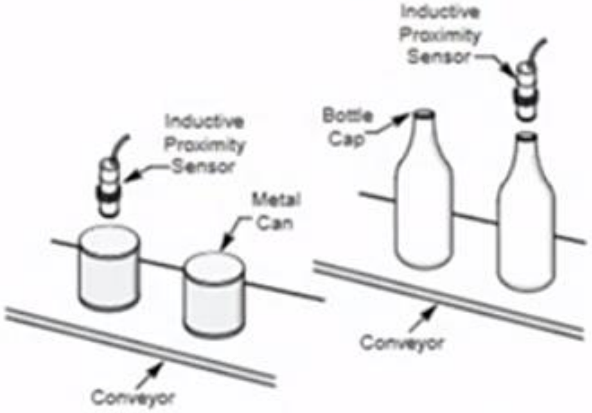
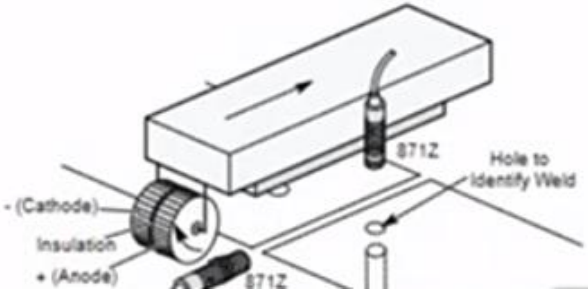
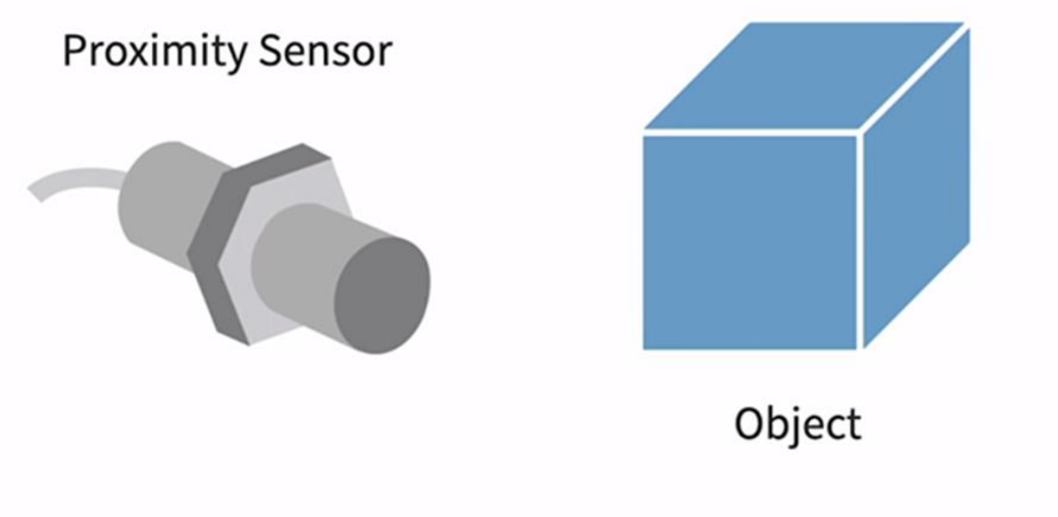
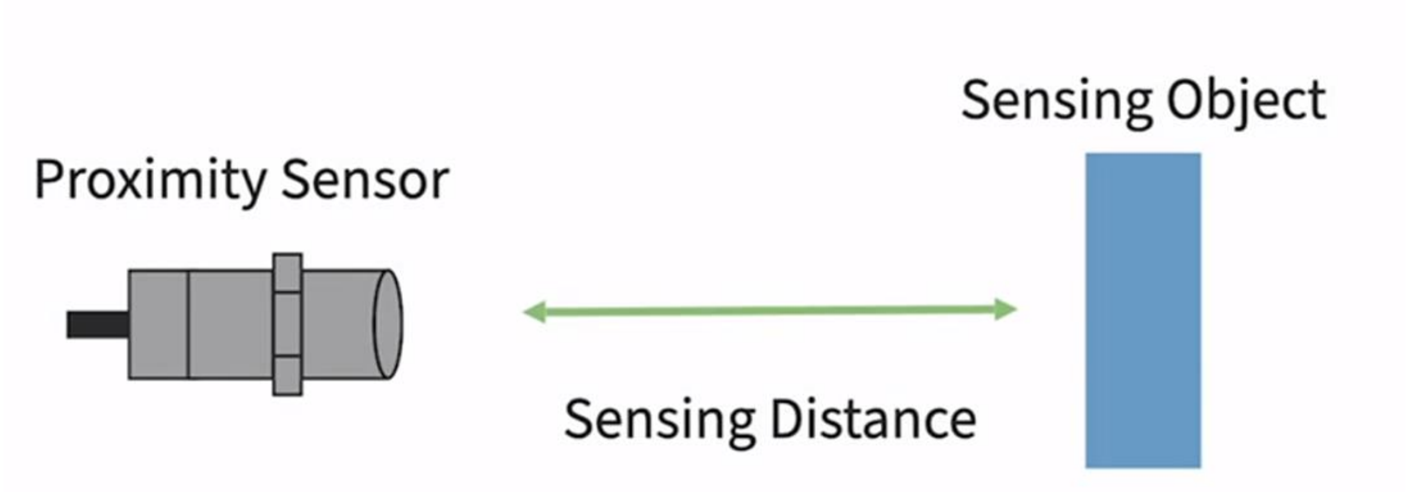


