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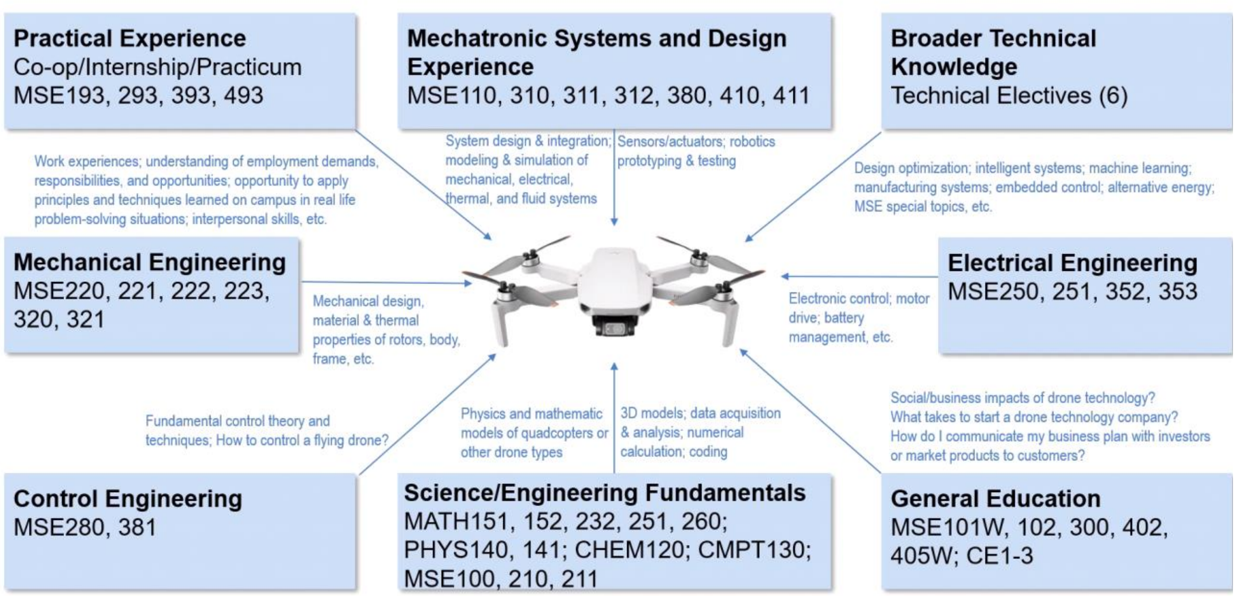
Chapter 1 -

MSE Course Mapping: How Do I Learn to Design My Own Drone?



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MSE 310: Sensor and Actuators

Course Objective:

This course introduces sensors and actuators for electromechanical, computer-controlled machines and devices. Component integration and design considerations are studied through examples selected from various mechatronic applications.
Laboratory exercises to strengthen the understanding of the course material

About Lecture

Instructor: Dr. Ahad Armin P. Eng.

- Email: aarmin@sfu.ca
- Course Website: Canvas – http://canvas.sfu.ca

Class Time: Monday 8:30-10:20 & Wednesday 8:30-9:20

Tutorial Time: Wednesday 9:30-10:20

In-person Lecture: SRYC 3310

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Course Composition

(**Dates are confirmed**)

Term Exam 60 % (Oct. 3rd, Nov 7th, Dec.5th)

In-class quiz 5 %: every Wednesday tutorial class

Lab Report 15 % (a compiled report of computing labs & lab demo**)**
(Report Deadline : two weeks after your lab session)

Project 20% (Report Deadline Date: **Dec 6th** Tuesday 11:59 PM**)**
Team Project with 3 members (No individual submission accepted)

- Composition of team members to be submitted until September 30th

No Final Exam

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Textbook

"Sensors, Actuators, and Their Interfaces: A Multidisciplinary Introduction, 2nd Edition", by Nathan Ida

https://shop.theiet.org/sensors-actuators-and-their-interfaces-2nd-edition

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Class Schedule

Week	Topic
1	Introduction
2	Performance Characteristics
3	Temperature sensors
4	Optical sensors and actuators
5	Electric and magnetic sensors and actuators
6	
7	
8	Mechanical sensors and actuators
9	
10	Acoustic sensors and actuators
11	
12	Radiation sensors and actuators

