EC4.201/EC4.404: Mechatronics System Design

Harikumar Kandath and Nagamanikandan Govindan

Robotic Research Center,
IIIT Hyderabad

harikumar.k@iiit.ac.in, nagamanikandan.g@iiit.ac.in

Lecture 1, Jan 04, 2025.

General Information

Mechatronics: Study of the integration of mechanical hardware, electrical/electronic hardware with computer hardware and software. Named by Tetsuro Mori from Japan when working with Yaskawa Electric Coorporation.
Applications: Robotics, Aerospace industry, automotive industry, process industry etc.

Course Objective: To introduce the design and development of a mechatronic system.
Instructors: Harikumar Kandath and Nagamanikandan Govindan.

MSD1 (Course Contents -2 credit)

UNIT 1 ♢ Sensors - structure of measurement systems, static characteristics, dynamic characteristics. ♢ Sensors in robotics - position, speed, acceleration, orientation, range. ♢ Actuators - general characteristics, motors, control valves.

Instructor: Harikumar Kandath

UNIT 2 ♢ : Introduction to mechanical elements and transformations, basic concepts of kinematics and dynamics, Devise models for rotational, translational, electromechanical, and mechanical systems.

Instructor: Nagamanikandan Govindan

MSD (Course Contents - 4 credit)

UNIT 1 ♢ Sensors - structure of measurement systems, static characteristics, dynamic characteristics. ♢ Sensors in robotics - position, speed, acceleration, orientation, range. ♢ Actuators - general characteristics, motors, control valves.

UNIT 3 ♢ Computer-based feedback control: Sampled data control, sampling and hold, PID control implementation, stability, bilinear transformation.

Instructor: Harikumar Kandath

MSD (Course Contents - 4 credit)

UNIT 2 ◊ : Introduction to mechanical elements and transformations, basic concepts of kinematics and dynamics, Devise models for rotational, translational, electromechanical, and mechanical systems.

UNIT 4 ◊ Design and analysis of mechanisms.

UNIT 5 ◊ Programming experiments.

Instructor: Nagamanikandan Govindan

References

1. Bentley, John P. “Principles of measurement systems,” Pearson education, 2005.

2. D.R. Coughanowr, ”Process system analysis and control,” McGraw Hill, 1991.

3. G.F. Franklin, J.D. Powell and M.L. Workman, “Digital control of dynamic systems”, Addison Wesley, 3rd edition, 1998.

4. Hartenberg, R., & Danavit, J, “Kinematic synthesis of linkages,” McGraw Hill, 1964.

5. Robert L. Norton,“DESIGN OF MACHINERY”, McGraw-Hill, 6th edition, 2019.

6. William Bolton,“Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering,” Pearson, 6th edition, 2015.

Evaluation Scheme - MSD 1 (2 credit)

- Quiz: 20%.
- Assignments: 40%.
  Simulations (MATLAB/PYTHON)
  Design (Fusion 360 software)
  Using Sensors
- End Sem (Mid Sem) 40%

Evaluation Scheme - MSD (4 credit)

- Quiz 1 and Quiz 2: 20%.
- Mid Sem: 20%.
- Assignments: 30%.
  Simulations (MATLAB/PYTHON)
  Design (Fusion 360 software)
  Using Sensors
- Project 30% (Instructions will be provided later)

Basic Definitions

System: A physical/mathematical entity that takes an INPUT and generates an OUTPUT.
Dynamical System: A **System** for which current OUTPUT depends on current (and/or previous) INPUT and previous OUTPUT.
Process: Any activity through which a physical **system** generates an **information**.

Example 1: Position, velocity and acceleration of a ground robot or Unmanned Aerial Vehicle (UAV).
system: ground robot or UAV; **process**: system in motion; **information**: position, velocity and acceleration.

Example 2: Temperature of human body.
system: human body; **process**: overall activities (metabolism); **information**: temperature.

Measurement System

Measurement system: Links **process** to the **observer** by quantifying the **information** called **measurement**.

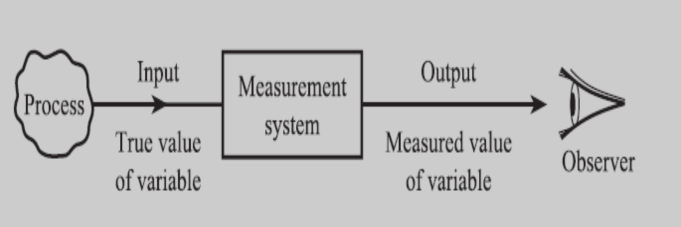


Figure: Purpose of measurement system

Measured value of variable (information) $\approx$ True value of variable (information).

Structure of Measurement System

Measurement system: Contains four basic modules.

- Sensing element.
- Signal conditioning element.
- Signal processing element.
- Data presentation element.