Figure 49 - Stainless Steel Sheet Welder



Operating Principle of Proximity Sensor

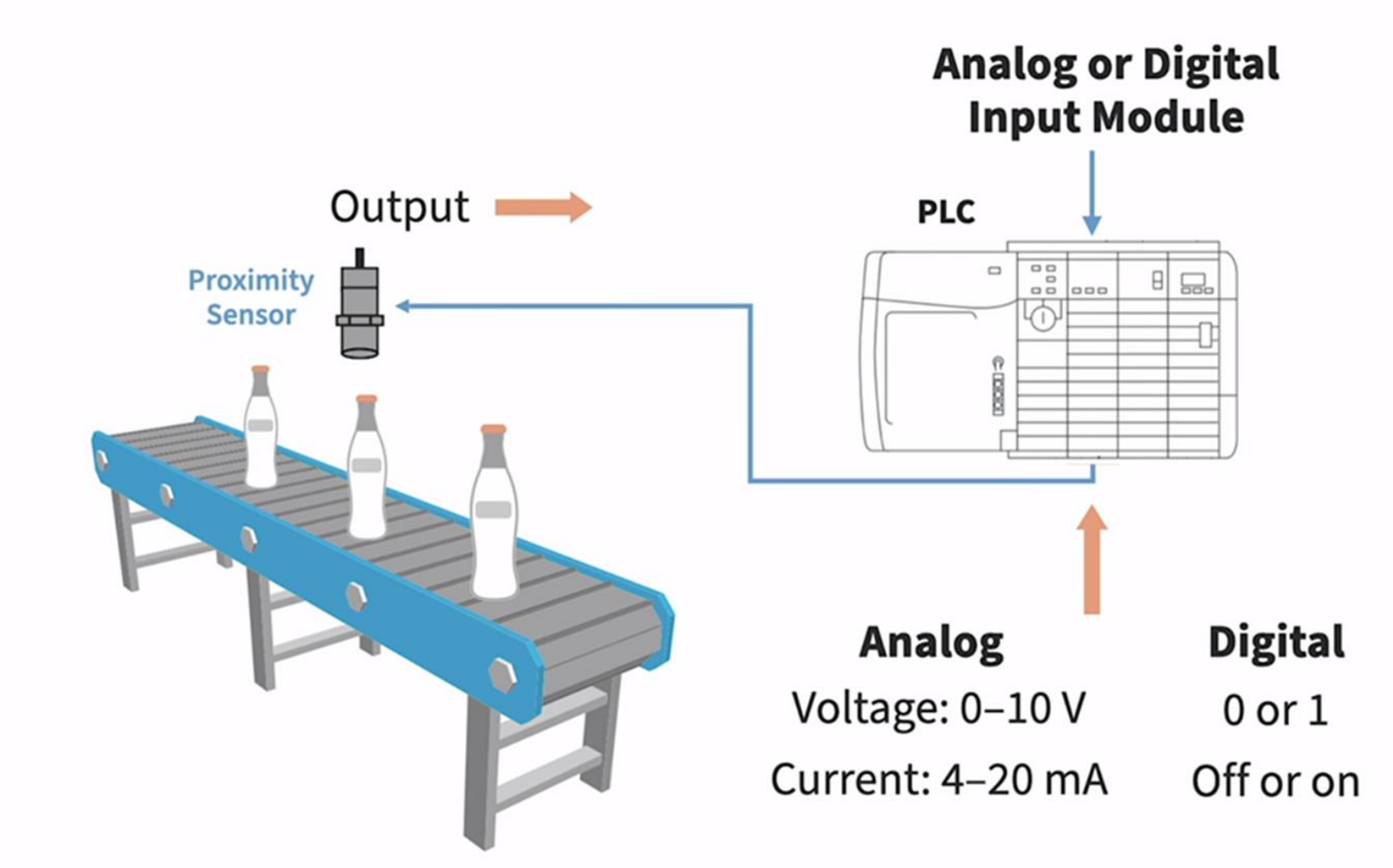




- ✓ Materials
- ✓ Shape
- ✓ Dimension
- ✓ Color
- ✓ Speed
- ✓ Package

The object serve as a reference for measuring, then the sensor gets calibrated

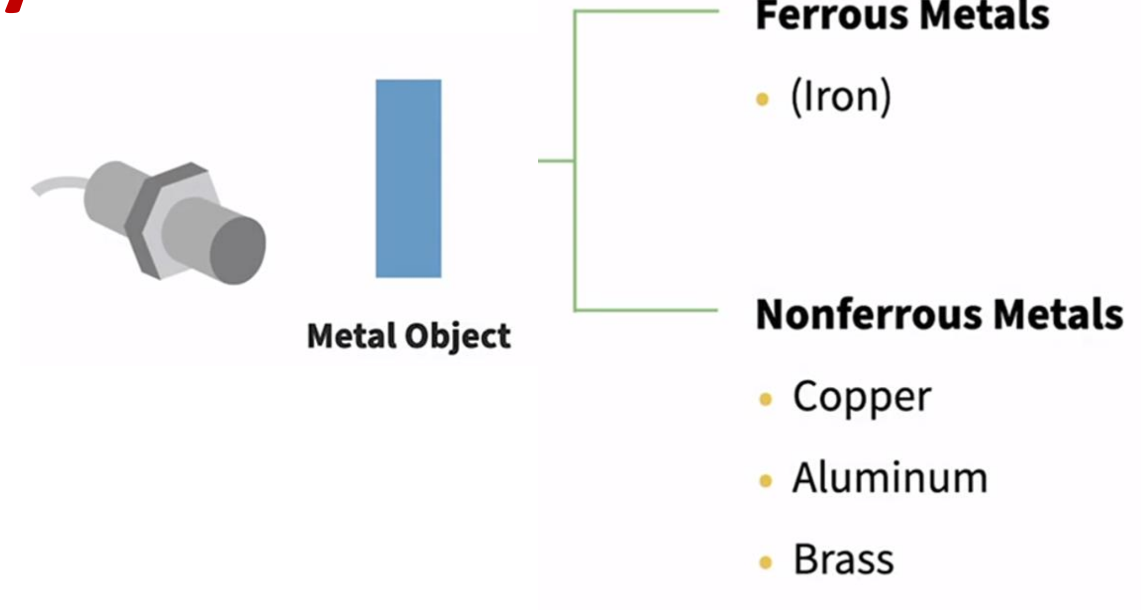
Operating Principle of Proximity Sensor

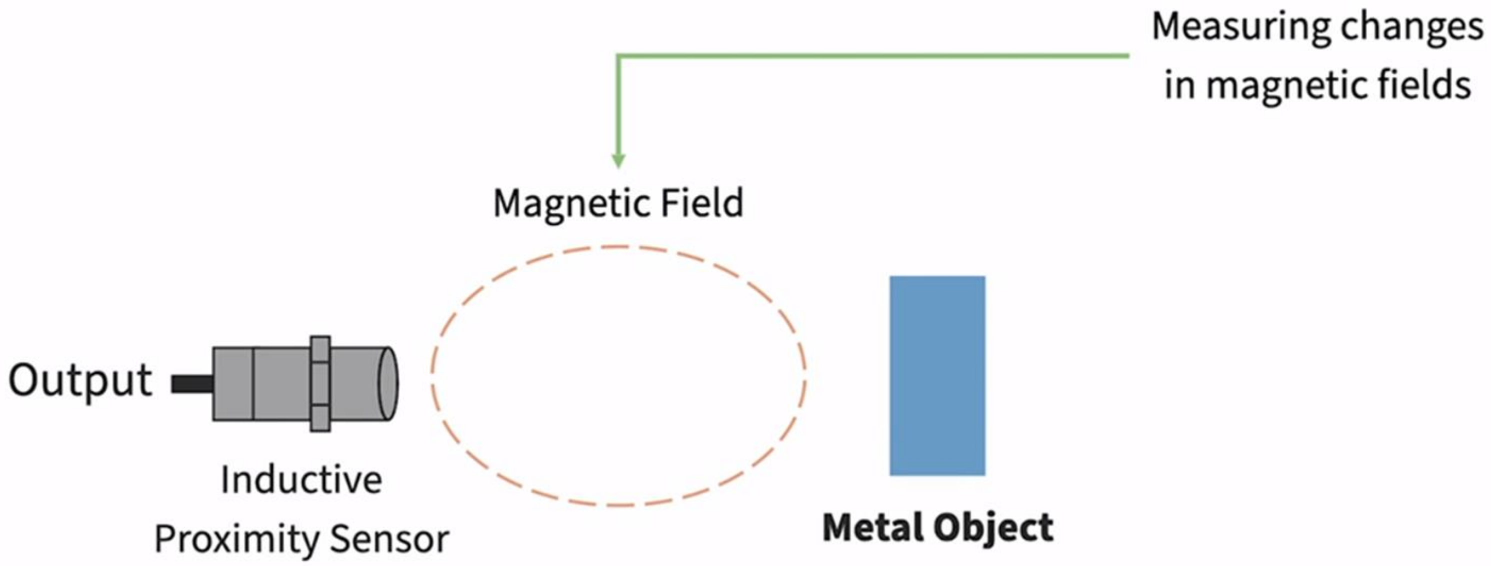


Inductive Proximity Sensors

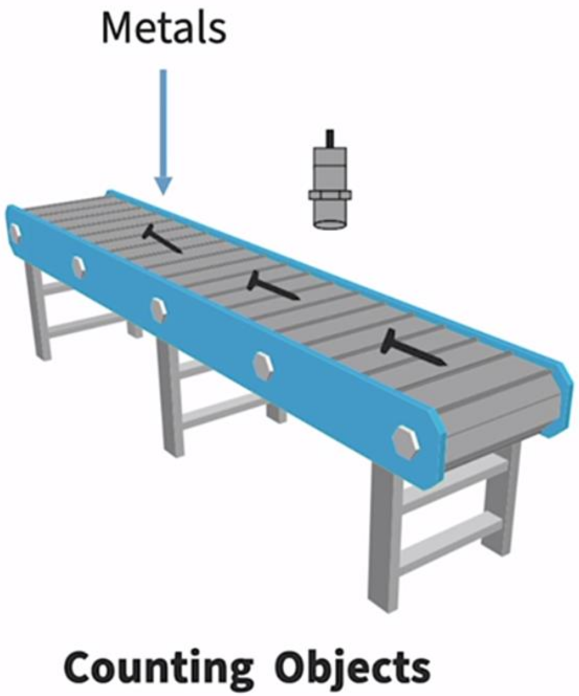
Inductive proximity sensors

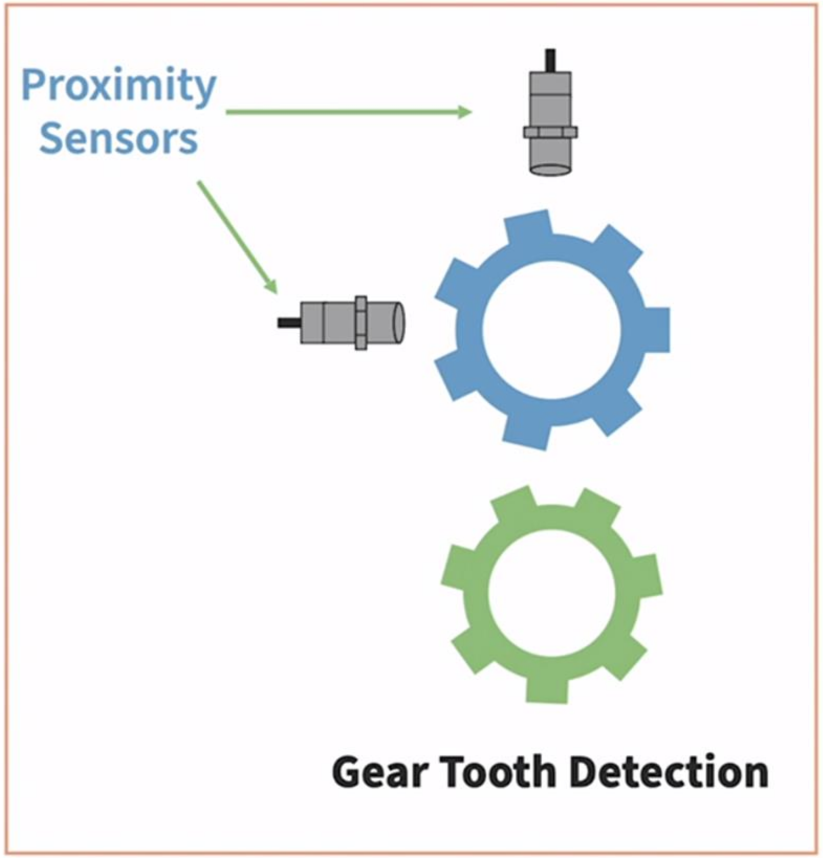
Electrical Principle
of **Inductance**

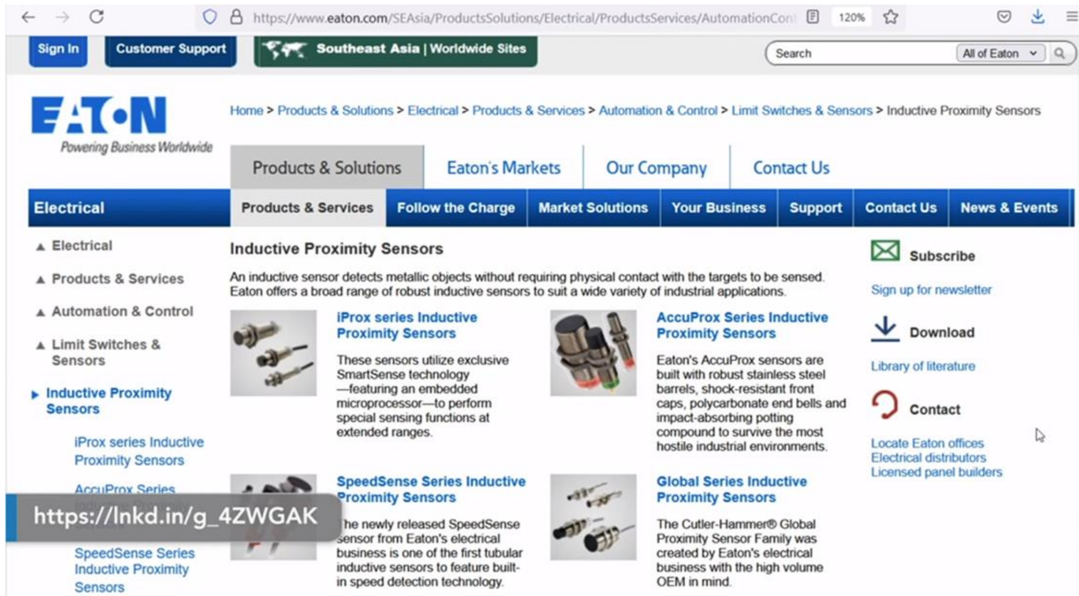




Inductive Proximity Sensors







Product Selection Guide

3

iProx

Page V8-T3-10

Overview

Designed to be the highest performing tubular inductive sensor. Standard features include extended sensing ranges, high noise-immunity, extreme durability and includes Autoconfigure Technology. Advanced features include output delay, speed detection and cloning with ProxView Software.

Applications

Automotive, machine tool, material handling where high sensing performance and inventory consolidation is a priority

E57 Premium+ Series

Page V8-T3-17

Overview

High performance inductive sensors include stainless steel models, extended ranges and right-angle sensing.

Applications

A wide variety of applications including those where customers require AC/DC universal inventory sensors

E57 Premium+ Series Short Barrel

Page V8-T3-29

Overview

Full featured sensors with shorter overall length than standard tubular sensors.