Lab Compositions

Lab sessions: Monday/Friday

Computing labs: SRYC 4080

Topic/Event:

Lab 1 (LabView Introduction)

Lab 2 (LabView Advanced)

Lab 3 (LabView Data Acquisition)
Lab 4 (Project Support)
Lab 5 (Project Demonstrations)

TEACHING ASSISTANTS (TA)

Name	E-mail
Victor Soares	vht2@sfu.ca
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Milad Seifnejad Haghighi	msa327@sfu.ca

Teaching Assistants will

- teach and participate in lab sessions
- help you with your lab-based assignments and projects
- grade your exams

Class Rules

Class Rules

- Class attendance and participation is **very important**
- No lateness/absence: be on time and enter quietly if you're late
- No cell phones: don't interrupt others' learning

Other Regulations

- Refer to SFU Calendar for general policies on course withdrawal, academic dishonesty, etc.
Specially any dishonesty conducted by mobile devices (smart phone or watch) in any quizzes or exams will be failed.

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GRADING POLICY

 If you’re unable to write any exams (or any other acceptable reasons as specified in the SFU Calendar), their contributions to the final grading will be transferred to other exam components.

 Late submission of reports: your mark will be reduced (10%, 20% depending on lateness).

 Your term marks will be posted on the Canvas by the end of the semester.

Additional Notes:

 The instructor has the right to change the grading scheme, and any changes will be announced in a lecture in advance.

 All examinations are closed-book, unless stated otherwise by the instructor.

 Self-contained calculators are allowed in all exams.

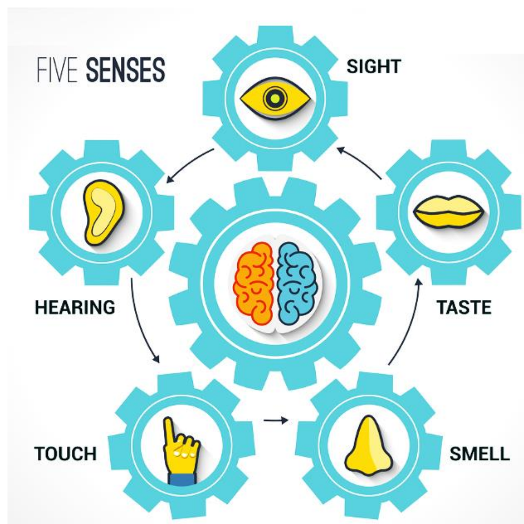
Chapter 1: Introduction

I. Introduction-Sensors/Actuators
II. Definition
III. Case Study-Sensors/Actuators
IV. Classification of sensors/Actuators
V. Units

Introduction-Sensors

The five senses

- Vision (Optical)
- Hearing (Acoustic)
- Smell and Taste (Chemical)
- Tactile/touch (Mechanical)



Question: Can humans sense other physical phenomena? How about other creatures?

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Introduction-Actuators

- Organisms also have a variety of actuators to interact with their environment such as hand, foot, eyes, and etc.

- In industry nowadays we have thousands of actuators:

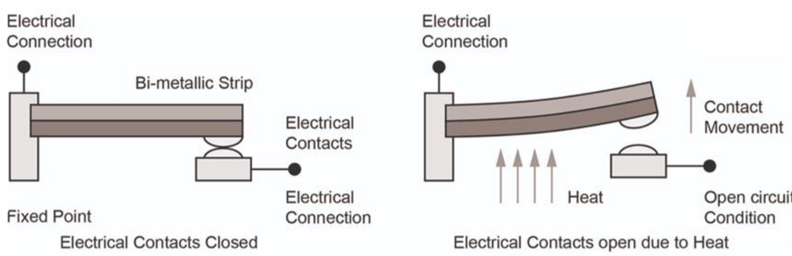
  - Circuit breakers (Thermal and/or Magnetic)
  - Optical Tweezers (Optical)
  - Electric motors (Electromagnetic)
  - Airbag deployment (Chemical)

Question: What are other examples of actuators can you think of? How would you categorize them?

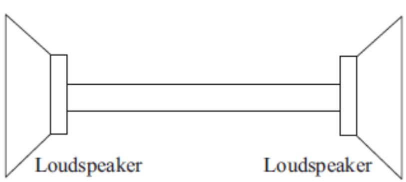
Can we have a device that can be used as both, a sensor or an actuator?