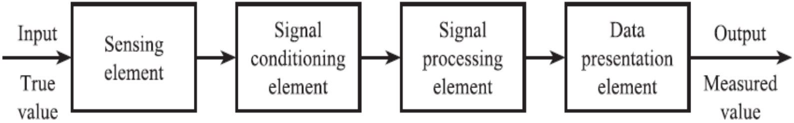


Figure: Structure of measurement system

Sensing Element

Role: Maintains direct/indirect contact with the process and gives an output that is a function of the variable to be measured.

Example 1: Thermocouple gives voltage output as a function of input temperature.
Example 2: Orifice plate gives pressure difference output as a function of input flow rate.

Signal Conditioning Element

Role: To convert the output of sensing elements into a form suitable for further processing. The output will be usually, a DC current, DC voltage or AC voltage.

Example 1: Deflection bridge which converts an impedance change into a voltage change.
Example 2: Amplifier which amplifies millivolts to volts.
Example 3: Oscillator which converts an impedance change into a variable frequency voltage.

Sensing element OR sensing element + signal conditioning element is called a **Transducer**. It converts one form of energy to another form.

Signal Processing Element

Role: Takes the output of the signal conditioning element and converts it into a form more suitable for presentation.

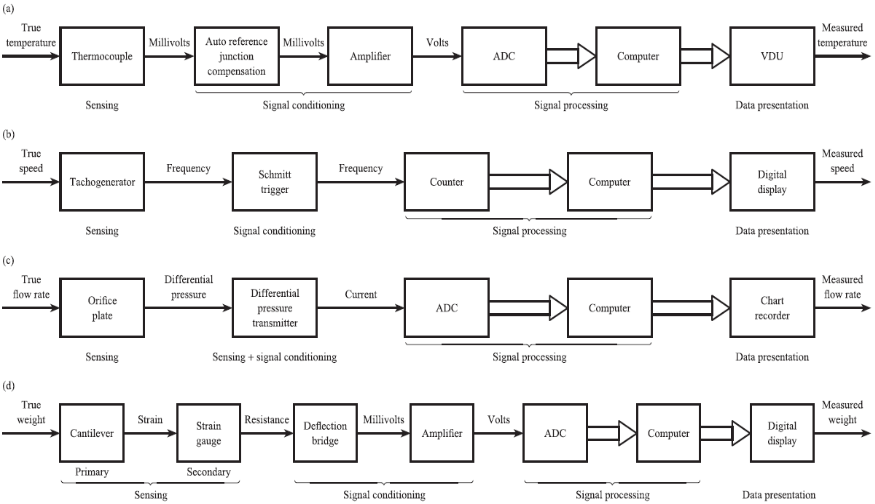
Example 1: Analogue-to-digital converter (ADC) which converts a voltage into a digital form for input to a computer.
Example 2: Computer which calculates the measured value of the variable from the incoming digital data.

Data Presentation Element

Role: Takes the output of signal processing element and presents the measured value in a form which can be easily recognised by the observer.

Examples: point-scale indicator, chart recorder, visual display etc.

Examples of Measurement Systems



Static Characteristics of Measurement System

- Range
- Span
- Non-linearity
- Sensitivity
- Environmental effects
- Hysteresis
- Resolution
- Error

Range and Span

- Input range: Specified by the minimum and maximum values of input denoted by I_{MIN} and I_{MAX} respectively.
- Output range: Specified by the minimum and maximum values of output denoted by O_{MIN} and O_{MAX} respectively.
- Input span: Maximum variation in input $(I_{MAX} - I_{MIN})$.
- Output span: Maximum variation in output $(O_{MAX} - O_{MIN})$.

Example: A thermocouple may have input range of 100^{o}C to 250^{o}C and output range of 4 mV to 10 mV. Similarly, input span is 150^{o}C (250^{o}C - 100^{o}C) and output span is 6 mV (10 mV - 4 mV).

Non-Linearity

Linearity: The relationship between input (I) and output (O) can be defined using a straight line.

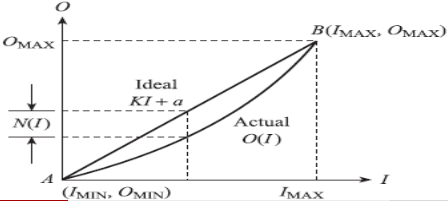
$$O - O_{MIN} = \frac{O_{MAX} - O_{MIN}}{I_{MAX} - I_{MIN}}(I - I_{MIN}) \tag{1}$$

$$O - 4 = \frac{6}{150}(I - 100) \tag{2}$$

Non-linearity, N(I)

$$N(I) = O(I) - (KI + a) \tag{3}$$

$$\hat{N} = \frac{max(|N(I)|)}{O_{MAX} - O_{MIN}} \times 100\% \tag{4}$$



Sensitivity

Sensitivity (S) is the change in the output for a small change in the input.

$$S = \frac{\delta O}{\delta I} \tag{5}$$

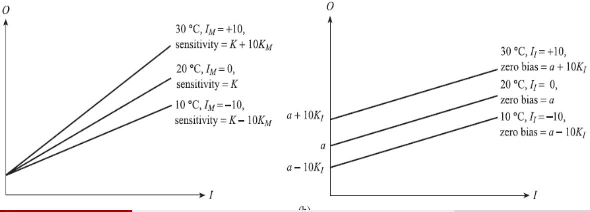
when $\delta I \to 0$

$$S = \frac{dO}{dI} \tag{6}$$

$$S = \frac{d}{dI}(KI + a + N(I)) = K + \frac{dN(I)}{dI} \tag{7}$$

Environmental Effects

- Modifying input: Changes the linear sensitivity, K is modified by $K + K_M I_M$. Here I_M is the modifying input with sensitivity K_M. Example: temperature is a modifying input for many sensors, like thermocouple.
- Interfering input: Zero bias is modified, a is modified to $a + K_I I_I$. Here I_I is the interfering input with sensitivity K_I. Example: temperature is also an interfering input for many sensors.

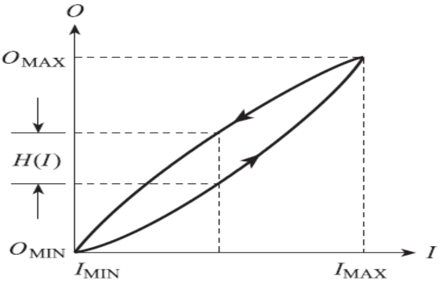


Hysteresis

Here for a given value of the input I, the output O may be different depending whether I is increasing or decreasing.

$$H(I) = O(I)_{<<} - O(I)_{>>} \tag{8}$$

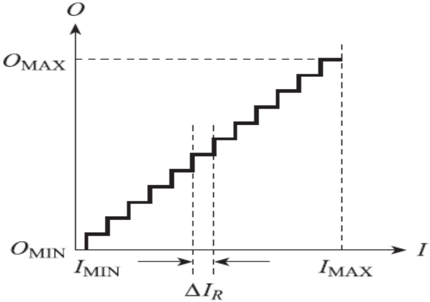
$$\hat{H} = \frac{max(|H(I)|)}{O_{MAX} - O_{MIN}} \times 100\% \tag{9}$$



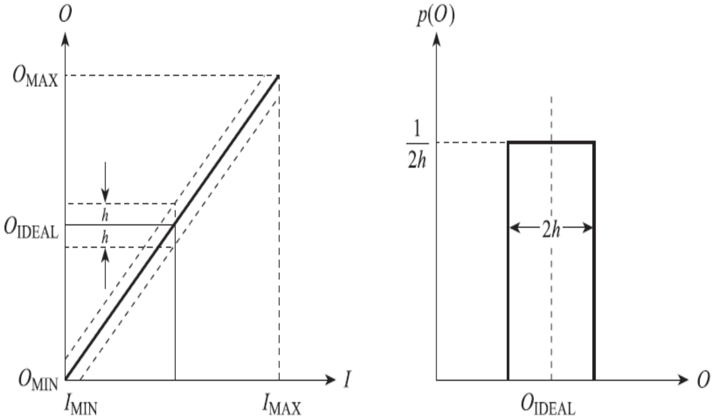
Resolution

Resolution (R) is the smallest change in the input that can be measured.

$$R = \frac{\Delta I_R}{I_{MAX} - I_{MIN}} \times 100\% \qquad (10)$$

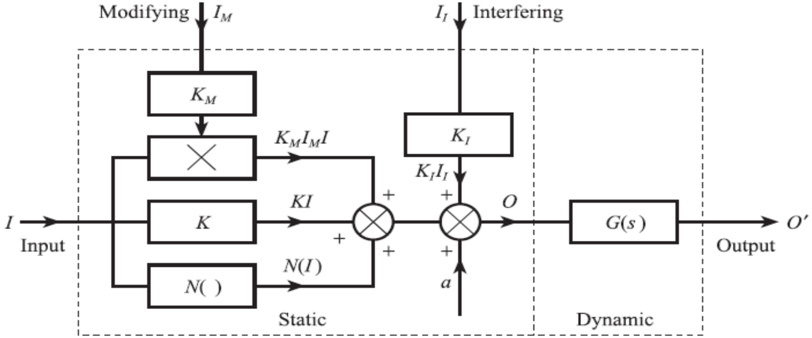


Error Band



Generalized model of a Measurement System

Generalized model of measurement system showing static and dynamic characteristics.



THANK YOU