Applications

Automation, robotics, transfer lines, conveyors, material handling

Global Proximity

Page V8-T3-36

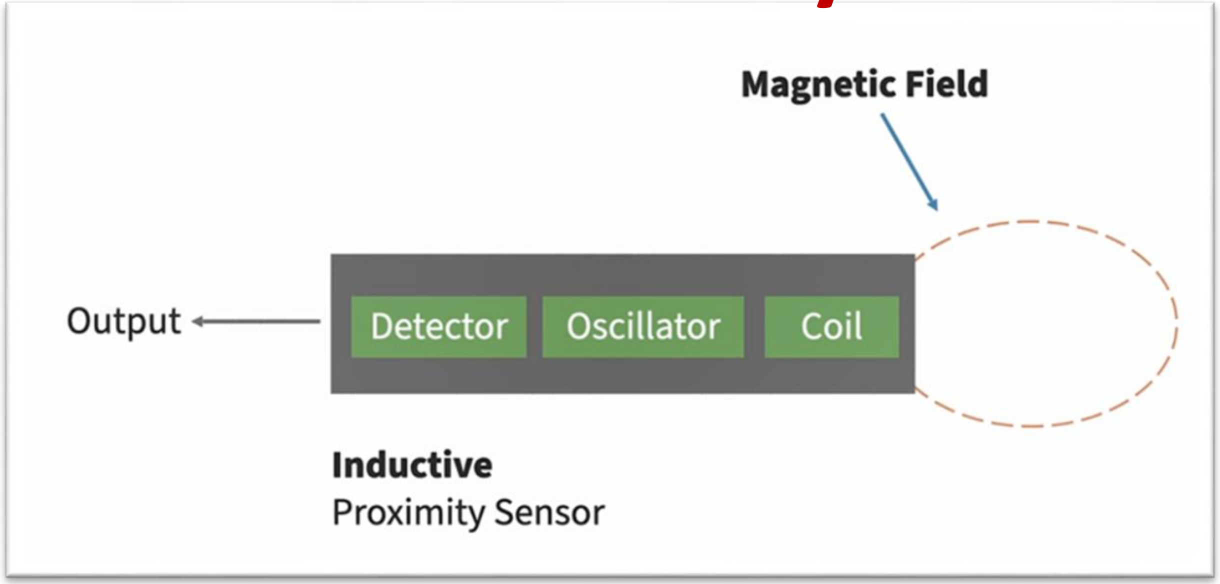
Overview

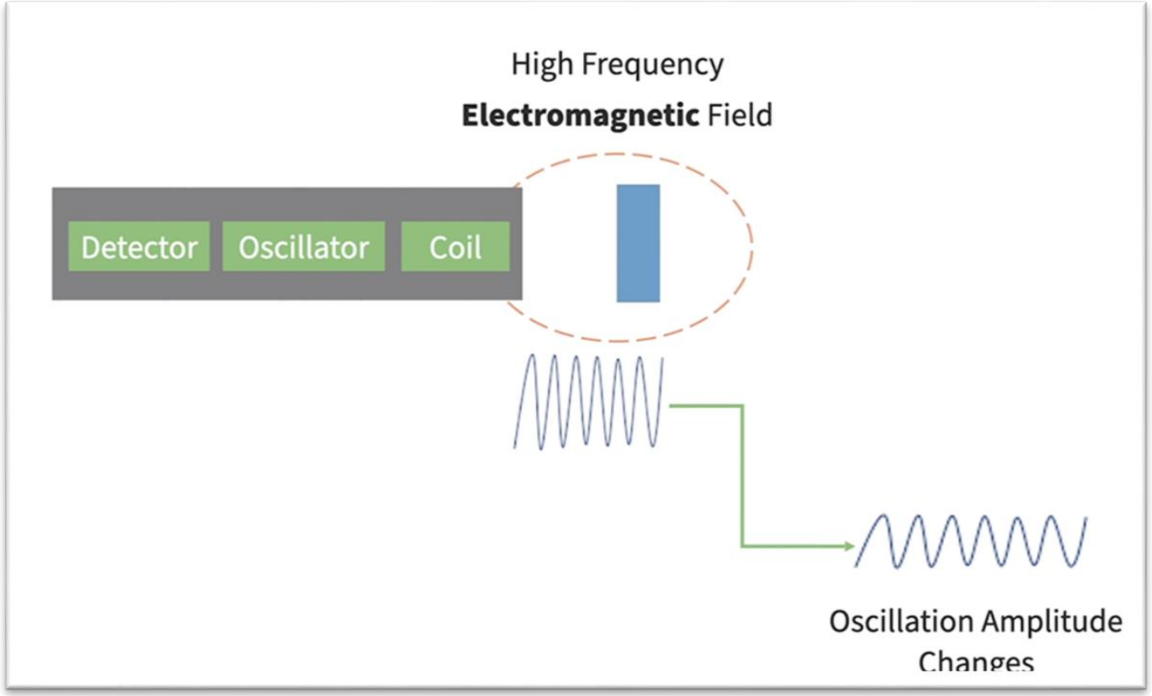
This full-line, tubular proximity sensor family provides a cost-effective solution for high volume OEM use.

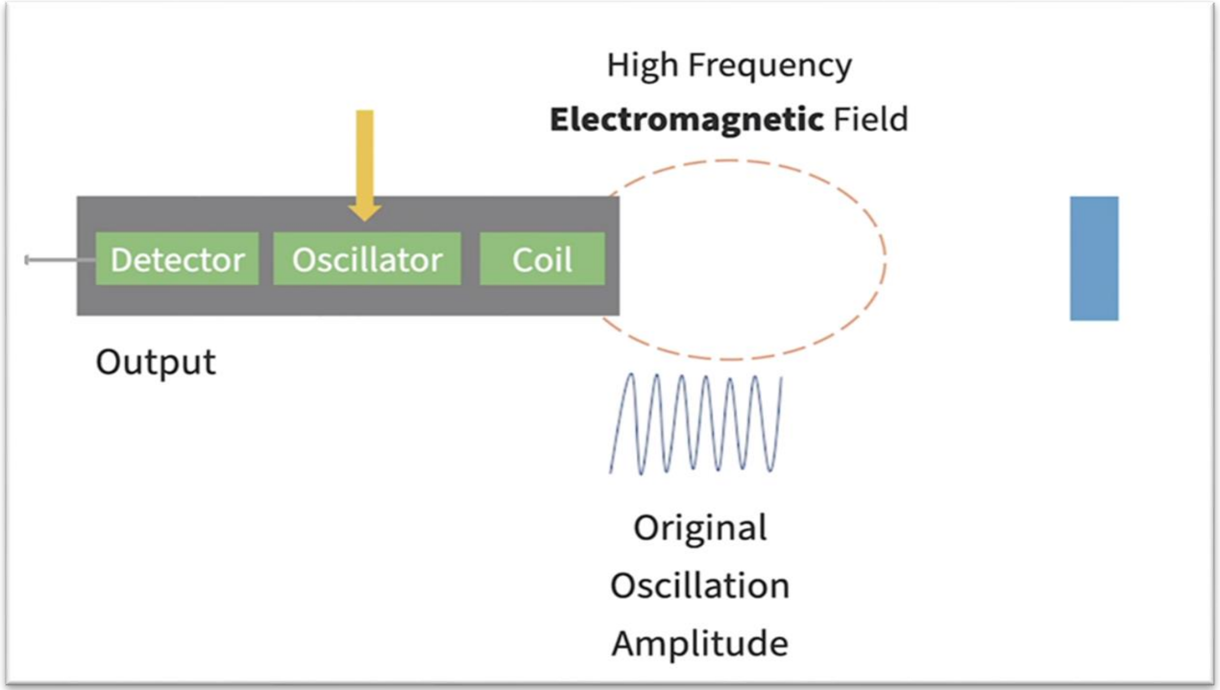
Applications

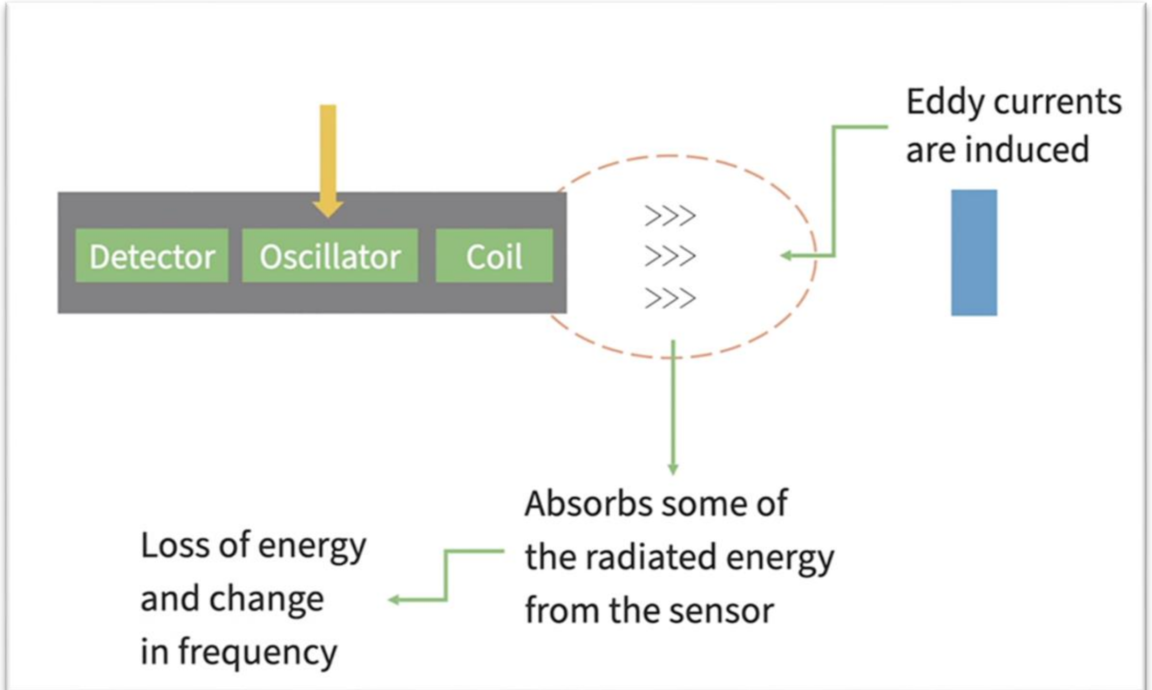
Machine tool detection, press applications, cam detection, material handling, valve and shaft position, automotive assembly