Definition

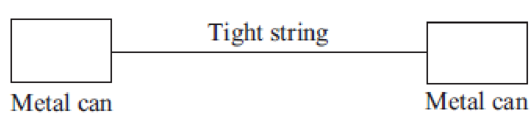
- There is always a blurred boundary between ***Sensors, Actuators*** and ***Transducers*** (three main components of this course)
  - For example: Bimetallic switch is a ***temperature sensor*** that ***activates*** a switch (cooking thermometer, thermostat). Sensor? or Actuator?



  - Connecting two loudspeakers



Which one is sensor, actuator, and transducer?



https://materiability.com/portfolio/thermobimetals/#&gid=3&pid=1

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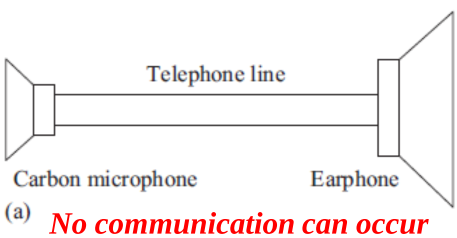
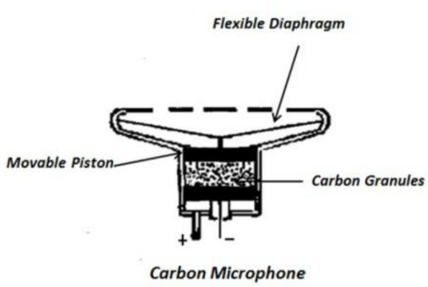
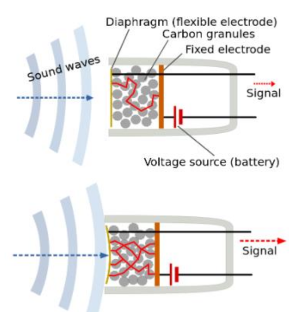
Definition

- Another Example is Carbon microphone.
- Operates on the principle of changes in resistance
  - ➢ Acoustic power moves a membrane, presses on carbon particles. This changes the resistance between the two electrodes of the microphone.



No communication can occur

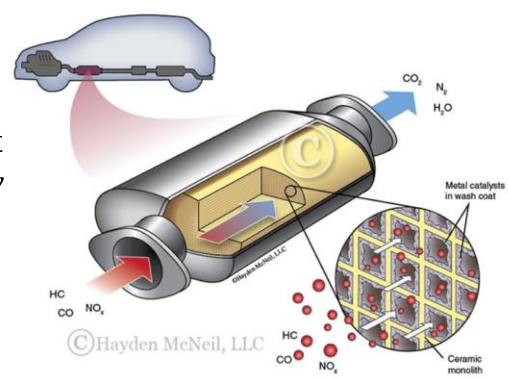




https://www.tekportal.net/carbon-microphone/

Definition

- ***Sensor:*** A device that *responds* to a physical stimulus.
- ***Transducer:*** A device or mechanism that *converts* power of one form into power of another form.
- ***Actuator:*** A device or mechanism capable of performing a *physical action* or *effect*.
- It is common to assume that ***sensors*** have an ***electrical output*** or ***actuators*** perform some type of motion or involve the exertion of force.
- We shall make ***no such*** assumptions:
  - ➢ The output of sensor can be mechanical/pneumatic, etc.
  - ➢ Physical action of an actuator may not involve force at all (*light bulb*, *display monitor*, or chemical reaction in catalytic *converter* of a car)



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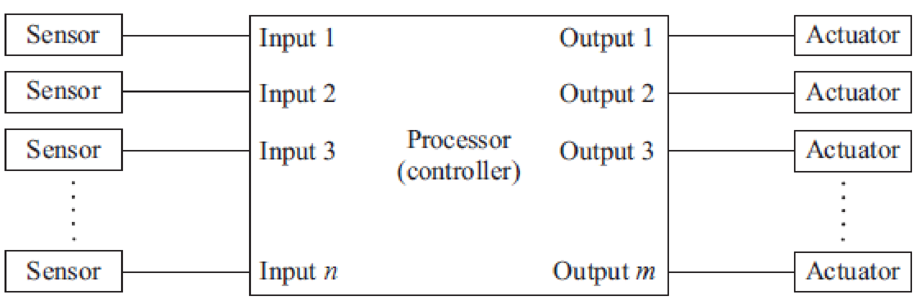
Definition

- More general definition is for a ***sensor*** to be the ***<u>input</u>*** to a system, whereas an ***actuator*** is an ***<u>output</u>***.
- In between, there is a processor that accepts the inputs, processes the data, and acts through the actuators which are connected to the output of the system.
  - ➢ processor interfaces between the sensors and actuators.