Inductive Proximity Sensors



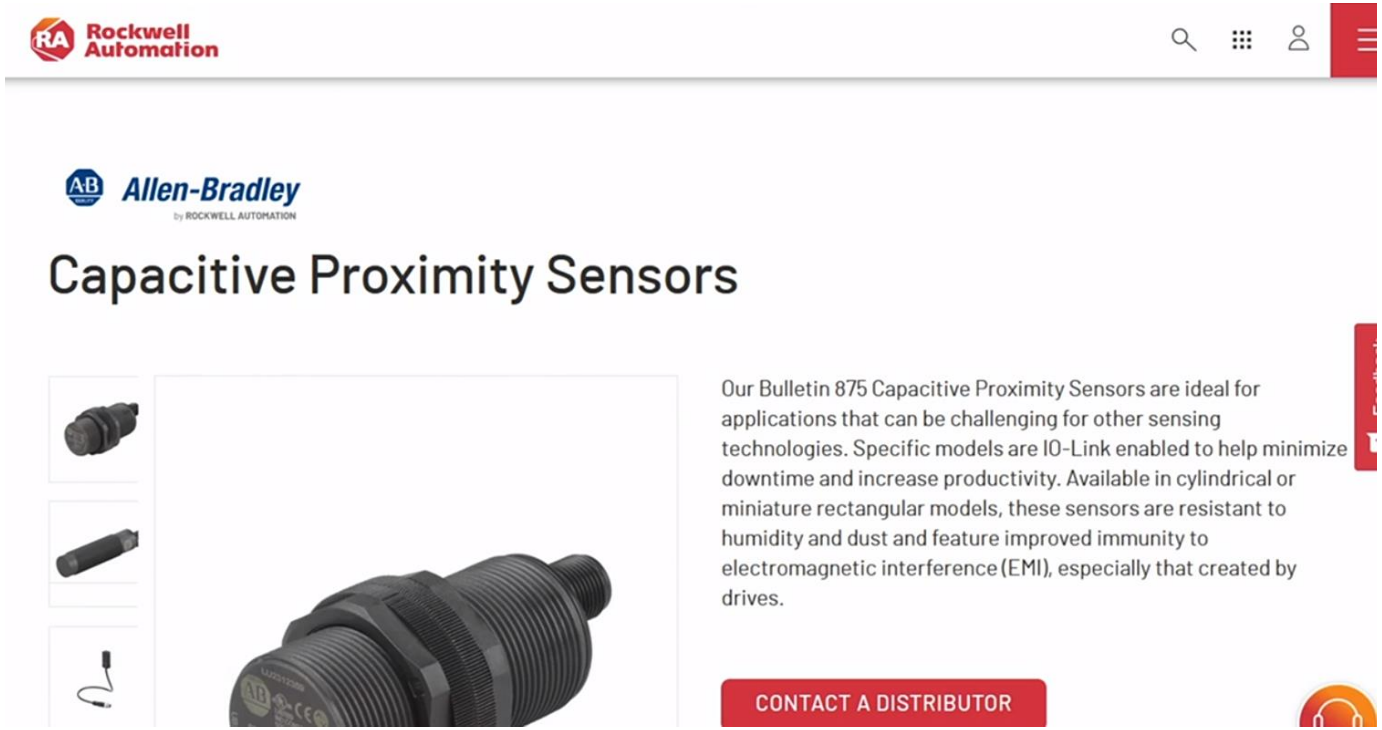




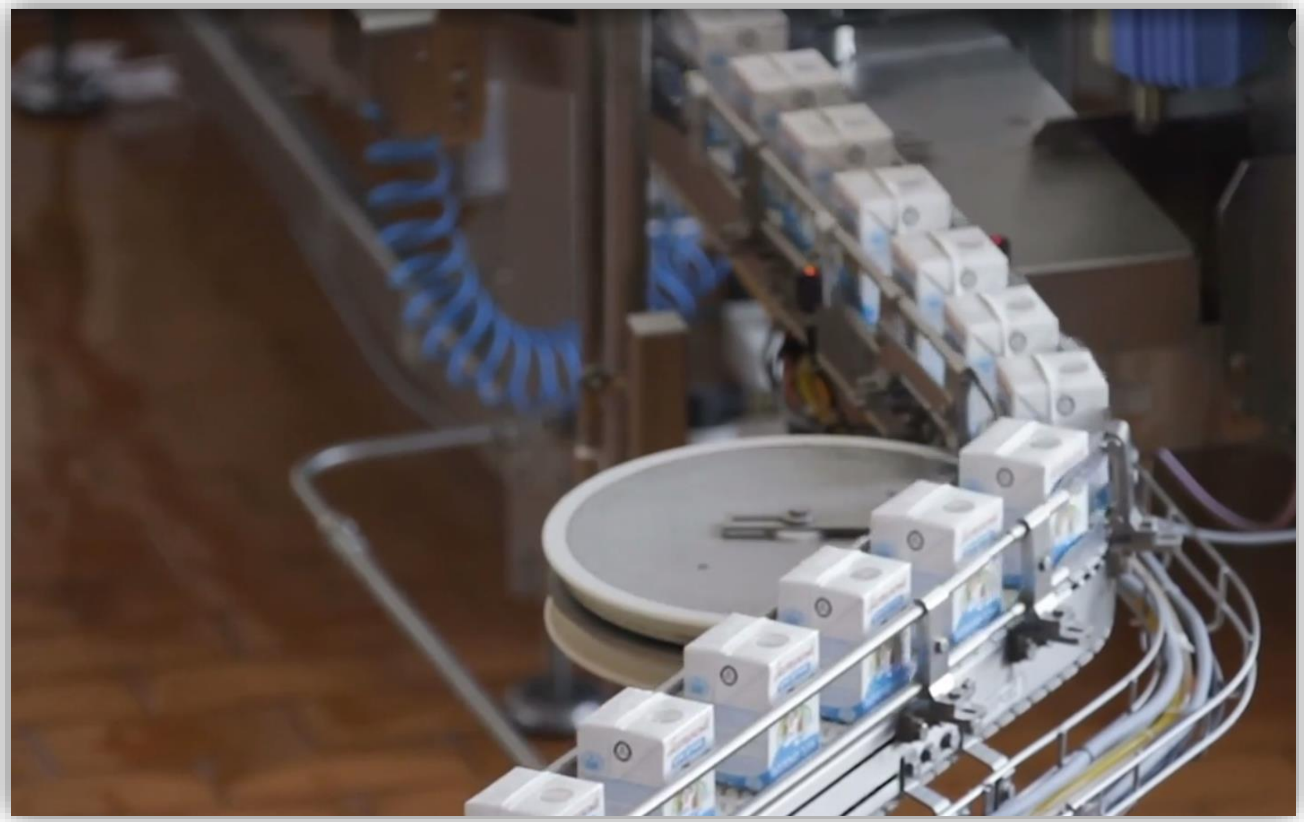


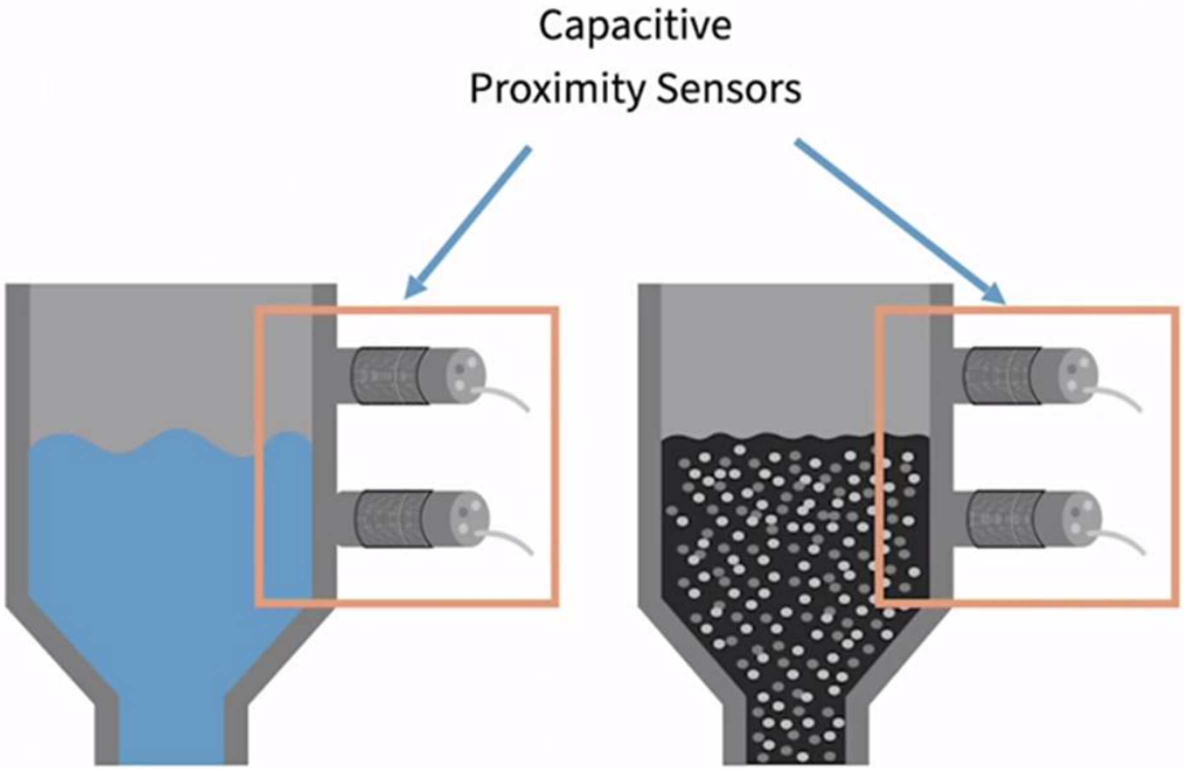
Capacitive Proximity Sensors

Non-contact sensors that can be used for Metal and Non-Metal objects (such as paper, glass and liquid). They detec the object through the change in Sensor's **Capacitance**.