Adopted from Fig. 1.4, Nathan Ida, 2e

Case Study

- A modern car contains dozens of sensors and actuators.
- All are connected to a processor (often called an electronic control unit [ECU]) as inputs and outputs.
- Some of the "sensors" are switches or relays used to just *detect* conditions
- Most of the actuators are *solenoids*, *valves*, or *motors*, but some are indicators such as the *low-oil-pressure lamp* or an "open door" *buzzer*.

Sensors?

Actuators?

https://en.wikipedia.org/wiki/Lamborghini_Aventador#/media/File:Aventador._(6675860749).jpg

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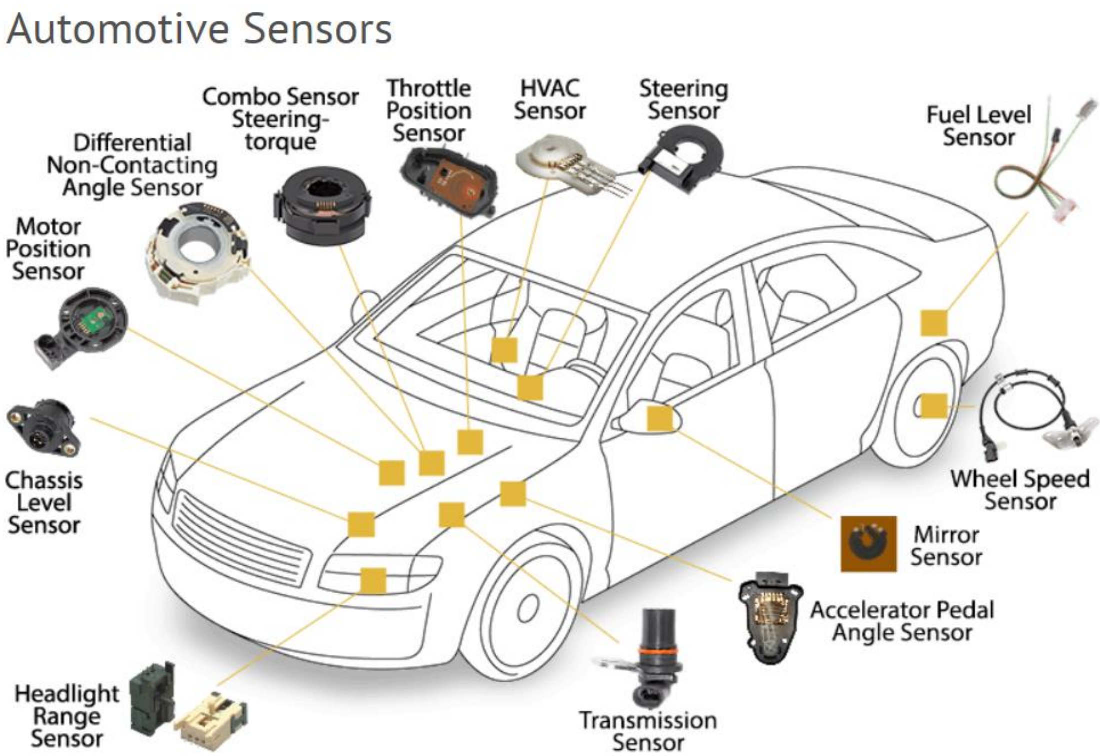
Case Study-Sensors



https://www.bourns.com/products/automotive/automotive-sensors

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Case Study-Sensors

Sensors

Crankshaft position (CKP) sensor
Camshaft position (CMP) sensor (two)
Heated oxygen sensor (HO_2S) (two or four)
Mass air flow (MAF) sensor
Manifold absolute pressure (MAP) sensor
Intake air temperature (IAT) sensor
Engine coolant temperature (ECT) sensor
Engine oil pressure sensor
Throttle position (TP) sensor (one to four)
Fuel composition sensor (for alternative fuels)
Fuel temperature sensor (one or two)
Fuel rail pressure sensor
Engine oil temperature sensor
Turbocharger boost sensor (one or two)
Rough road sensor
Knock sensor (KS) (one or two)
Exhaust gas recirculation sensor (one or two)
Fuel tank pressure sensor
Evaporative emission control pressure sensor
Fuel level sensor (one or two)
Purge flow sensor
Exhaust pressure sensor
Vehicle speed sensor (VSS)
Cooling fan speed sensor
Transmission fluid temperature (TFT) sensor
A/C low-side temperature sensor
A/C evaporator temperature sensor
A/C high-side temperature sensor
A/C refrigerant overpressure
Left A/C discharge sensor
Right A/C discharge sensor
Power steering pressure (PSP) switch
Transmission range sensor
Input/turbine speed sensor
Output speed sensor
Secondary vacuum sensor
Alternative fuel gas mass sensor
Accelerator pedal position sensor (two)
Barometric pressure sensor
Cruise servo position sensor
Brake boost vacuum (BBV) sensor
Wheel speed sensor (one on each wheel)
Steering hand wheel speed sensor
Left heater discharge sensor
Right heater discharge sensor
Mirror horizontal position sensor
Mirror vertical position sensor
Driver recline sensor
Driver lumbar horizontal sensor
Driver lumbar vertical sensor
Driver belt tower vertical sensor
Recline sensor
Right rear position sensor

Adopted from Nathan Ida, 2e

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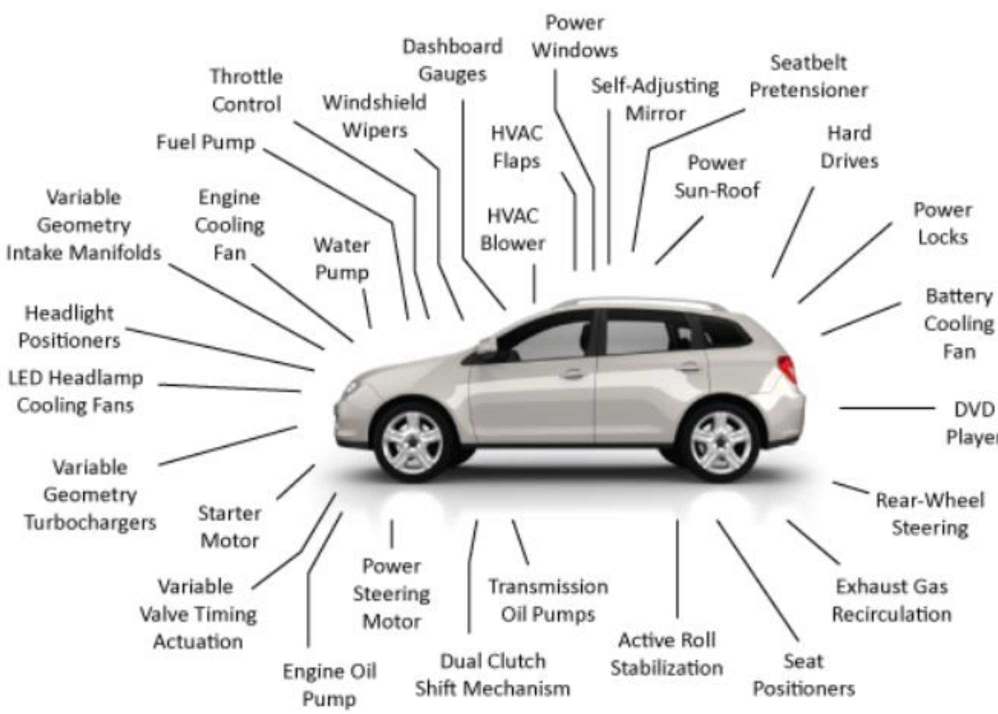
Case Study-Sensors