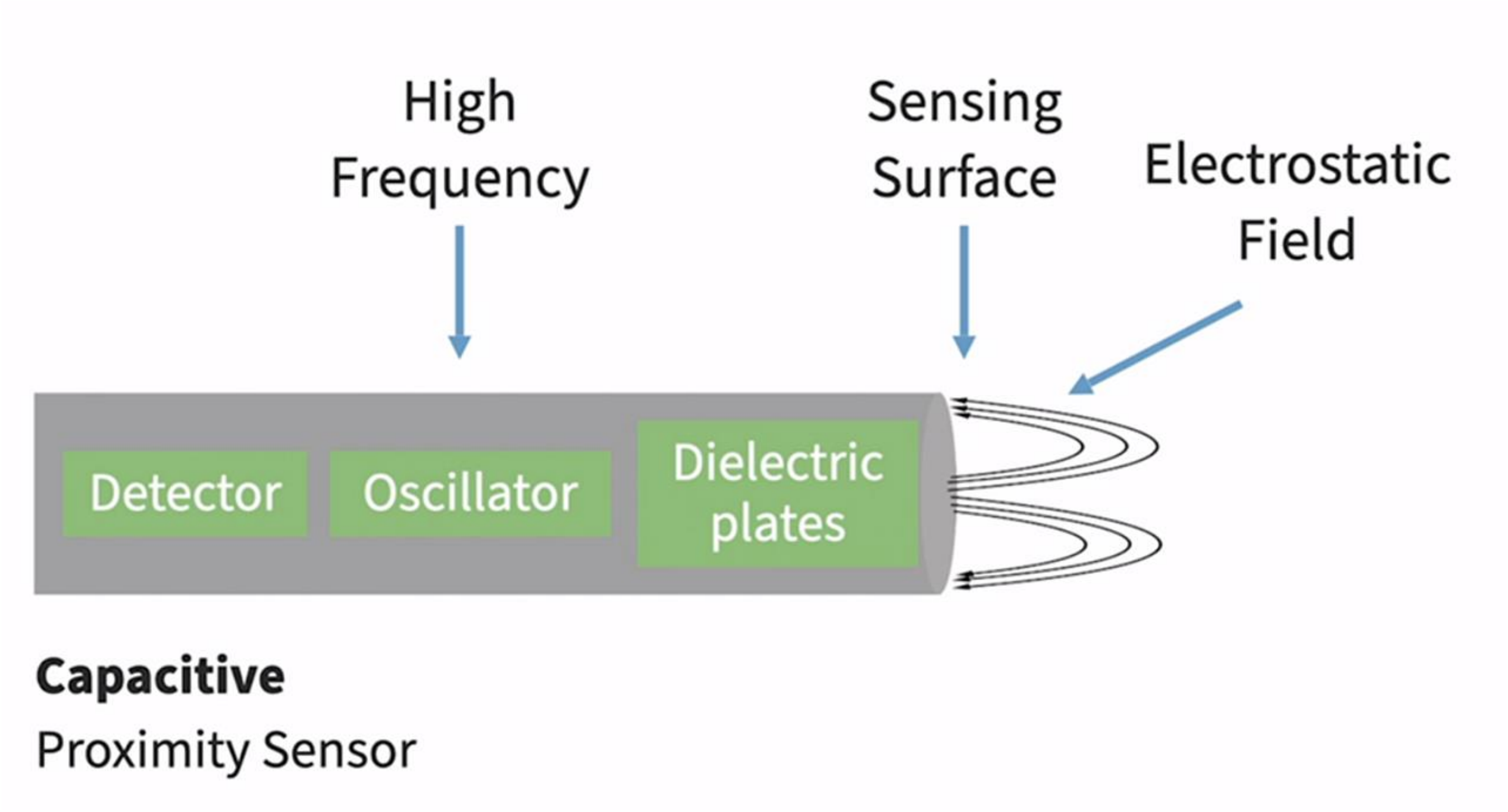


Applications of Capacitive Proximity Sensors

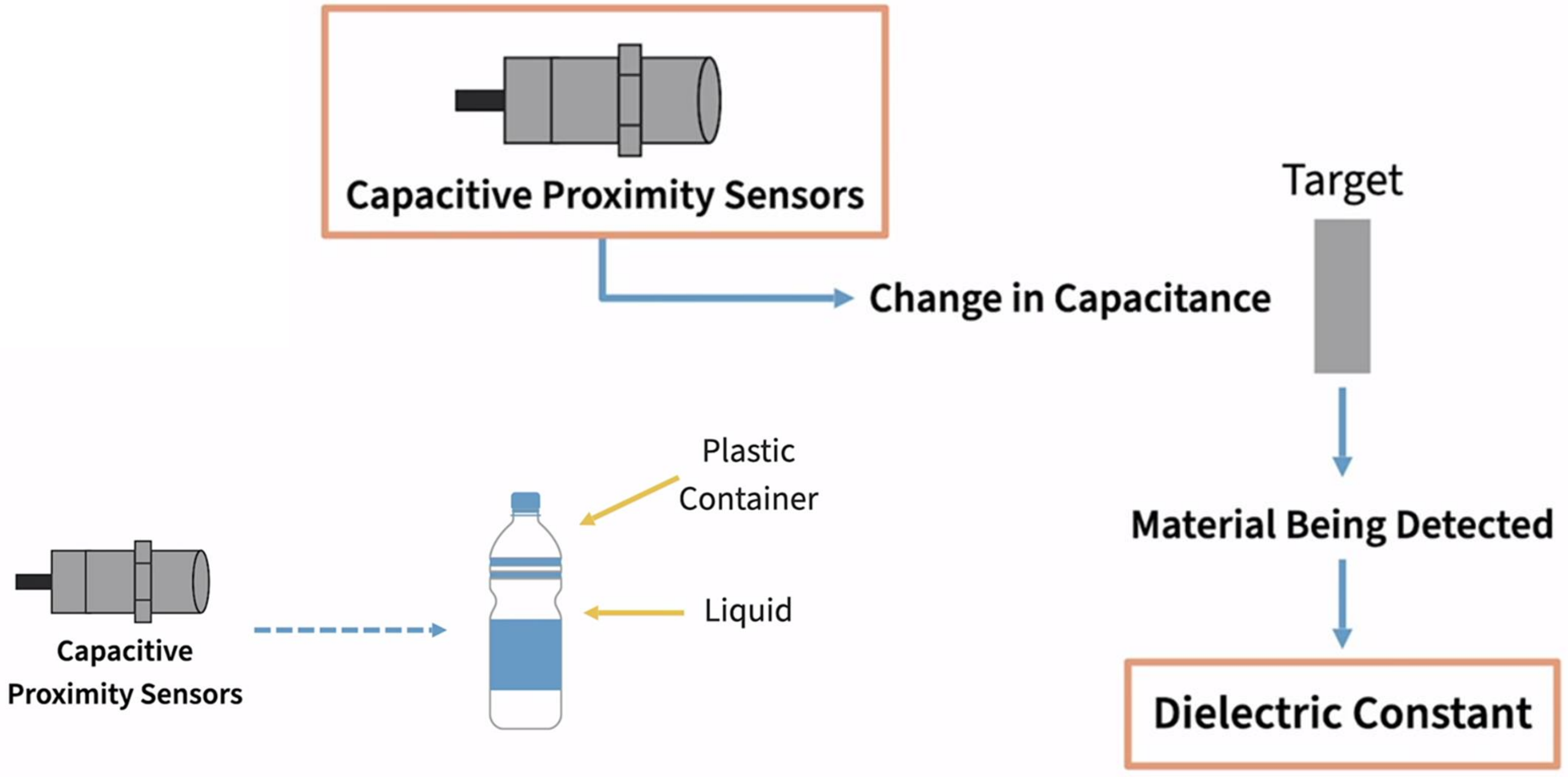




Operation Principle of Capacitive Proximity Sensors



Operation Principle of Capacitive Proximity Sensors



Paper (1 ream, 500 sheets)	0.55
Wood	0.45
Stone	0.65
Ceramic tile	0.25
PVC	0.15

Environmental Factors

Capacitive sensors can be compromised by humidity and moisture on the sensor face. Oil or water droplets on the sensor face can cause the unit to become unstable. Dust and moisture in the atmosphere have less of an effect on unshielded sensors than on shielded models.

Mounting Considerations

The sensor must be securely mounted on a firm, stable surface, or support. A mounting configuration, which is unstable or subject to excessive vibration, may cause intermittent operation.

Shielded vs. Unshielded

Shielded sensors can be mounted flush with surrounding materials. Unshielded sensors must be mounted such that the area around the sensing face is free of any material, which could trigger the sensor. Minimum clearance in all directions should be equal to the diameter or width of the sensor.

Spacing Between Devices

When two shielded or unshielded sensors are facing each other, they must be mounted far apart to avoid interference. Minimum spacing should be eight times the housing diameter or width. When two shielded sensors are mounted side by side, the minimum distance between them must be greater than one diameter or width. When two unshielded sensors are mounted side by side, the distance between them should be at least four times their diameter or width. See Dimensions section for housing sizes.

M18x1	Y	Pico	18 (0.71)	[illegible]	[illegible]
	N	Cable		51.8 (2.04)	51.8 (2.04)
	N	Pico			
M30x1.5	Y	Cable	30 (1.18)	53.1 (2.09)	53.1 (2.09)
	Y	Micro			
	N	Cable		52.1 (2.05)	46.1 (1.81)
	N	Micro			
N/A	N	Cable	34 (1.34)	52 (2.05)	N/A
	N	Micro			

Dielectric Constants of Industrial Materials

This is a partial listing. For more information, see the CRC Handbook of Chemistry and Physics (CRC Press), the CRC Handbook of Tables of Applied Engineering Science (CRC Press), or other applicable sources.

Dielectric Constants

Material	Value
Acetone	19.5
Acrylic resin	2.7…4.5
Air	1.000264
Alcohol	25.8
Ammonia	15…25
Aniline	6.9
Aqueous solutions	50…80
Bakelite	3.6
Benzene	2.3
Carbon dioxide	1.000985
Carbon tetrachloride	2.2
Celluloid	3
Cement power	4
Cereal	3…5

Definition of Controller:

Once a robot has a motion plan, it is time to act. How do you ensure that the robot's execution follows the desired plan? Controlling a large robotic system to do a task often involves solving many smaller control problems, reaching down to the level of controlling individual motors.

Controller

The combination of hardware and software that together program and control a robotic system.

A programmable device that converts an error signal to a current/voltage command, which regulates the behavior of the dynamic system.

Feedforward (Open-Loop)

Uses the model of the dynamics of the controlled system to make proactive decisions on the commands to send to the robot actuators

Feedback (Closed-Loop)

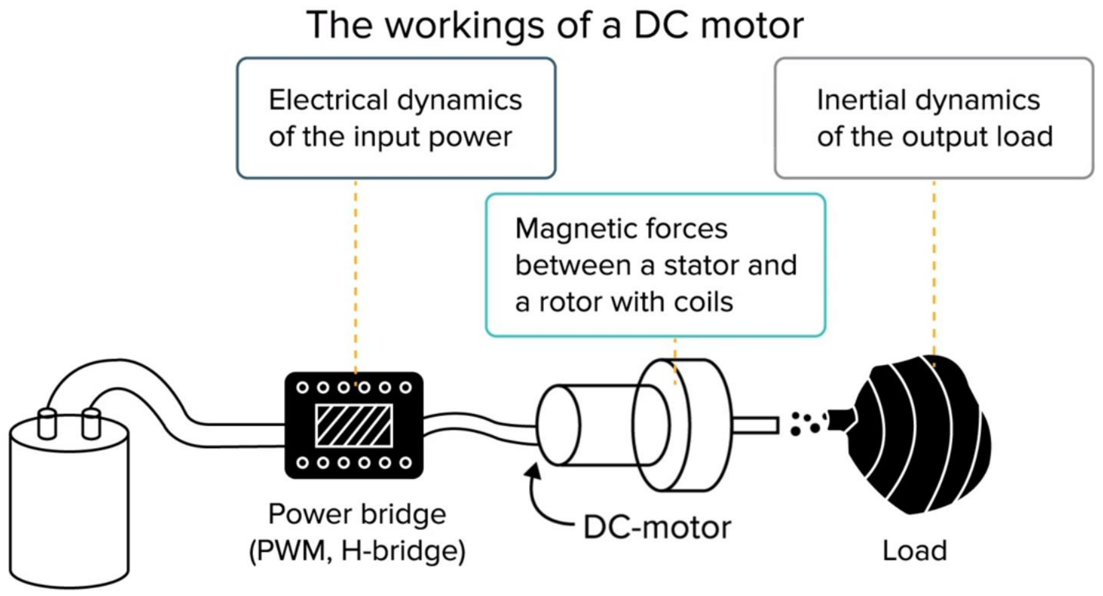
Uses the output of the dynamic system as an input to the control decision process. More robust differences between the real and modeled systems than open-loop control.

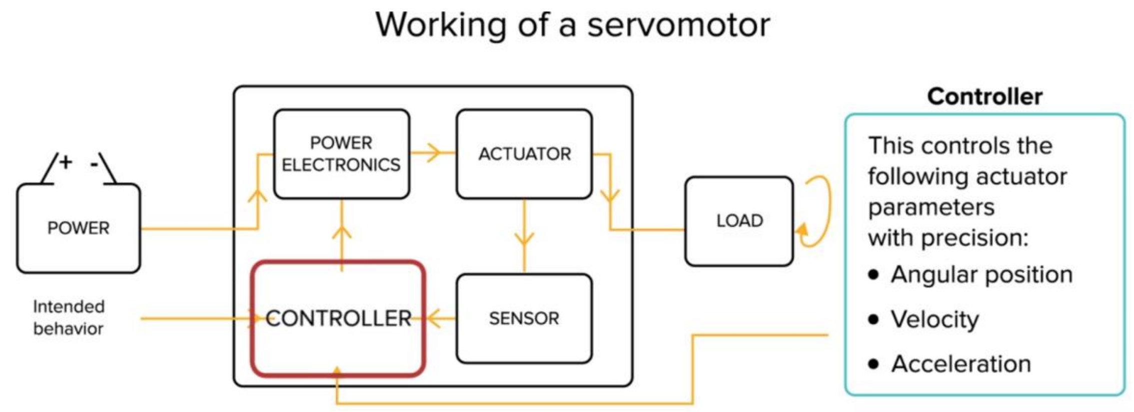
Control

The study of the process of regulating the output of an actuator or the behavior of a dynamical system

Control and Regulation

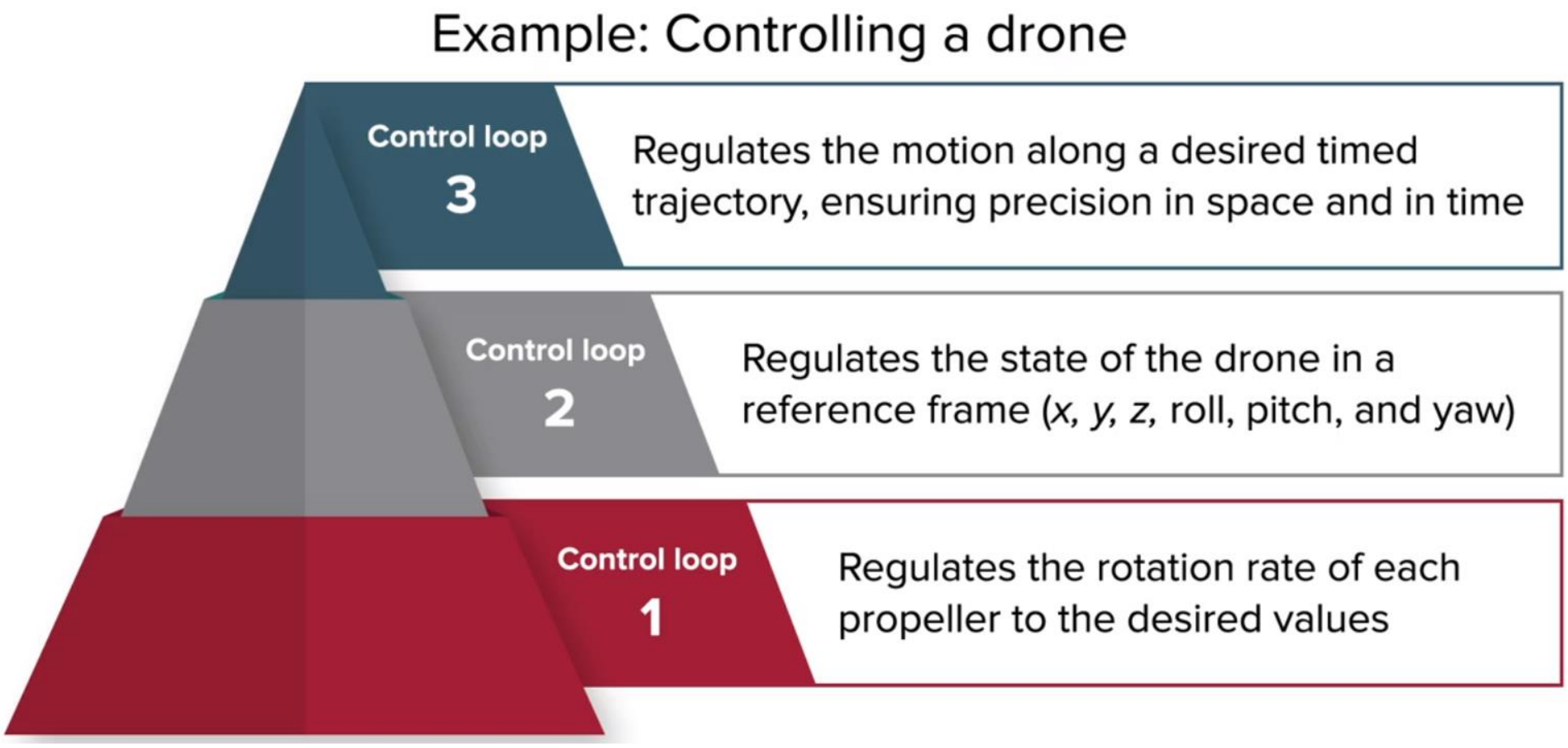
- Control is tightly connected with the notion of regulation
- The goal of control is to maintain a physical quantity around the desired value, even when we have imperfect knowledge of the dynamics governing that physical quantity
- For example:
  - Balancing a robot on a single wheel around the vertical with an uncertain mass
  - Maintaining a rotary actuator around a particular angle while fighting against external forces



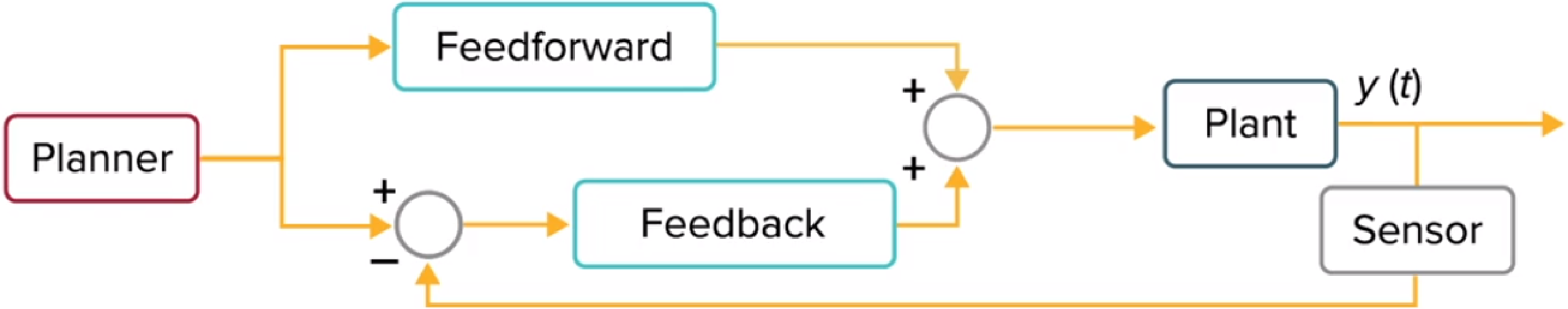


Control
The study of the process of regulating the output of an actuator or the behaviour of a dynamical system

Hierarchy of the control Loop



Feedforward vs. Feedback



Feedforward or open-loop control

- Uses the model of the dynamics of the controlled system to make proactive decisions on the commands to send to the robot actuators
- Control focuses on fast decision rates possibly with simpler models

Feedback or closed-loop control

- Uses the output of the dynamic system as an input to the control decision process while overcoming the differences between the real and modeled systems
- The output signal is usually captured by a sensor that facilitates the process of regulating the output to a desired value

Feedforward vs. Feedback

Feedforward or open loop control

- Uses the model of the dynamics of the controlled system to make proactive decisions on the commands to send to the robot actuators
- Control focuses on fast decision rates possibly with simpler models
- It is proactive and can anticipate the needs of the system

VS.

Feedback or closed loop control

- Uses the output of the dynamic system as an input to the control decision process while overcoming the differences between the real and modelled systems
- The output signal is usually captured by a sensor that facilitates the process of regulating the output to a desired value
- It is reactive and this leads to delays due to latency in sensing and processing

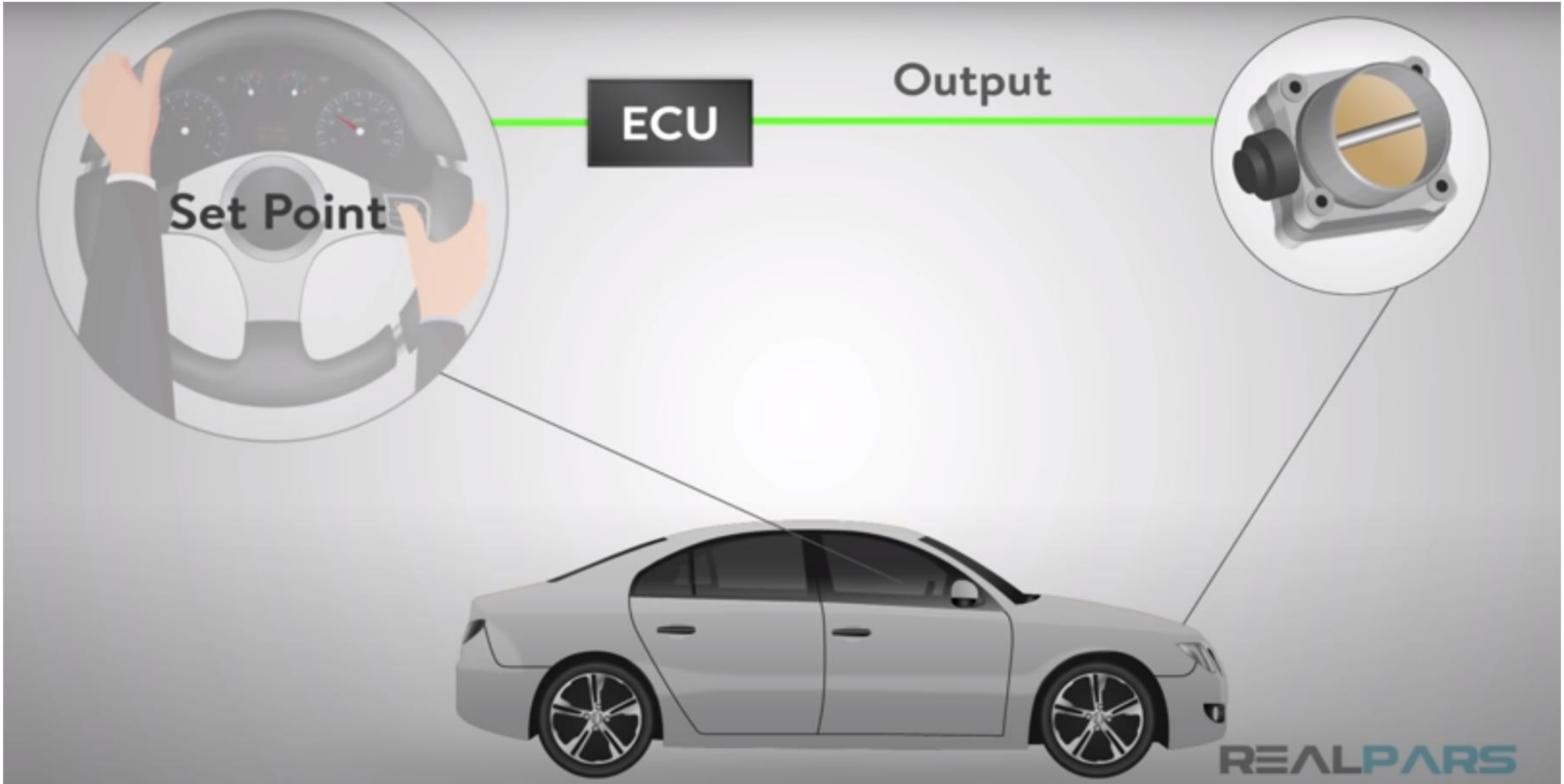
In class assignment-Submit in ilearn

In this group assignment:

1.Select a robotic system from a news article, popular culture (i.e., movie, book, comic, etc.), or your imagination that moves autonomously. Your selected robot should enable you to explore topics in control.

2. With your selected robot in mind, please write a response that includes the following points:
   - What is one physical quality that needs to be regulated during the task? (e.g., position, velocity, force, etc.)
   - If you were to use feedback, what sensor could the robot use to measure the physical quality? (e.g., encoder, IMU, etc.)
   - Explain any hierarchies of control within this task.
   - Briefly describe a control task your robot performs. Considering the task, answer the following questions:
   - What would be the failure case of your system if the desired value is not sufficiently regulated?

PID controller



Types of Controllers

- Commonly used continuous controller
- Design or selection of the parameters are not trivial

Proportional Integral Derivative (PID)

- Parameters can be selected through optimization

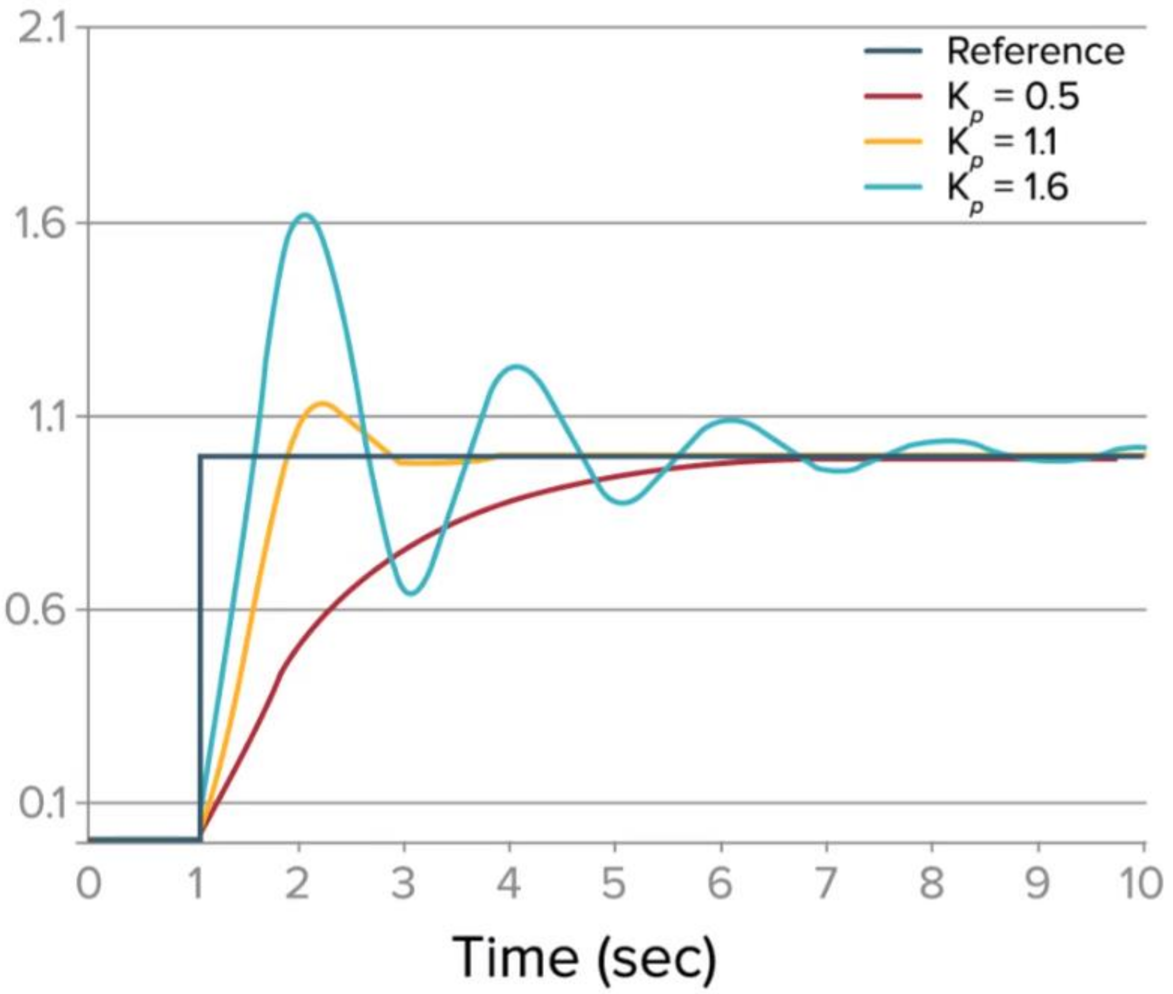
Linear Quadratic Regulator (LQR)

- Suitable for systems subject to non-linear dynamics and to constraints, such as actuator limits or under actuation

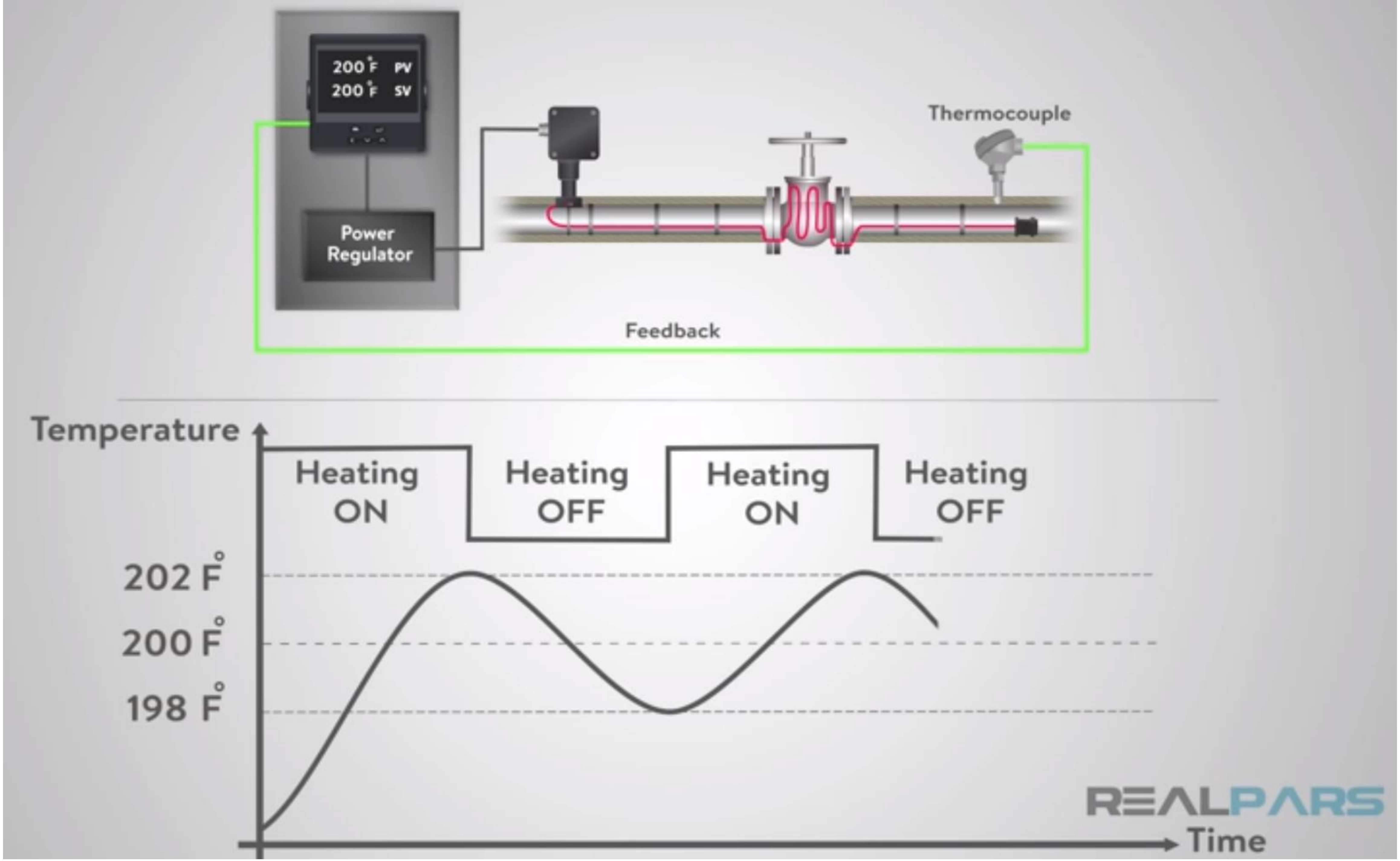
Model Predictive Control (MPC)

Proportional Controller

Proportionality constant



Source: TimmyK. (2014). *Graph showing output on PID controller* [Illustration]. https://commons.wikimedia.org/wiki/File:PID_varyingP.jpg


200°F PV
200°F SV
Power Regulator
Thermocouple
Feedback
Temperature
Heating ON
Heating OFF
Heating ON
Heating OFF
202 F°
200 F°
198 F°
REALPARS
Time

Limitations of Proportional Controller

Steady-state error

- As the controller is gradual, static forces, such as friction, make it difficult or impossible to reach the target because:
  - When approaching the target, the magnitude of the control signal decreases
  - The moment the magnitude goes below the parasitic static forces, the system stops moving without reaching the target

Overshooting

- Increasing K_p makes the controller faster but also:
  - Increases overshooting
  - Encourages undesired oscillations around the target

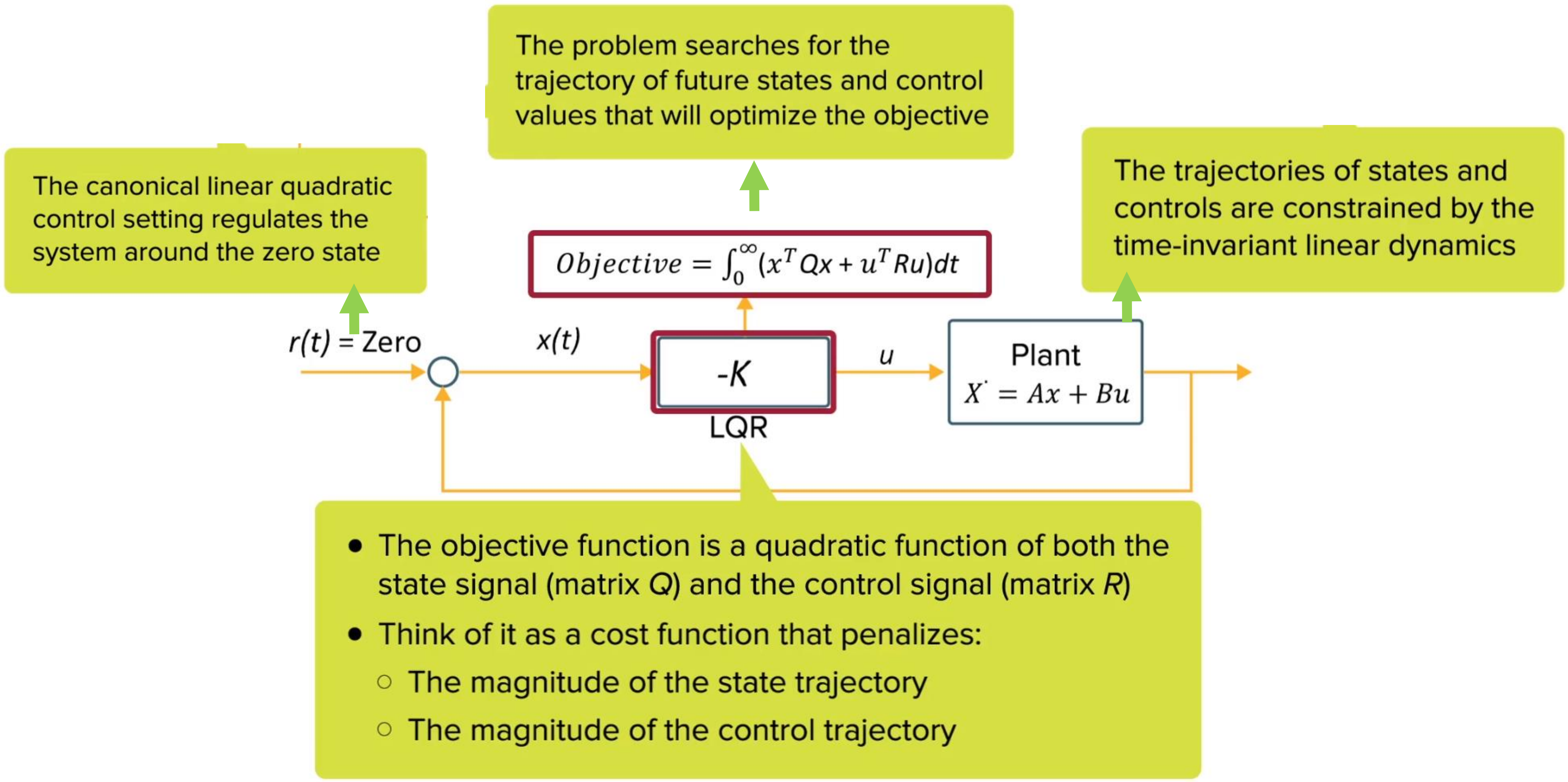
Linear-Quadratic Regulators

Linear time-invariant (LTI) system

In a linear system, there is a proportional relationship between the input and the output

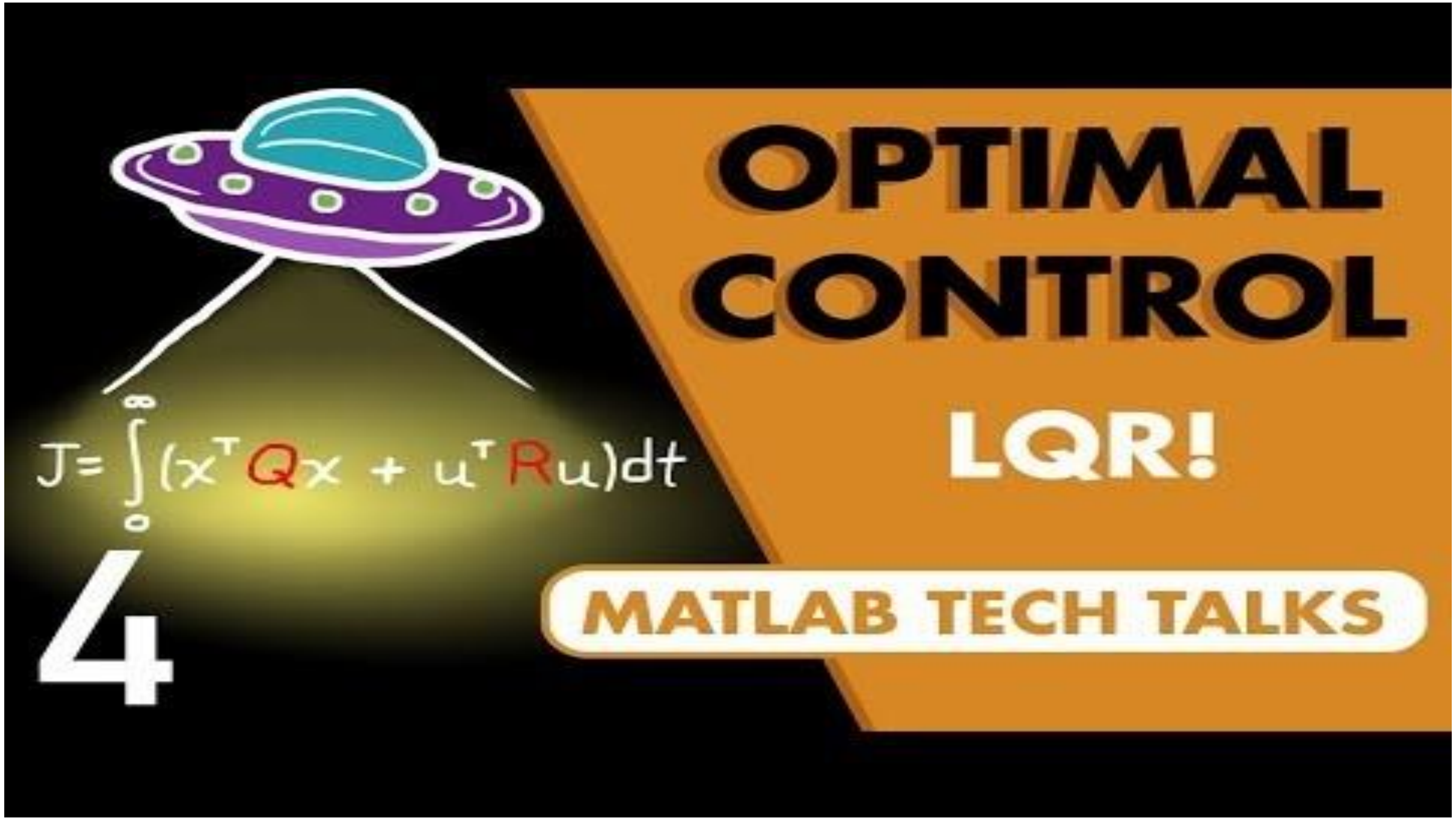
In a time-invariant system, that proportionality remains constant in time

- Linear systems are theoretical constructs
- They help explain the structure of control problems
- They are relevant to real non-linear systems
- The linear control law involves proportionality of the position and velocity, analogous to the proportional and derivative controllers in a proportional-integral-derivative (PID) controller


The problem searches for the trajectory of future states and control values that will optimize the objective
The canonical linear quadratic control setting regulates the system around the zero state
The trajectories of states and controls are constrained by the time-invariant linear dynamics
$Objective = \int_0^\infty (x^T Qx + u^T Ru)dt$
$r(t)$ = Zero
$x(t)$
-K
LQR
u
Plant
$X^\cdot = Ax + Bu$
• The objective function is a quadratic function of both the state signal (matrix Q) and the control signal (matrix R)
• Think of it as a cost function that penalizes:
○ The magnitude of the state trajectory
○ The magnitude of the control trajectory

Watch at home

What Is Linear Quadratic Regulator (LQR) Optimal Control?



https://www.youtube.com/watch?v=E_RDCFOlJx4&ab_channel=MATLAB

End of week 7