A/C refrigerant pressure sensor
Rear vertical sensor
Front horizontal sensor
Front vertical sensor
Lumbar forward/aft sensor
Lumbar up/down sensor
Left front mirror vertical position sensor
Right front mirror vertical position sensor
Driver front vertical sensor
Driver rear vertical sensor
Driver seat assembly horizontal sensor
Twilight photocell
Seat back heater sensor
Telescope position sensor
Tilt position sensor
Security system sensor
Automatic headlamp leveling device (AHLD)
AHLD rear axle sensor
Window position sensor
Evaporative emission (EVAP) system leak detector
Left front position sensor
Right front position sensor
Left rear position sensor
Right rear position sensor
Level control position sensor
Tire pressure monitor (TPM) system sensor (four)
Vehicle stability enhancement system (VSES) sensor
Yaw rate sensor
Lateral accelerometer sensor
Steering sensor
Brake fluid pressure sensor
Left front/driver side impact sensor (SIS)
Electronic front end sensor (one or two)
Outside air temperature sensor
Ambient air temperature sensor
Passenger compartment temperature sensor (one or two)
Output air temperature sensor (one or two)
Solar load sensor (one or two)
Rear discharge temperature sensor front axle sensor
Right-hand panel discharge temperature sensor
Discrete sensor
Evaporator inlet temperature sensor
Left-hand sun load sensor
GPS antennas, satellite antennas, radio antennas, ultrasound and accelerometers for theft prevention, etc.

Adopted from Nathan Ida, 2e

Case Study-Actuators



https://cecas.clemson.edu/cvel/auto/actuators/motors-electric.html

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Case Study-Actuators

Actuators

Turbocharger wastegate solenoid (two)
Exhaust gas recirculation (EGR) solenoid
Secondary air injection (AIR) solenoid
Secondary air injection switching valve (two)
Secondary air injection (AIR) pump
EVAP purge solenoid valve
Evaporative emission (EVAP) vent solenoid
Intake manifold tuning (IMT) valve solenoid
TCC enable solenoid
Torque converter clutch
Shift solenoid A
1–2 shift solenoid valve
Shift solenoid B
2–3 shift solenoid valve
Shift solenoid C
Shift solenoid D
Shift solenoid E
3–2 shift solenoid
Shift/timing solenoid
1–4 upshift (skip shift) solenoid
Line pressure control (PC) solenoid
Shift pressure control (PC) solenoid
Shift solenoid (SS) 3
Shift solenoid (SS) 4
Shift solenoid (SS) 5
Intake resonance switchover solenoid
Reverse inhibit solenoid
Pressure control (PC) solenoid
A/T solenoid
Torque converter clutch (TCC)/shift solenoid
Brake band apply solenoid
Intake manifold runner control (IMRC) solenoid
Left front ABS solenoid (two)
Right front ABS solenoid (two)
Left rear ABS solenoid (two)
Right rear ABS solenoid (two)
Left TCS solenoid (two)
Right TCS solenoid (two)
Steering assist control solenoid
Left front solenoid
Right front solenoid
Left rear solenoid
Right rear solenoid
Exhaust solenoid valve
Secondary air injection switching valve (two)
Evaporative emission system purge control valve
Exhaust pressure control valve
Intake plenum switchover valve
Exhaust gas recirculation system valve 1
Exhaust gas recirculation system valve 3

Adopted from Nathan Ida, 2e

SFU Case Study-Actuators

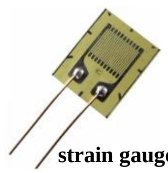
Fuel solenoid
Cruise vent solenoid
Cruise vacuum solenoid
Right front inlet valve solenoid
Right front outlet valve solenoid
Left rear inlet valve solenoid
Left rear outlet valve solenoid
Right rear inlet valve solenoid
Right rear outlet valve solenoid
Left front TCS master cylinder isolation valve
Left front TCS prime valve
Right front TCS master cylinder isolation valve
Right front TCS prime valve
Exhaust solenoid valve short to ground (GND)
Throttle actuator control (TAC) motor
Pump motor
Mirror motor (one on each side)
Tilt/telescope motor
Throttle valve
Electronic brake control module (EBCM) control valve
Level control exhaust valve
Left front inlet valve solenoid
Left front outlet valve solenoid
Front washer motor
Rear washer motor
Front wiper relay
Rear wiper relay
HVAC actuator
Coolant thermostat
Injectors (air, fuel) (one per cylinder)
Window motors
Electric door motors
Cooling fans in engine
Cooling/heating fans in compartment
Starter motor
Alternator
Catalytic converter

Adopted from Nathan Ida, 2e

Classification of sensors

- There is no single method of classification general enough to include all types of sensors and actuators. Some main classifications of **sensors** are:

1. **Active** vs **Passive:**


strain gauges


thermistors


proximity sensors

Active:

- ➢ Requires ***external power*** (they can only be used after a source is connected so that an electric signal can be modified by the relevant property change)
- ➢ Often called ***Parametric Sensors***, as they depend on change of sensor parameters (strain gauges, thermistors, capacitive proximity sensors, etc.)

Passive:


solar cells


piezoelectric sensors

- ➢ ***Do not*** require external power
- ➢ Often called ***Self-Generating*** *(e.g. solar cells, piezoelectric sensors, and magnetic microphones)*

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Classification of sensors

2. **Contact** vs **Non-contact**
- Some sensors can be used in both mode (Thermistor measuring the temperature of an engine is a *contact sensor*, but when measuring ambient temperature in the car it is not)

3. **Absolute vs Relative**
- An absolute sensor reacts to a stimulus in reference to an absolute scale (Thermistor, Proximity sensor, etc.)
- A relative sensor's output depends on a relative scale (Thermocouple, Pressure sensor, etc.)

4. **Application**
5. **Physical phenomena used**
6. **Detection method**
7. **Sensor specifications,** and many others.

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Classification of sensors/actuators

By area of detection	By measured output	By physical effects and laws
Electric	Resistive	Electrostrictive
Magnetic	Capacitive	Electroresistive
Electromagnetic	Inductive	Electrochemical
Acoustic	Current	Electro-optic
Chemical	Voltage	Magnetoelectric
Optical	Resonant	Magnetocaloric
Thermal	Optical	Magnetostrictive
Temperature	Mechanical	Magnetoresistive
Mechanical		Photoelectric
Radiation		Photoelastic
Biological		Photomagnetic
		Photoconductive
		Thermomagnetic
		Thermoelastic
		Thermo-optic
		Thermoelectric

By specifications	By area of application	Other classifications
Accuracy	Consumer products	Power
Sensitivity	Military applications	Interfaces
Stability	Infrastructure	Structure
Response time	Energy	
Hysteresis	Heat/thermal	
Frequency response	Manufacturing	
Input (stimulus) range	Transportation	
Resolution	Automotive	
Linearity	Avionics	
Hardness	Marine	
Cost	Space	
Size	Scientific	
Weight		
Construction materials		
Operating temperature		

Adopted from Table. 1.1, Nathan Ida, 2e

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Classification of Actuators

- Beside all classification of sensor that applies to actuators, there are some additional classifications for actuators:

By type of motion	By power
Linear	Low-power actuators
Rotary	High-power actuators
One axis	Micropower actuators
Two axes	Miniature actuators
Three axes	Microactuators
	MEMS actuators
	Nanoactuators

Adopted from Table. 1.2, Nathan Ida, 2e

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Units (Base SI Units)

Physical quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Adopted from Table. 1.3, Nathan Ida, 2e

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Derived Units

- Most other metric units in common use are derived from the base units based on their relationship.
- $\boldsymbol{Force}\ (\boldsymbol{N}) = Mass(kg) \times Acceleration\left(\frac{m}{S^2}\right)$

$$\boldsymbol{N} = \left(\frac{\boldsymbol{kg.m}}{\boldsymbol{S^2}}\right)$$

- ***Electric Potential (Volt):*** Voltage describes the amount of energy associated with electric charge as it moves around in a circuit.
  - Voltage = Electric field intensity × Distance
  - Electric field intensity in terms of force F and charge q (Coulomb's law): $E = F/q$, whose units are newtons/coulomb (N/C).
  - Coulomb is the unit of charge measured as ampere-seconds (A.s)

$$\boldsymbol{V = E.d}$$

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Derived Units

- ***Capacitance (Farad):*** The farad is derived from the relation between charge and voltage: $C = \frac{Q}{V}$

$$\boldsymbol{C = \frac{Q}{V}}$$

- ***Energy (Joule):*** Energy is force integrated over distance

$$\boldsymbol{J = (N.m) = (\frac{kg.m^2}{S^2})}$$

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Unit Conversion

$$W = H \times \frac{1}{1} \times \frac{1}{1}$$

- Pounds per square inch (psi) is commonly used in the United States as a measure of pressure.
  - ➢ Convert psi into metric units.

$$\frac{N}{m^2} = \frac{lbf}{in^2} \times \frac{N}{lbf} \times \frac{in^2}{m^2}$$

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Unit Prefixes

Prefix	Symbol	Multiplier	Examples	Notes
yocto	y	10^{-24}		
zepto	z	10^{-21}		
atto	a	10^{-18}		
femto	f	10^{-15}	fs (femtosecond)	Optics, chemistry
pico	p	10^{-12}	pF (picofarad)	Electronics, optics
nano	n	10^{-9}	nH (nanohenry)	Electronics, materials
micro	µ	10^{-6}	µm (micrometer)	Electronics, distances, weights
milli	m	10^{-3}	mm (millimeter)	Distances, chemistry, weights
centi	c	10^{-2}	cl (centiliter)	Fluids, distances
deci	d	10^{-1}	dg (decigram)	Fluids, distances, weights
deca	da	10^{1}	dag (decagram)	Fluids, distances, weights
hecto	h	10^{2}	hl (hectoliter)	Fluids, surfaces
kilo	k	10^{3}	kg (kilogram)	Fluids, distances, weights
mega	M	10^{6}	MHz (megahertz)	Electronics
giga	G	10^{9}	GW (gigawatt)	Electronics, power
tera	T	10^{12}	Tb (terabit)	Optics, electronics
peta	P	10^{15}	PHz (petahertz)	Optics
exa	E	10^{18}		
zetta	Z	10^{21}		
yotta	Y	10^{24}		

Adopted from Table. 1.4, Nathan Ida, 2e

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Units – Letter case

- Units are usually written in lower case (m, s, kg, etc.)
- If the unit is named after a person, then the first letter of the person's name is capitalized (dB, N, K, Hz, etc.)
- Spelling a unit is usually in small letters including the person's name (pascal, hertz, etc.).
- Prefixes including and lower than kilo are written in small letters (micrometer, nanometer, kilogram)
- Prefixes above kilo (k) are usually capitalized (MB, GB, TB, etc.)

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Decibels and its use

- There are instances in which the use of the common prefixes is inconvenient.
- When a physical quantity spans a very large range of numbers, it is difficult to properly grasp the magnitude of the quantity
- For example, the human eye can see luminance from $10^{-6}\ to\ 10^{6}\ \frac{cd}{m^2}$
- Idea of using dB:
  1) Give a reference value (e.g., the minimum luminance we can see) or a standard constant (e.g., 10^{-6})
  2) Divide your measurement by the reference quantity above
  3) Take the base 10 log of the ratio
  4) If the quantities are **power related** (power, power density, energy, etc.), multiply by 10
     $$p = 10\ \log_{10} \frac{P}{P_0}$$
  5) If the quantities are **field related** (voltage, current, force, pressure, etc.), multiply by 20
     $$v = 20\ \log_{10} \frac{V}{V_0}$$

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Example Luminance to the human eye

- in the case of vision, the reference value is $10^{-6}\,\frac{cd}{m^2}$.

$$l = 10\ \log_{10}\frac{L}{10^{-6}}$$

- A luminance of $10^{-6}\,\frac{cd}{m^2}$ is therefore 0 dB.
- A luminance of$10^{3}\,\frac{cd}{m^2}$ is 90 dB.
- Human eye has a span of 120 dB (between 10^{-6} and $10^{6}\,\frac{cd}{m^2}$).

- **Benefits of using dB**
  - ➢ Compressing very large ranges to a short one (scaling down)
  - ➢ The product of ratios becomes a sum of decibels
  - ➢ Can be easily understood when working with human perception for example in music, interactive arts, etc. such as light, power, audio, and pressure.

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Example 1.8: Use of decibels

- A power sensor for detection of cellular phone transmissions is rated for an input power range of -32 to 18 dBm. Calculate the range and span of the sensor in terms of power.

Hint: The fact that the range is given in dBm means that the reference value is 1 mW

Solution:

Example 1.9: Voltage amplification and dB

- An audio amplifier is used to amplify the signal from a microphone. The peak voltage produced by the microphone is 10 μV and the amplifier is required to produce a peak output voltage of 1 V as input to a power amplifier. Calculate the amplification of the amplifier in dB.

Solution: