Introduction to Mechatronics (ES2304)

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Punjab Engineering College (PEC), Chandigarh

(Deemed to be University)

Course Name : Introduction to Mechatronics

Course Code : ES 2304

Credits : 04

L T P : 3-0-2

Course Objectives:

The objective of the course content is to:

1. **Impart knowledge and information about mechatronics system.**
2. **Understand the concepts of signal conditioning and data acquisition for intelligent systems.**
3. **Develop the basics for mechatronic product design**

Course Outcomes:

By the end of this course, the student will be able:

CO1: To understand the basic concepts, applications and components of mechatronic system.

CO2: To analyze sensing, signal conditioning and data acquisition circuits.

CO3: To design product and systems theoretically as well as practically with Intelligence.

CO4:To apply the knowledge of mechatronic system for industrial applications.

Topic	Hr
Introduction to Mechatronics : Introduction, Elements of Mechatronics system, Classification of Mechatronics system, Mechatronic system intelligence, Components involved in intelligent system design and development, measurements and control system as a part of mechatronics system, Application of Mechatronic systems	6
Sensors and transducers : Introduction, Performance characteristics of transducers, Transducer for displacement (Potentiometer, strain-gauge, Optical encoder, LVDT, Hall effect sensor); velocity (Tachogenerator), force (load cell), pressure (Piezoelectric sensors, Tactile sensor), liquid level (Floats, Differential pressure), Temperature (Bimetallic strips, RTDs, Thermistors, Thermocouples) and light sensor (Photovoltaic-transducer, LDR, Photodiode, Photo Transistor).	8

Signal conditioning: Operational amplifier (Inverting, Non-inverting, Summing, Integrating, Differential amplifiers, comparator), protection, filtering, digital signals (R-2R ladder DAC and Successive Approximation ADC), Concepts of multiplexers **7**

Controllers: ***Basics of number system, binary, octal and hexadecimal systems with their conversion from one system to other. Boolean algebra, logic gates, ICs, flip-flops & counters.*** Microprocessor, Microcontroller, PLC & their Architectures, Working Principle, Software Programs (Assembly/High Level), Interfacing Aspects **7**

Flipped Learning (NPTEL MOOCs) - *https://nptel.ac.in/courses/112107298*)

Basics of number, binary, octal and hexadecimal systems with their conversion from one system to other. Boolean algebra, logic gates, ICs, flip-flops. (Unit 5 Lecture 21&22) PLC Controller (Unit 7 Lecture 33)

Actuators and mechanisms: **8**

Pneumatic and hydraulic actuation systems: Directional control valves, Pressure control valves, cylinders

Mechanical actuation systems: Kinematic chain, cam, gear, clutches, ratchet and pawl, belt and chain drive, bearings

Electrical actuation systems: Relays, Solid-state Switches (Diode, Thyristor, Triac, BJT, FET), DC and AC motors, brushless dc motor, stepper motors, servo motors

Flipped Learning (NPTEL MOOCs) -
https://nptel.ac.in/courses/112107298)

Mechanical actuation systems: **Kinematic chain, cam, gear, ratchet and pawl, belt and chain drive, bearings (Unit 3 Lecture 11)**

Pneumatic and hydraulic actuation systems: **Directional control valves, Pressure control valves, cylinders (Unit 3 Lecture 12)**

Robotics: Types of motions, Function, Governing Laws, Classification, Features and Components of Robots, System Automation **6**

Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	Mechatronics by W Bolton , 6th edition, Pearson Education	2019
2	**Mechatronics by Tilak Thakur 2st edition, Oxford University Press**	2023
3	Mechatronics by Dan Necsulescu, Pearson Education	2001
4	Mechatronics by H M T Limited, TMH	2017
5	Mechatronics Principles, Concepts & Applications by Nitaigour P Mahalik, TMH	2017

S.No.	Link of Journals, Magazines, websites and Research Papers
1.	Mechatronics, Prof. Pushparaj Mani Pathak | IIT Roorkee https://onlinecourses.nptel.ac.in/noc21_me27/preview https://archive.nptel.ac.in/courses/112/107/112107298/
2.	Design of Mechatronic Systems, Prof. Prasanna Gandhi, IIT Bombay https://onlinecourses.nptel.ac.in/noc21_me129/preview
3.	Mechatronics and Manufacturing Automation, IIT Guwahati , Dr. Shrikrishna N. Joshi https://nptel.ac.in/courses/112103174

Unit-1
Understanding Mechatronics

S. No.	Content Detail	PL	Learning Objectives	Teaching Learning aids/Methods	Source / Book
1	Introduction to Mechatronics, Elements of Mechatronics system, Classification of Mechatronics system,	2	(i)Understand the concept of Mechatronics, its interdisciplinary nature, and the integration of mechanical, electrical, computer science, and control engineering principles. (ii)Identify and classify the key elements constituting a Mechatronics system (iii)Analyze and evaluate the components involved in designing intelligent Mechatronic systems. (iv)Comprehend measurement techniques and control system methodologies utilized in Mechatronics. (v)Explore real-world applications of Mechatronic systems across various industries such as automotive, aerospace, robotics, healthcare, and manufacturing. Understand how Mechatronics principles are integrated into practical scenarios to solve complex engineering problems.	Black board, PPT, Video, animation / (i) Lecture (ii) & (v) cooperative learning strategy - Jigsaw Method	Mechatronics by W Bolton and Mechatronics by Tilak Thakur https://nptel.ac.in/courses/112107298
2	Mechatronic system intelligence, Components involved in intelligent system design and development,	2		PPT, video, animation / (iii)Lecture / Discussion	Mechatronics by W Bolton and Mechatronics by Tilak Thakur https://nptel.ac.in/courses/112107298
3	Measurements and control system as a part of mechatronics system, Application of Mechatronic systems	2		PPT, video, animation / (iv)PBL (i)to (v) Gamification (Unit Quiz)	Mechatronics by W Bolton and Mechatronics by Tilak Thakur https://nptel.ac.in/courses/112107298

WHAT IS CONTROL?

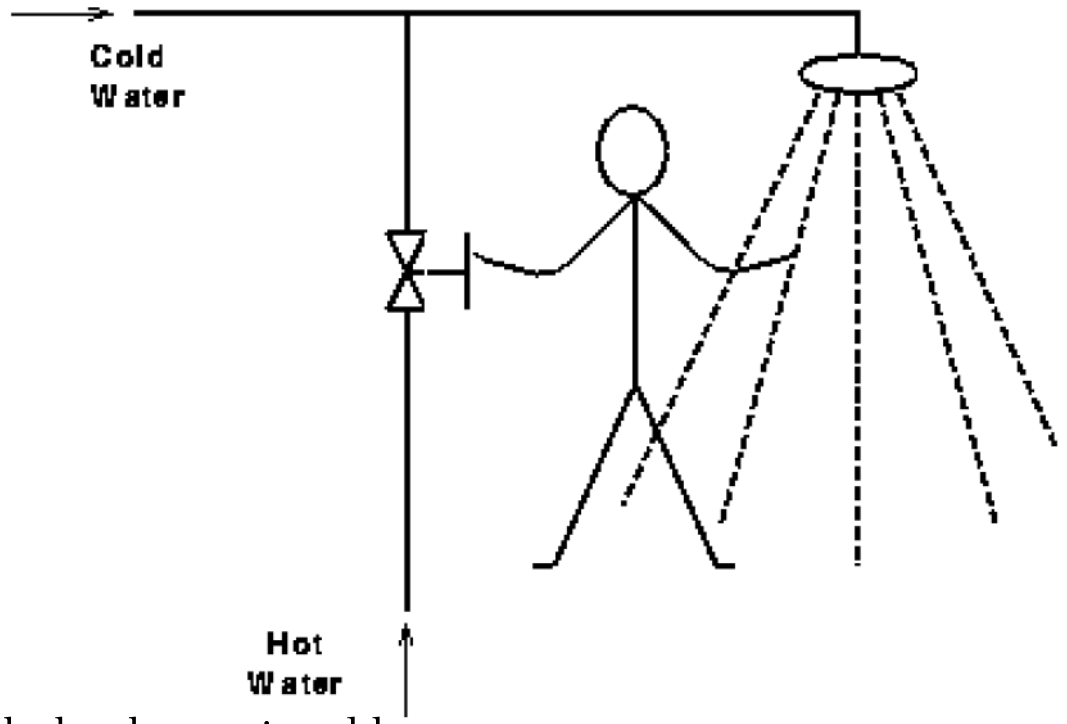
Control is the process of altering, manually or automatically, the performance of a system to a desired one.

WHY CONTROL?

Because systems by themselves usually do not behave the way we would like them to.

Manual Control System

Consider a simple manual control system shown below.



- To begin with the shower is cold.
- To start the heating process the valve in the hot water line is opened.
- The operator can then determine the effectiveness of the control process by standing in the shower.
- If the water is too hot, the valve should be closed a little or even turned off. If the water is not hot enough then the valve is left open or opened wider.

Functions of a Control System

It can be seen that this control system, completed by the operator, possesses the following functions:

- **Measurement**

This is essentially an estimate or appraisal of the process being controlled by the system. In this example**, this is achieved by the right hand of the operator.**

- **Comparison**

This is an examination of the likeness of the measured values and the desired values. **This is carried out in the brain of the operator.**

Functions of a Control System

- **Computation**

✓ This is a **calculated judgment** **that indicates how much the measured value and the desired values differ and what action and how much should be taken.**

✓ In this example, the operator will calculate the difference between the desired temperature and the actual one.

✓ **Accordingly the direction and amount of the adjustment of the valve are worked out** and the order for this adjustment is sent to the left hand from the brain of the operator.

✓ If the outlet water temperature is lower, then the brain of the operator will tell the left hand to open the steam valve wider.

Functions of a Control System

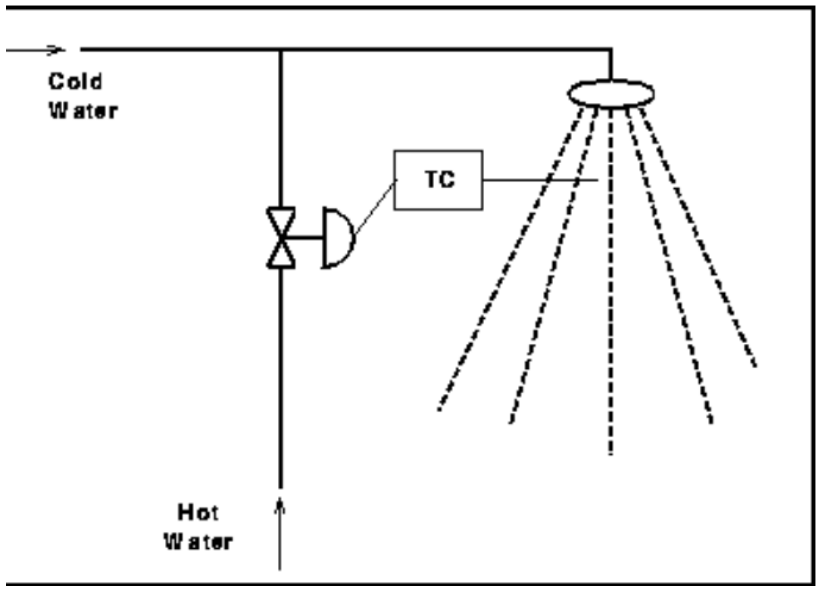
- **Correction**

✓This is ultimately the materilisation of the order for the adjustment. **The left hand of the operator takes the necessary actions following the order from brain.**

✓Therefore, a control system must have the abilities of **measurement, comparison, computation and correction.**

Automatic Control System

1) Use a temperature measurement device to measure the water temperature, which replaces the right hand of the operator. This improves accuracy.
2) Instead of manual valves, use a **control valve**, which is driven by electricity. This will replace the left hand of the operator.
3) Put a device called a controller i.e. **a temperature controller, to replace the brain of the operator.** This has the functions of comparison and computation and can give orders to the control valve.

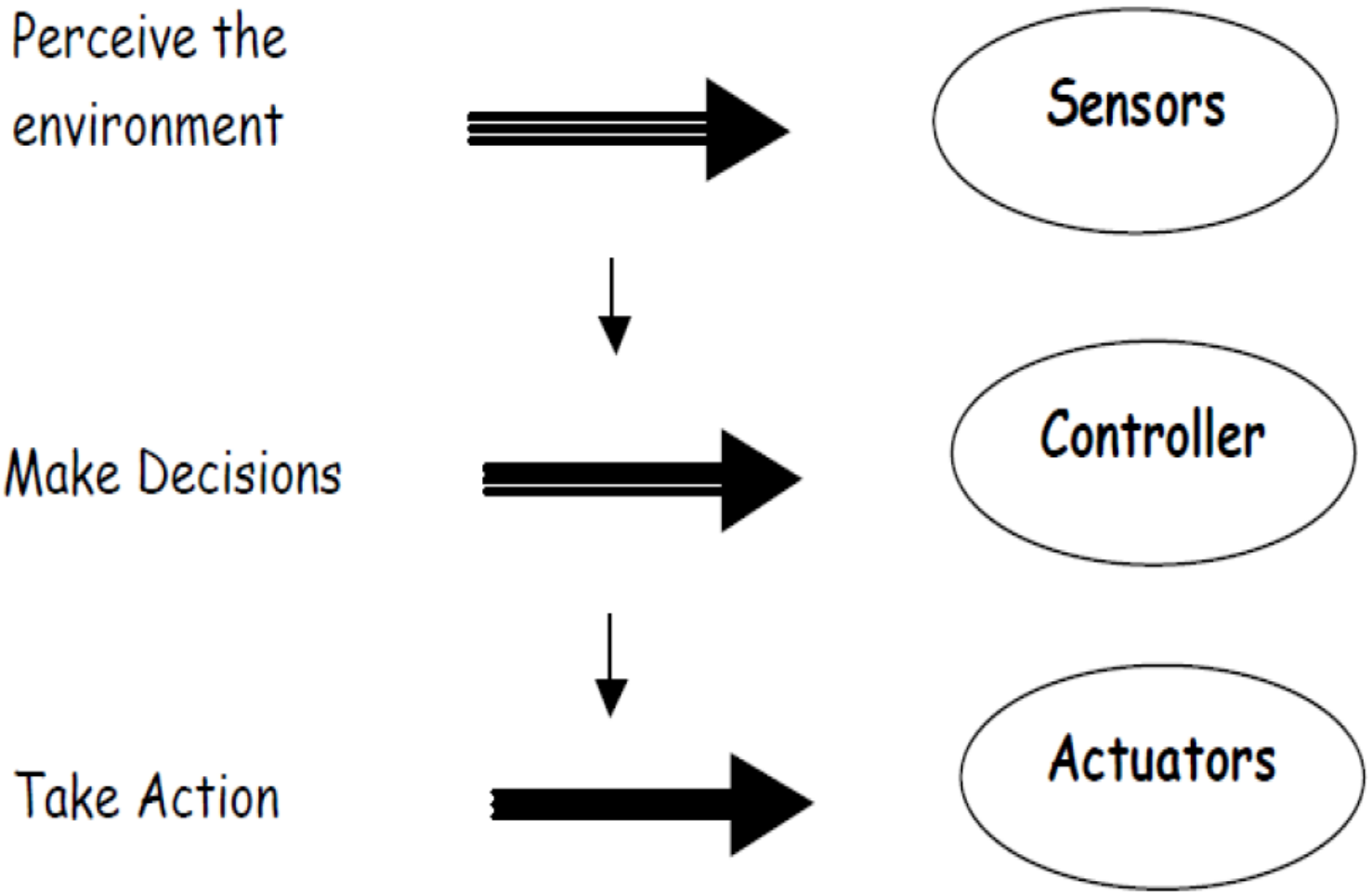


4) The signal and order connections between the measurement device, control valve and controller are transfered through cables and wires, which replace the nerve system in the operator.

Hardware of a Control System

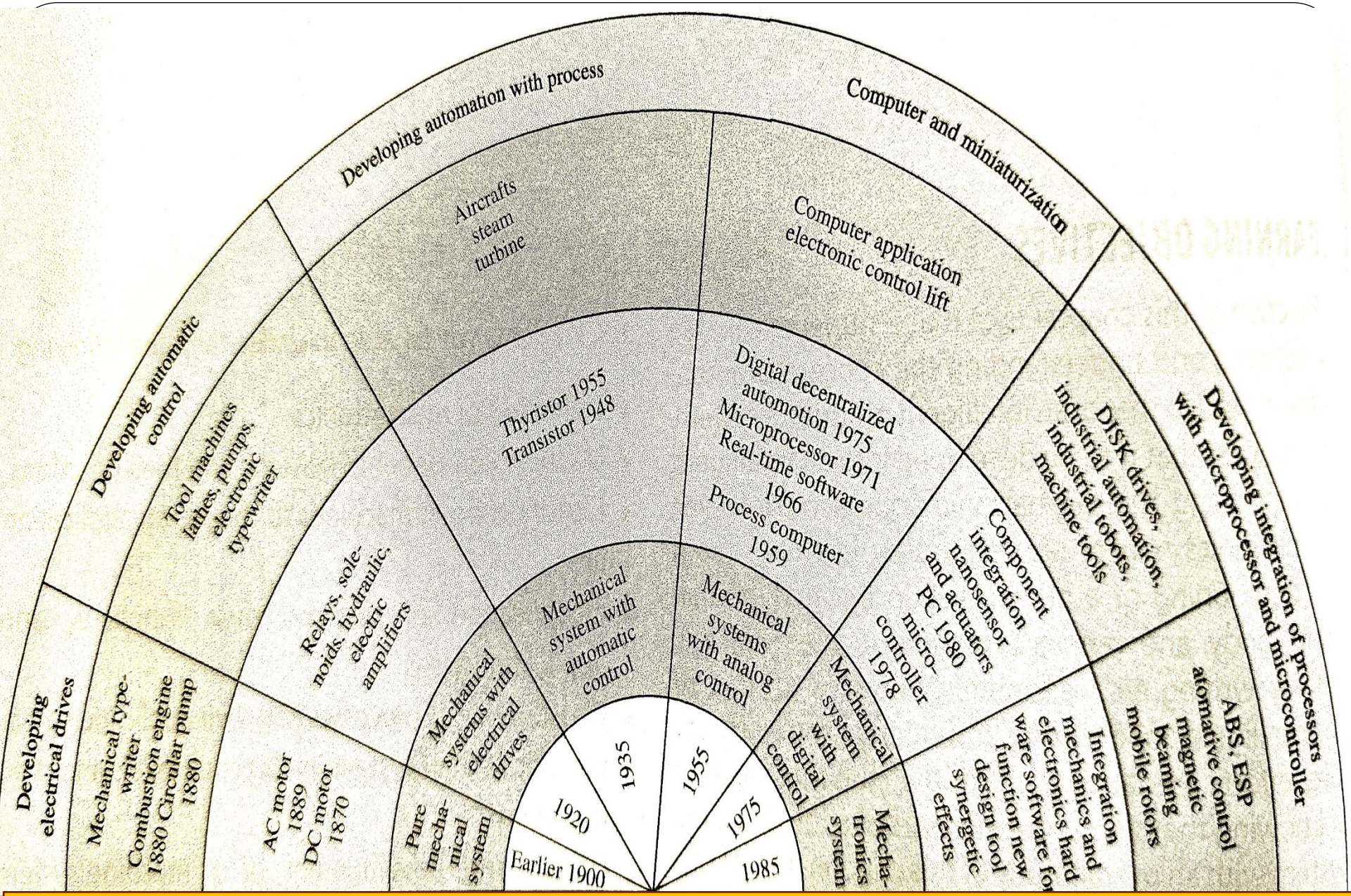
- **Sensor -** a piece of equipment to measure system variables. It serves as the signal source in automatic control.
- **Controller -** a piece of equipment to perform the **functions of comparison and computation**.
- **Control Element -** a piece of equipment **to perform the control action**.
  - ✓ This element receives signals from the controller and performs some type of operation on the process.
  - ✓ Generally the control element is simply a **control valve**.

Essentials in Mechatronics System



Evolution

The term mechatronics was first introduced by **Tetsuro Muri**, a Japanese engineer of Yasakawa Electric Corporation in 1969. However, it was introduced in academics first in 1996 after related publication in the refereed and reputed journals of *IEEE and ASME Transactions on Mechatronics*.



Evolution of Mechatronic System

The evolution levels of Mechatronics are:

1) Primary level Mechatronics (first)
2) Secondary level Mechatronics (second)
3) Tertiary level Mechatronics (third)
4) Quaternary level Mechatronics (fourth)

- **Primary level Mechatronics (first):**

  In the early days Mechatronics products were at primary level containing I/O devices such as sensors, and actuators that integrated electrical signals with mechanical action at the basic control level.

  Examples: electrically controlled fluid valves and relays

- **Secondary level Mechatronics (second):**

  This level integrates **microelectronics into electrically controlled devices.**

  Examples: cassette player.

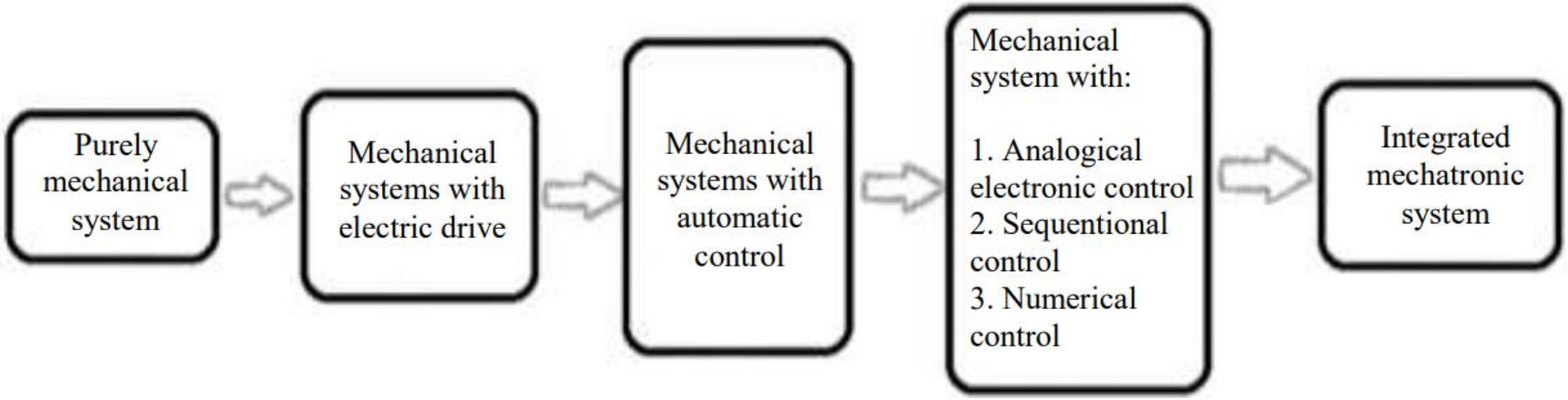
- **Tertiary level Mechatronics (third):**
- This incorporates advanced feedback functions into control strategy, thereby enhancing the quality in terms of sophistication.
- Mechatronics system at this level is called 'smart system'.
- The control strategy includes microelectronics, microprocessor and other application specific integrated circuits (ASIC).

Examples: : Control of Electrical motor used to activate industrial robots, hard disk, CD drives and automatic washing machines etc.

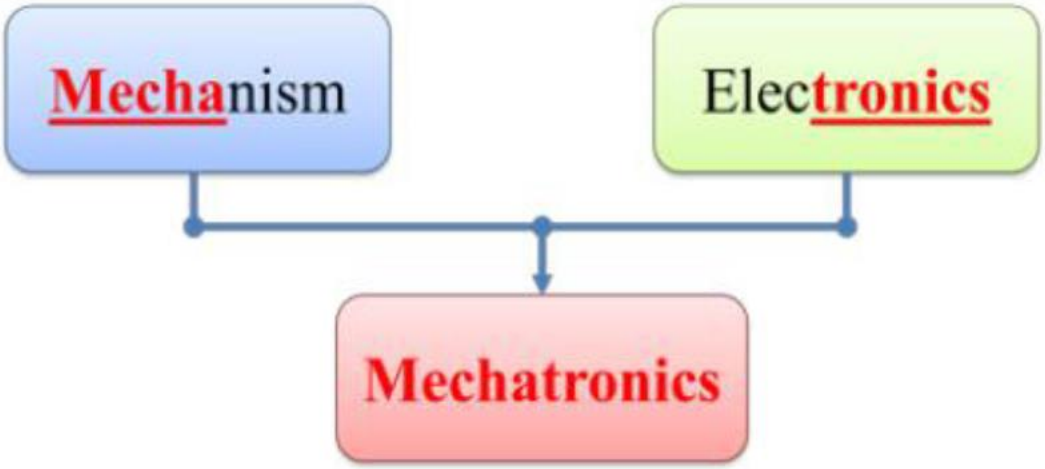
- **Quaternary level Mechatronics (fourth):**
- This level includes intelligent control in Mechatronics system.
- The level attempts to improve smartness a step ahead by introducing intelligence and fault detection and isolation (FDI) capability system.

Examples: artificial neural network and fuzzy logic technologies.

Evolution of the Mechatronics System



Definitions of Mechatronics



- Mechatronics is a concept of Japanese origin (1970's) and can be defined as the application of electronics and computer technology to control the motions of mechanical systems.
- The term **'mechatronics' was coined by Yasakawa Electric Company** to refer to the use of electronics in mechanical control

Definitions of Mechatronics

- **Integration** of electronics, control engineering, and mechanical engineering.

  W. Bolton

- **Application** of complex decision making to the operation of physical systems.

  D. M. Auslander and C. J. Kempf

- Synergistic **integration** of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes.

  F. Harshama, M. Tomizuka

Definitions of Mechatronics

- Methodology used for the optimal design of electromechanical products.

  D. Shetty and R. A Kolk

- Field of study involving the analysis, design, synthesis, and selection of systems that combine electronics and mechanical components with modern controls and microprocessors.

  D. G. Alciatore and M. B. Histand

Definitions of Mechatronics

- Mechatronics is defined as the interdisciplinary field of engineering that deals with the design of products whose function relies on the integration of mechanical, electrical, and electronic components connected by a control scheme.

❖ **Computer algorithm** to modify the behavior of a mechanical system.

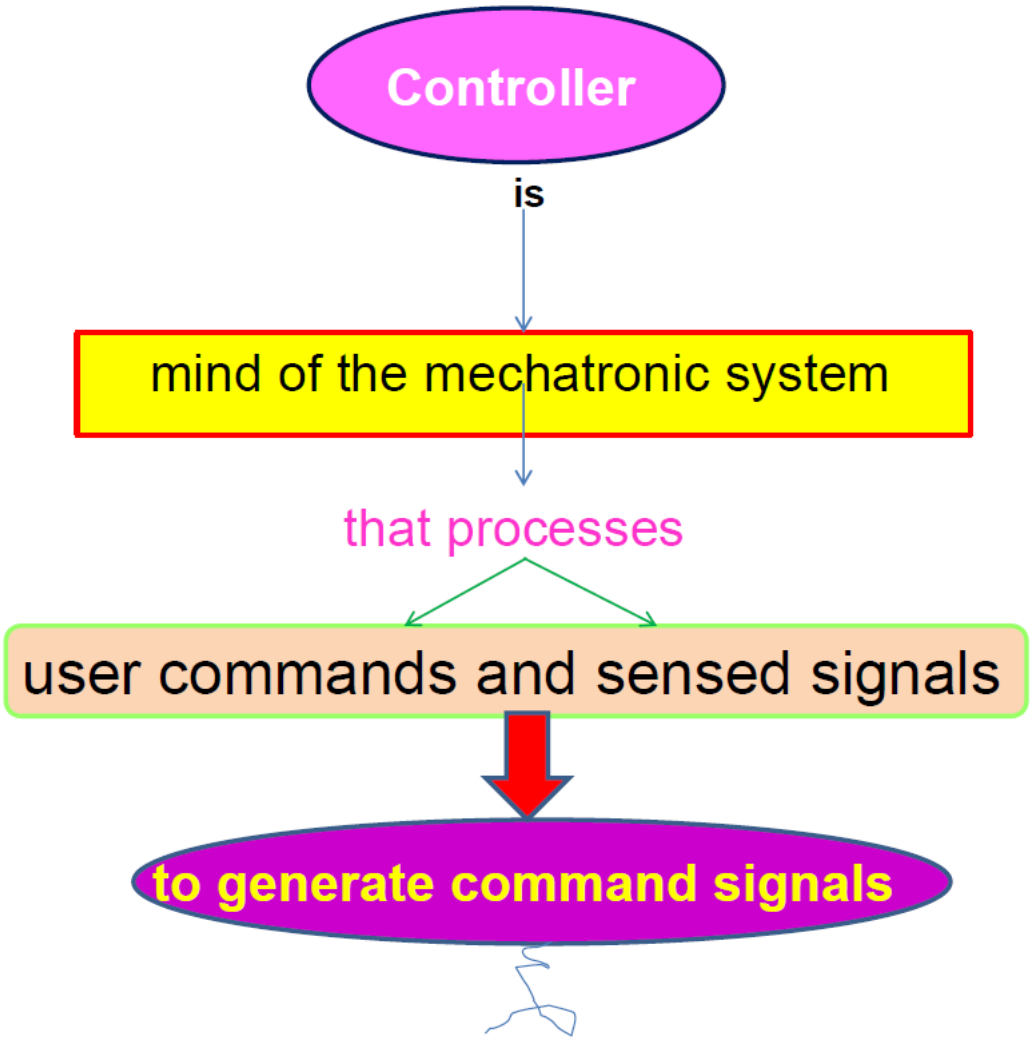
❖ **Electronics** are used to transduce information between the computer science and mechanical disciplines.

Definitions of Mechatronics

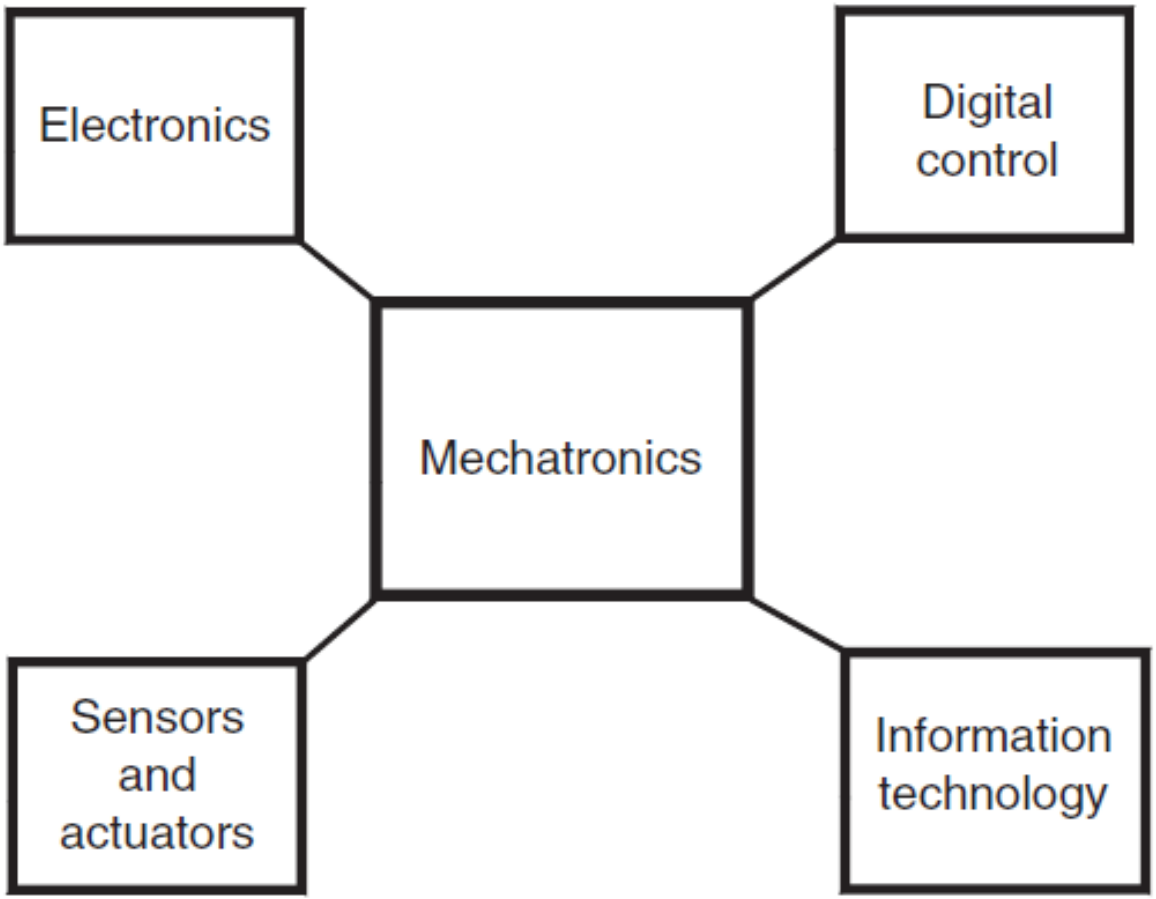
Mechatronics: Working Definition

- Mechatronics is the synergistic integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software to manage complexity, uncertainty, and communication in engineered systems.

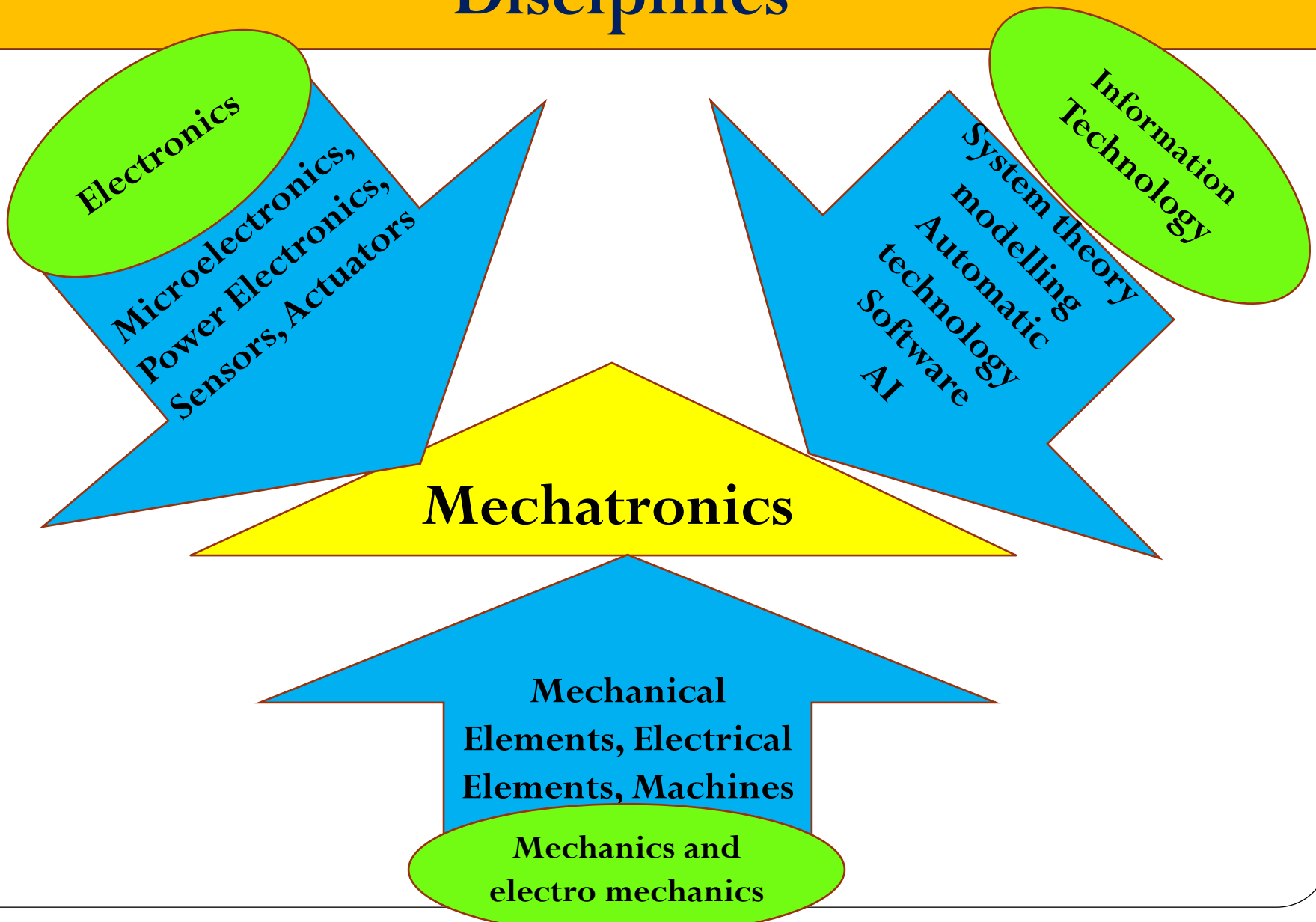
MECHATRONICS



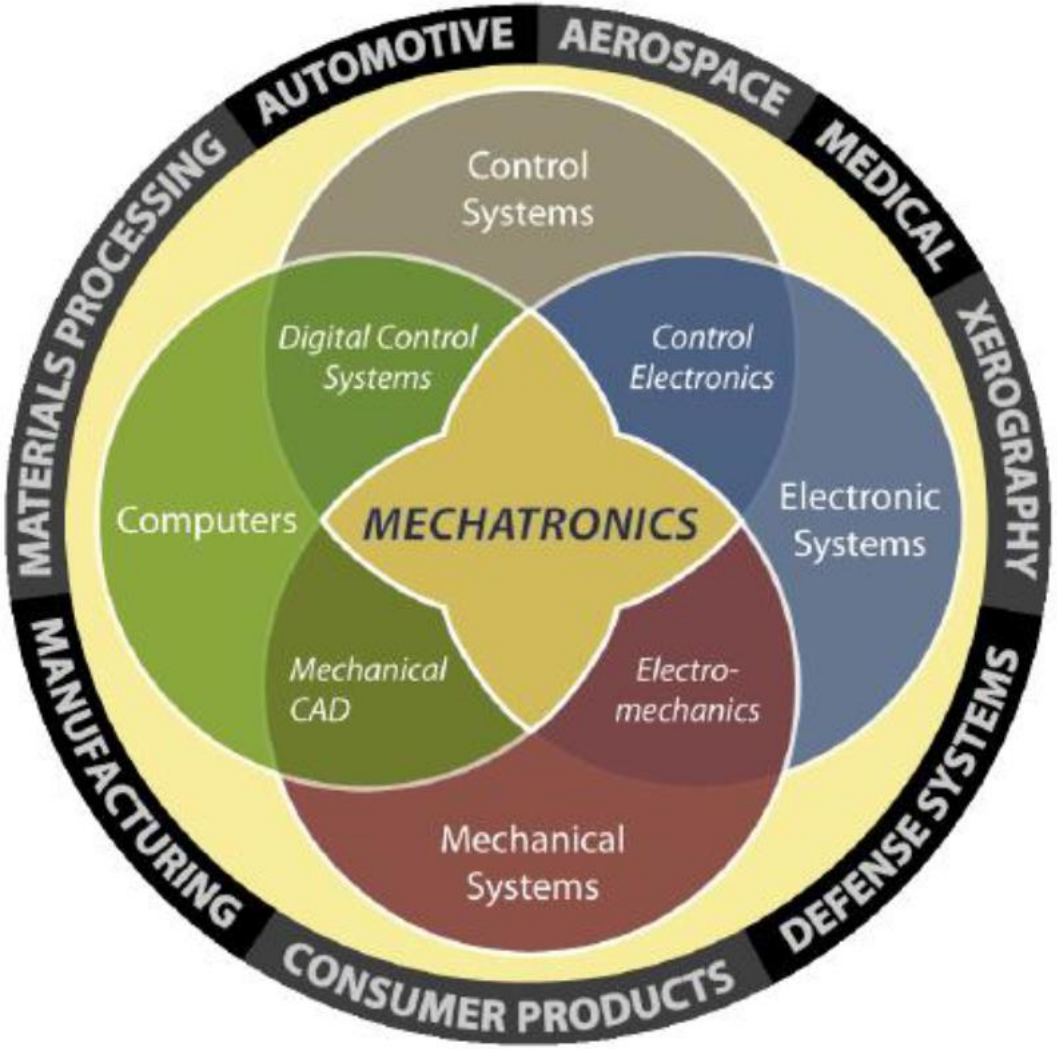
Main Components of a Mechatronic System

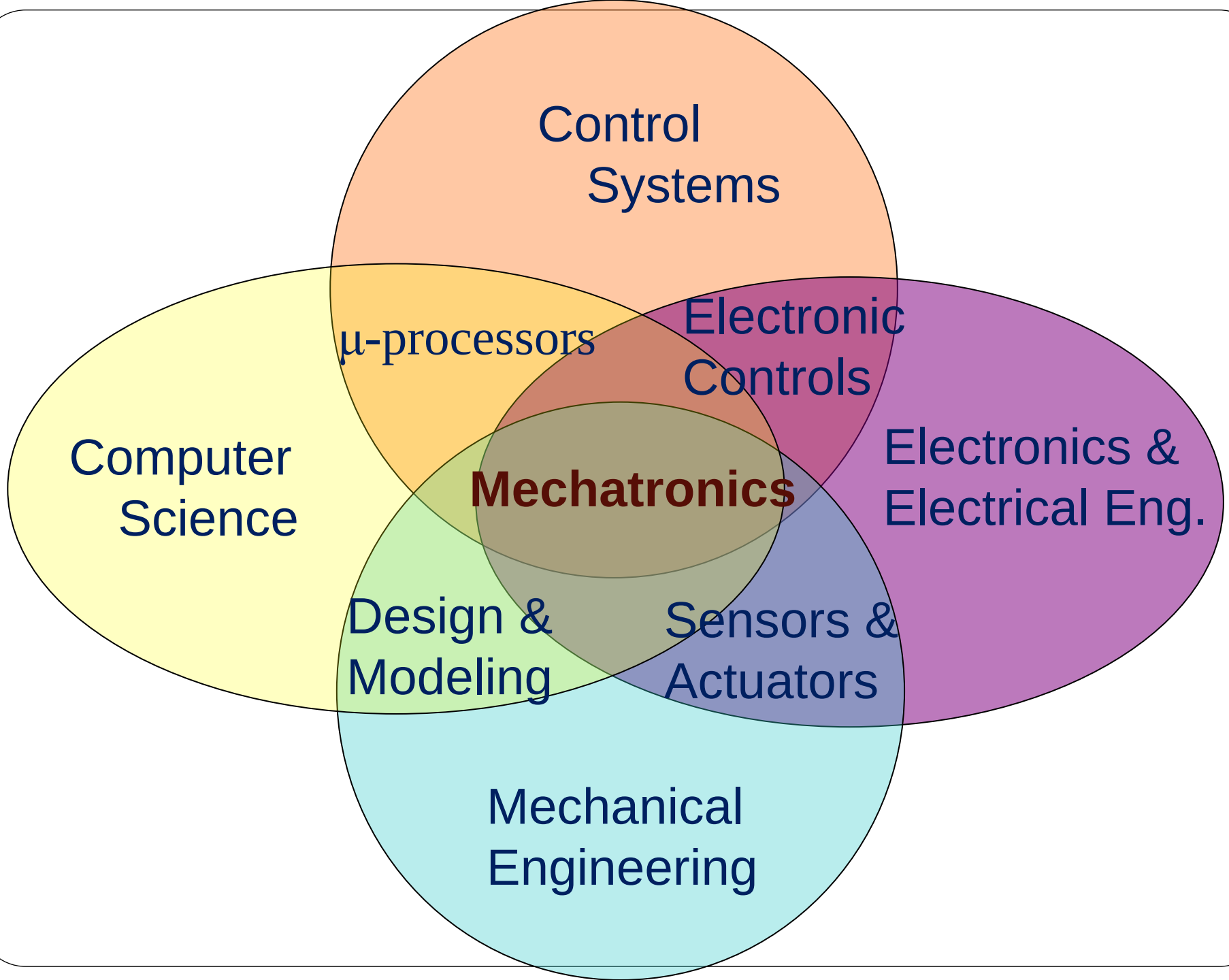


Individual Integration of Different Disciplines



MECHATRONICS




Control
Systems
μ-processors
Electronic
Controls
Computer
Science
Mechatronics
Electronics &
Electrical Eng.
Design &
Modeling
Sensors &
Actuators
Mechanical
Engineering

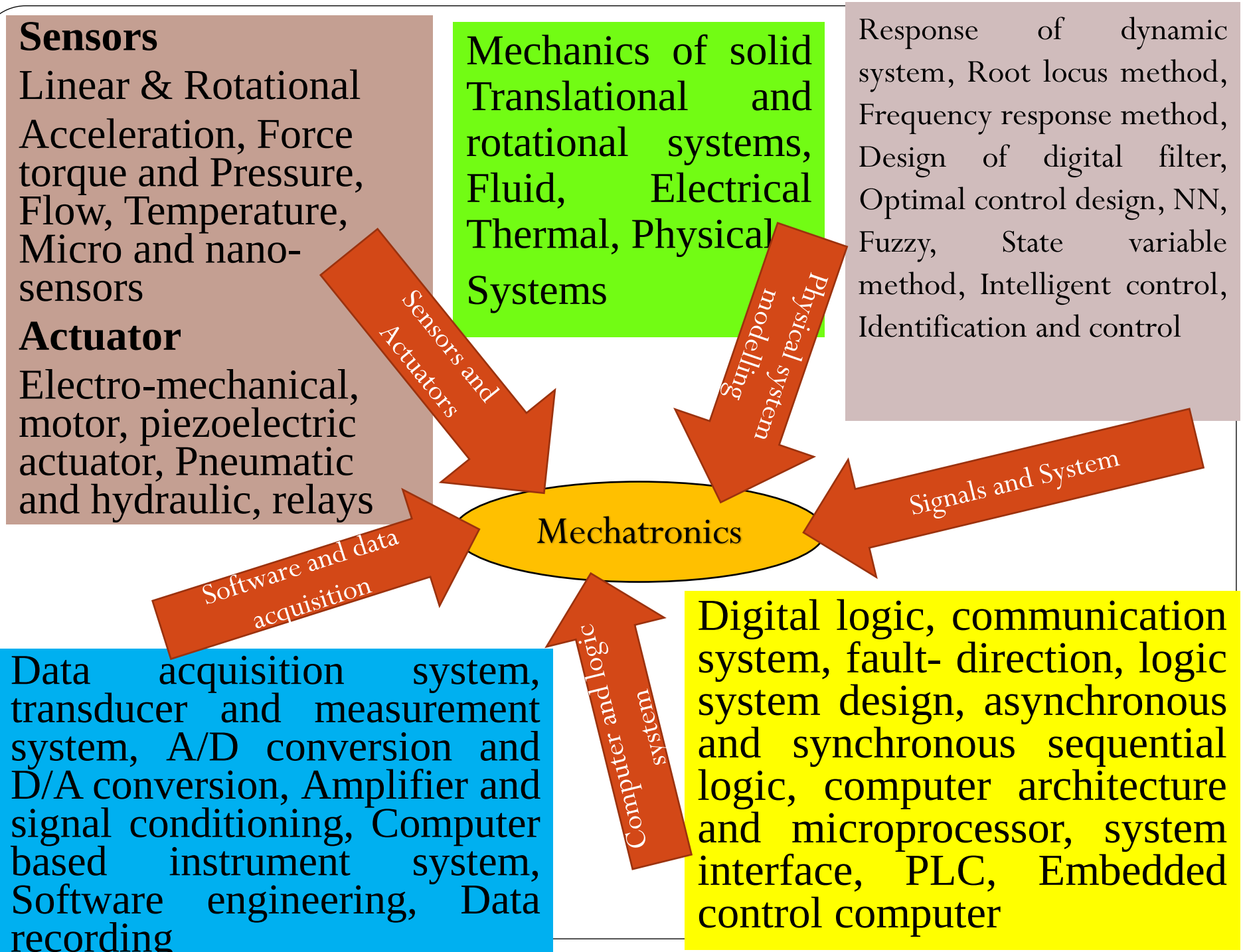
Advantages of Mechatronics

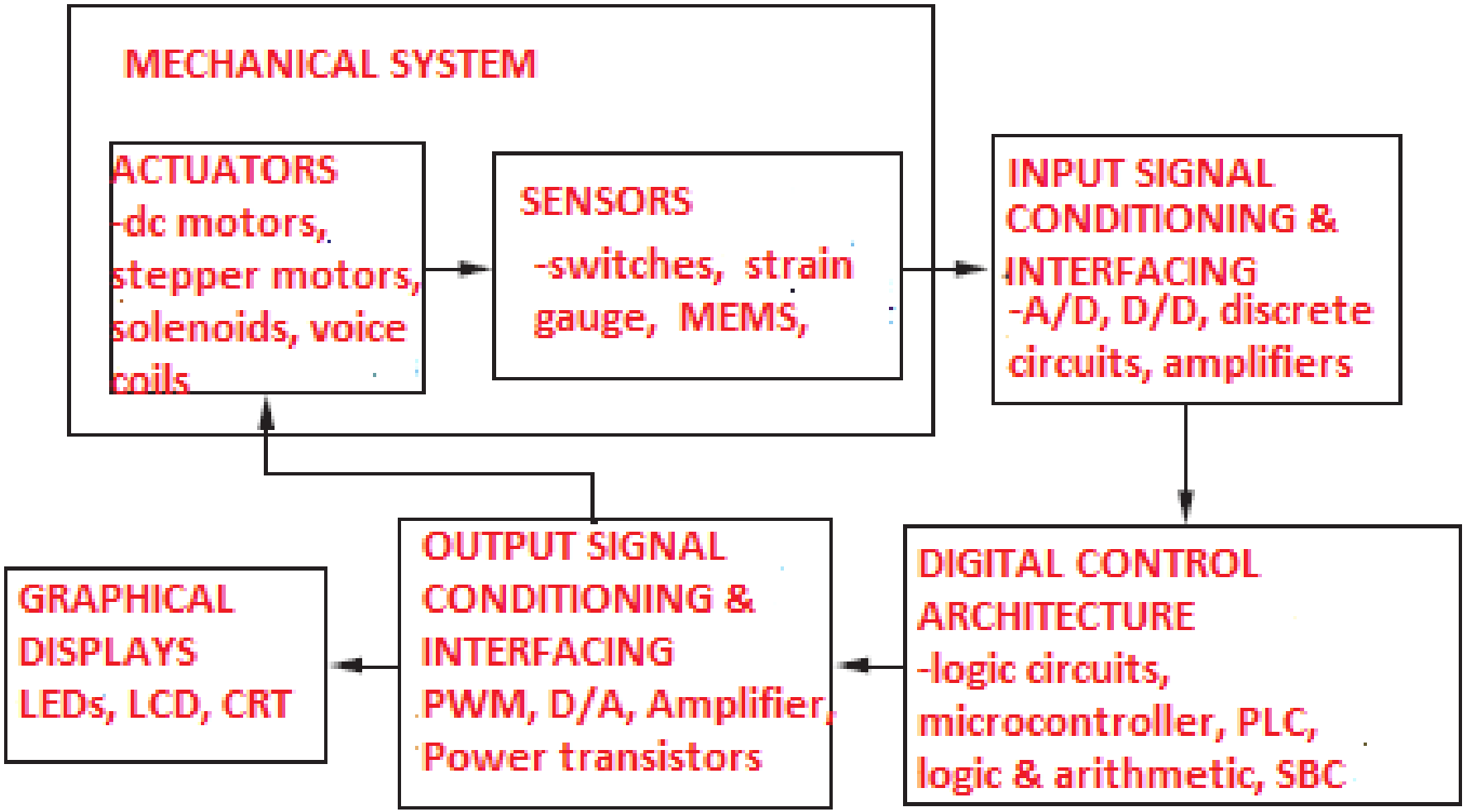
- It has made easy to design products and processes.
- Mechatronics system helps in optimizing performance and quality.
- The products produced are cost effective and of good quality.
- Higher degree of flexibility.

Disadvantages of Mechatronics

- Knowledge of different engineering disciplines for design and implementation is imperative.
- It is expensive to incorporate mechatronics approach to an existing / old system.
- Specific problems for various systems will have to be addressed separately and properly.
- High initial cost of the system.

Key Elements Of Mechatronics


Sensors
Linear & Rotational
Acceleration, Force torque and Pressure, Flow, Temperature, Micro and nano-sensors
Actuator
Electro-mechanical, motor, piezoelectric actuator, Pneumatic and hydraulic, relays
Mechanics of solid Translational and rotational systems, Fluid, Electrical Thermal, Physical Systems
Response of dynamic system, Root locus method, Frequency response method, Design of digital filter, Optimal control design, NN, Fuzzy, State variable method, Intelligent control, Identification and control
Sensors and Actuators
Physical system modelling
Signals and System
Software and data acquisition
Mechatronics
Computer and logic system
Data acquisition system, transducer and measurement system, A/D conversion and D/A conversion, Amplifier and signal conditioning, Computer based instrument system, Software engineering, Data recording
Digital logic, communication system, fault- direction, logic system design, asynchronous and synchronous sequential logic, computer architecture and microprocessor, system interface, PLC, Embedded control computer


MECHANICAL SYSTEM
ACTUATORS
-dc motors, stepper motors, solenoids, voice coils
SENSORS
-switches, strain gauge, MEMS,
INPUT SIGNAL CONDITIONING & INTERFACING
-A/D, D/D, discrete circuits, amplifiers
DIGITAL CONTROL ARCHITECTURE
-logic circuits, microcontroller, PLC, logic & arithmetic, SBC
OUTPUT SIGNAL CONDITIONING & INTERFACING
PWM, D/A, Amplifier, Power transistors
GRAPHICAL DISPLAYS
LEDs, LCD, CRT

- **Sensors**

A sensor is a device that measures a physical quantity and converts it into an 'electrical signal' which can be read by an observer or by an instrument.

- Temperature sensors
- Displacement, position, motion and velocity sensors,
- Fluid sensors, liquid flow, liquid level
- Light sensors etc.

Sensors


Gyroscope


Lever Switch


Linear Encoder


GPS


Camera


Laser Rangefinder


Piezo Bend


Accelerometer


Sonar Ranging


PIR


Rotary Encoder


Metal Detector


Pendulum Resistive Tilt


Pyroelectric Detector


Pressure

Resistive Bend

Gas

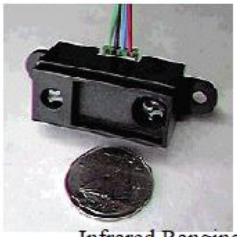

UV Detector


Radiation


Magnetometer


IR Modulator Receiver


Microphone


Infrared Ranging


CDS Cell


Compass


Magnetic Reed Switch

- **Actuator**

❖ Actuator is a device that can convert electrical energy to mechanical energy.

❖ Actuators are **used to produce motion or action**, such as linear motion or angular motions.

❖ An actuator is a component of a machine that is **responsible for moving or controlling a mechanism or system**.

- **Actuator**
- **Mechanical Actuation systems** Mechanical actuators are transducers that convert mechanical energy into electrical energy:

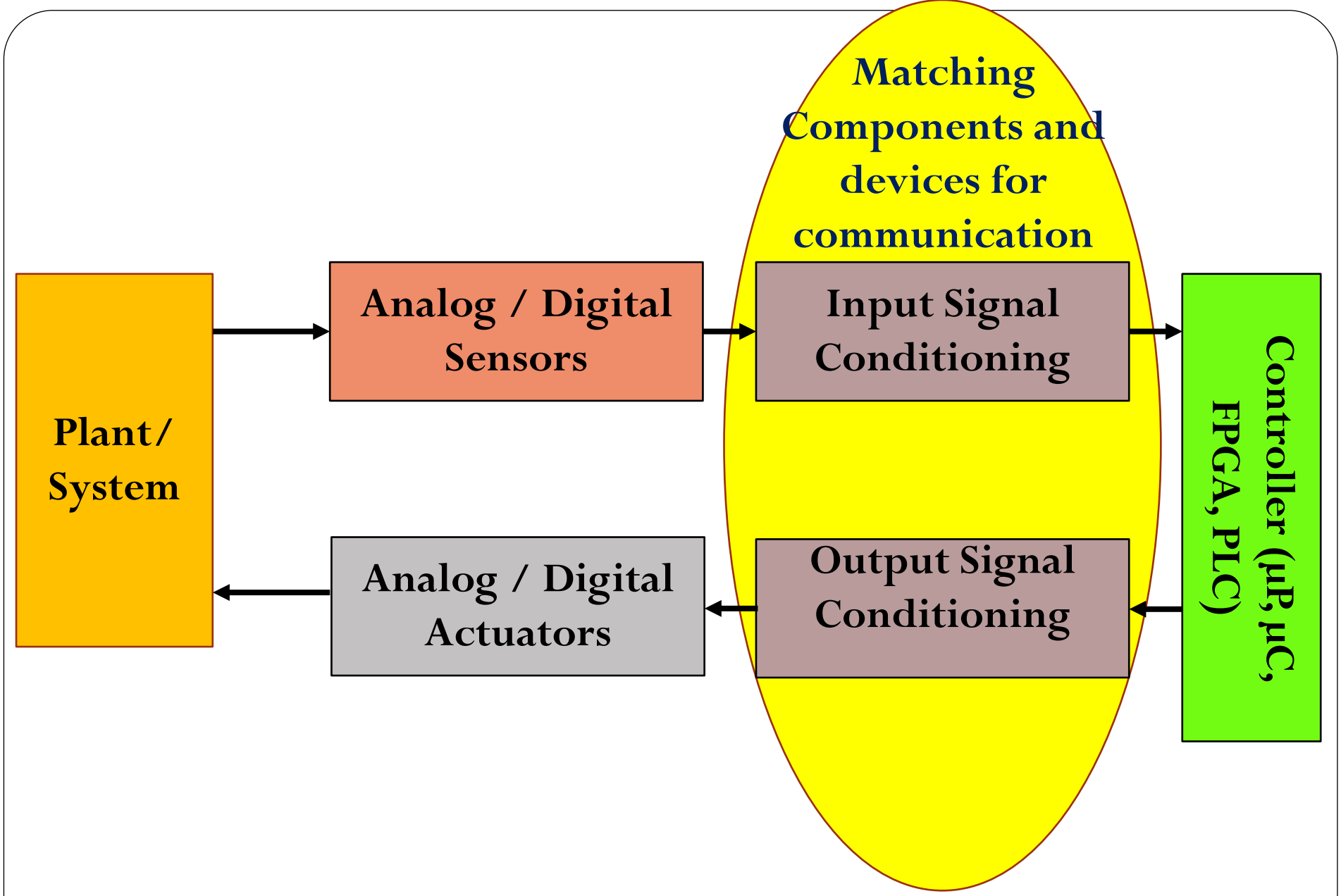
  – hydraulic cylinders and pneumatic cylinders, Gear trains Belt and chain drives, bearings etc.,
- **Electrical Actuation systems**

  Mechanical switches - Keyboards, limit switches, switches, Relays

  Solid-state switches - Diodes, thyristors, transistors

  Solenoids– Push something, Starter solenoid, pneumatic or hydraulic valve

  Drive systems - DC, AC, or stepper motors



Basic Elements of Mechatronic System

Input Signal Conditioning

Intelligent Controllers

Output Signal Conditioning

Smart Sensors

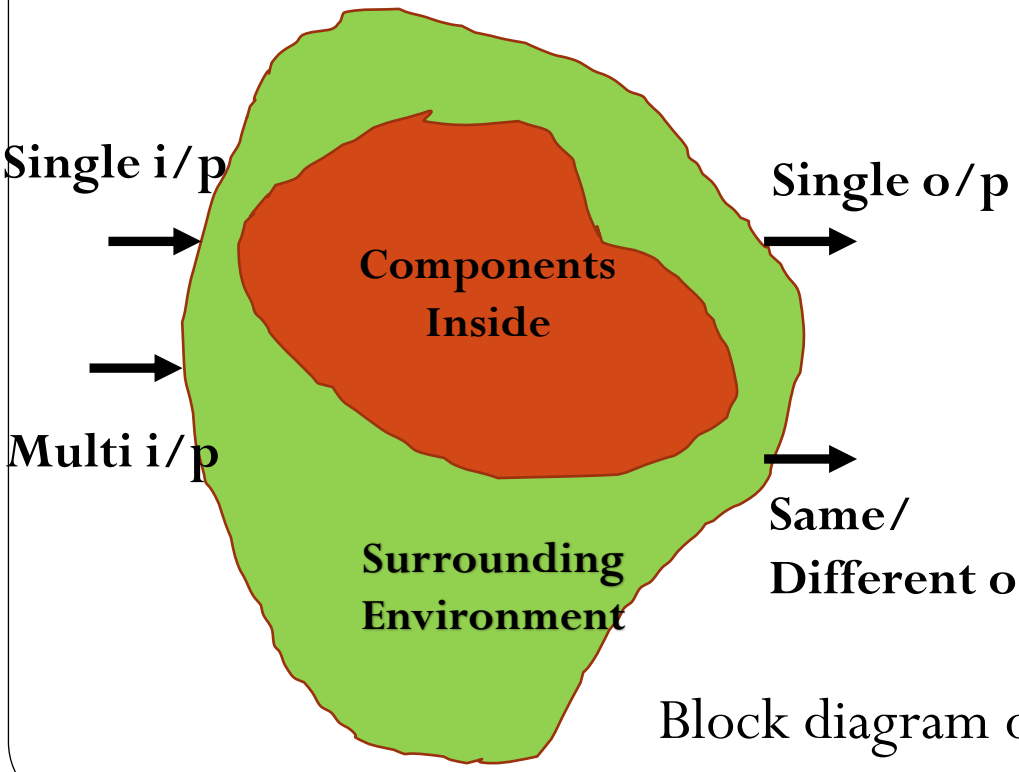
Intelligent Actuators

Plant / system

System

- Various components (parts) interact interdependently such that an output(s) corresponding to input(s) is obtained.
- Same or different i/p , o/p in same or different environment.

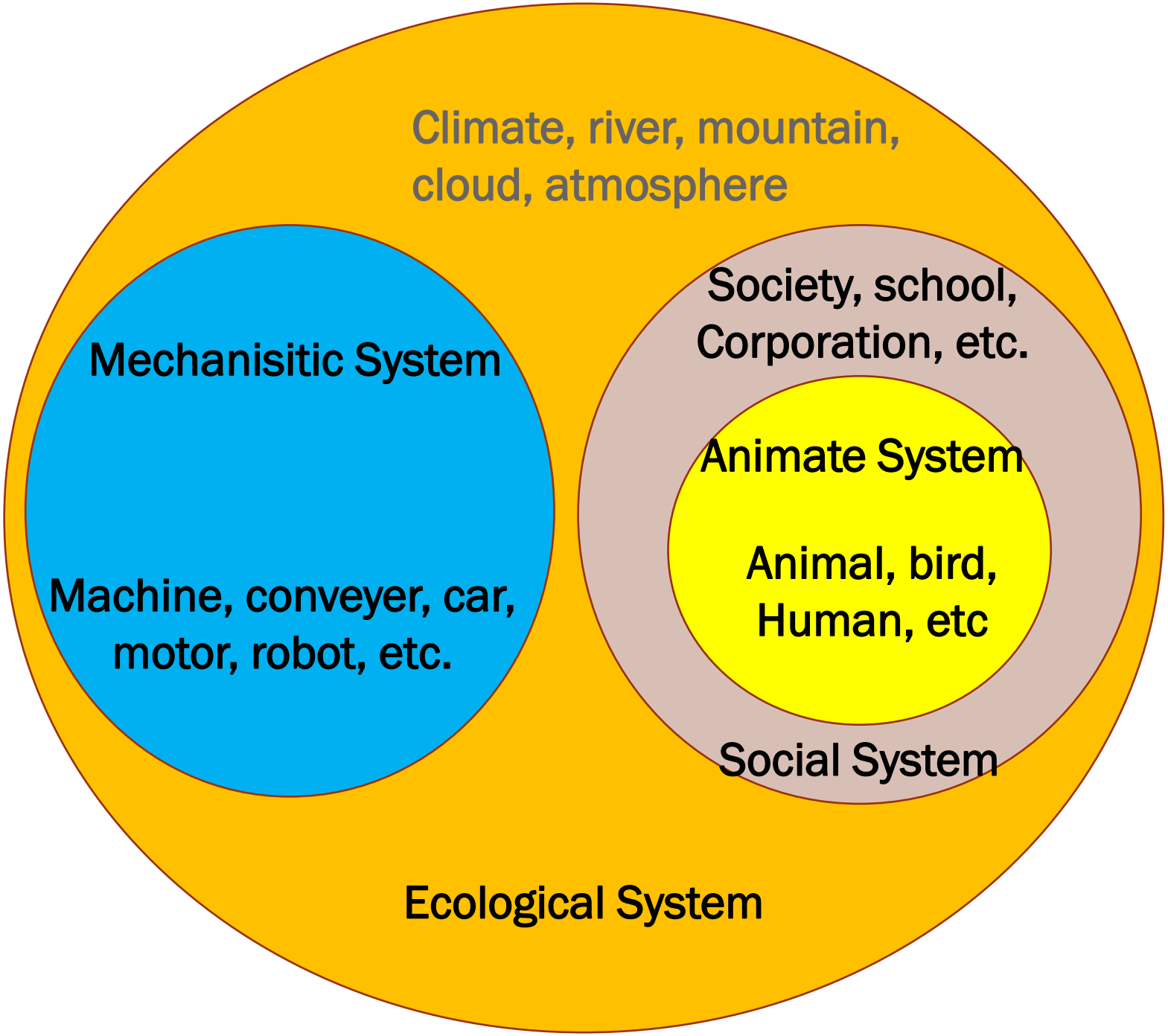
Therefore there exists a choice in a system and/or its components to produce the same output or different outputs depending on the integration of different hardware and software components used in the system.



Block diagram of system

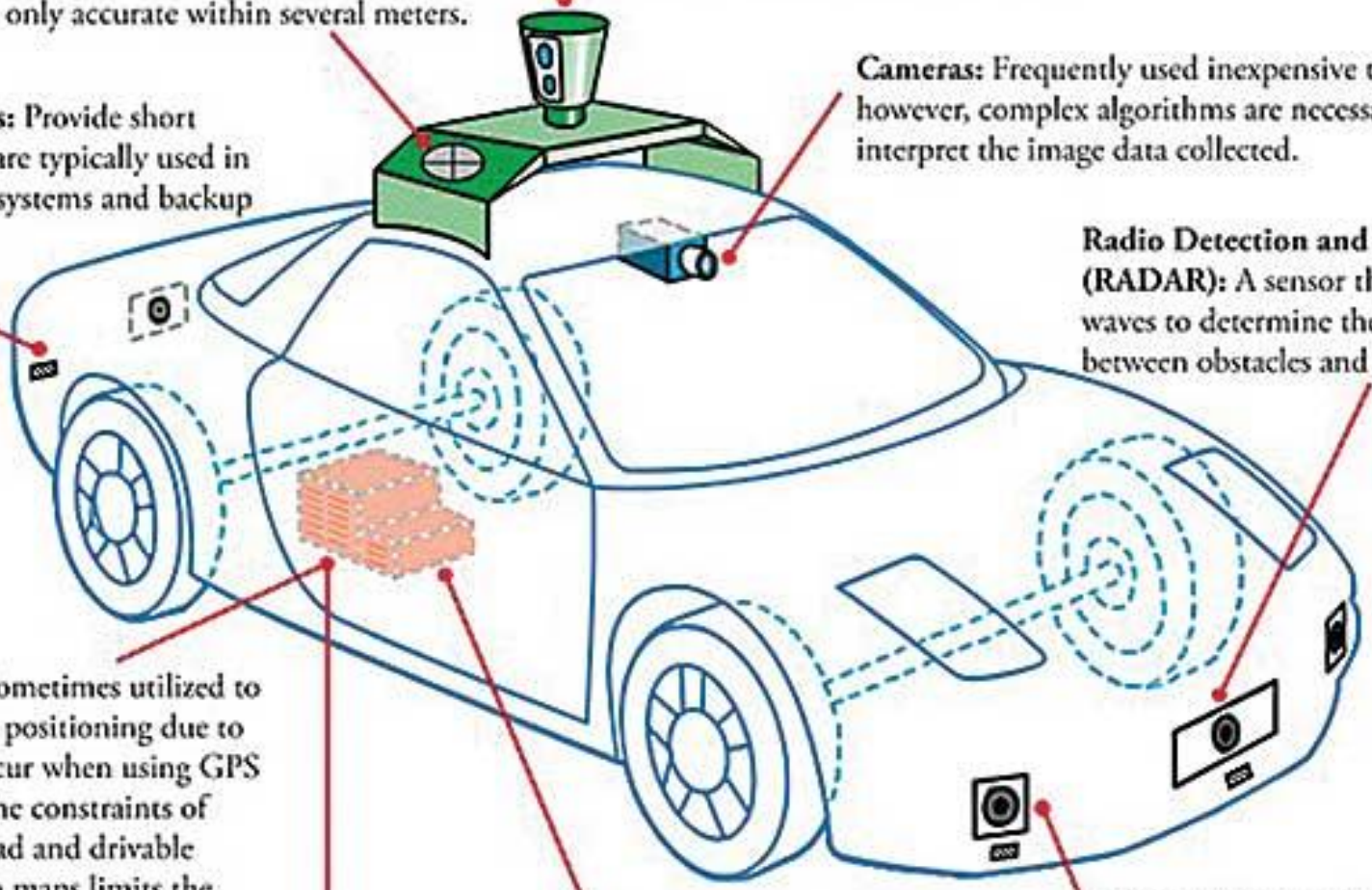
Classification of Systems

- Mechanistic systems
- Ecological systems
- Social system
- Animate system


Climate, river, mountain,
cloud, atmosphere
Mechanisitic System
Machine, conveyer, car,
motor, robot, etc.
Society, school,
Corporation, etc.
Animate System
Animal, bird,
Human, etc
Social System
Ecological System

1.Mechatronic System(Intelligent)

People desire to have their most of **SYSTEMS** (machine, toys, vehicles, home ect.) to be **Smart and Intelligent** enough ,which is **Capable** to **Talk(audio) / Walk(action) /Report(display) / Inform Etc**. as per operating /functioning **Environment and Situations** of the system through UNILATERAL OR BILATERAL COMMUNICATION link.



Global Positioning Systems (GPS): Locate the vehicle by using satellites to triangulate its position. Although GPS has improved since the 2000s, it is only accurate within several meters.

Light Detection and Ranging (LIDAR): A 360-degree sensor that uses light beams to determine the distance between obstacles and the sensor.

Ultrasonic sensors: Provide short distance data that are typically used in parking assistance systems and backup warning systems.

Cameras: Frequently used inexpensive technology, however, complex algorithms are necessary to interpret the image data collected.

Radio Detection and Ranging (RADAR): A sensor that uses radio waves to determine the distance between obstacles and the sensor.

Prebuilt Maps: Sometimes utilized to correct inaccurate positioning due to errors that can occur when using GPS and INS. Given the constraints of mapping every road and drivable surface, relying on maps limits the routes an AV can take.

Dedicated Short-Range Communication (DSRC): Used in Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) systems to send and receive critical data such as road conditions, congestion, crashes, and possible rerouting. DSRC enables platooning, a train of vehicles that collectively travel together.

Inertial Navigation Systems (INS): Typically used in combination with GPS to improve accuracy. INS uses gyroscopes and accelerometers to determine vehicle position, orientation, and velocity.

Infrared Sensors: Allow for the detection of lane markings, pedestrians, and bicycles that are hard for other sensors to detect in low lighting and certain environmental conditions.

1.IC Engine System / Electric motor with control

2. Power Transmission System / Drive train – flywheels, clutch, gear, CVT (Automatic)

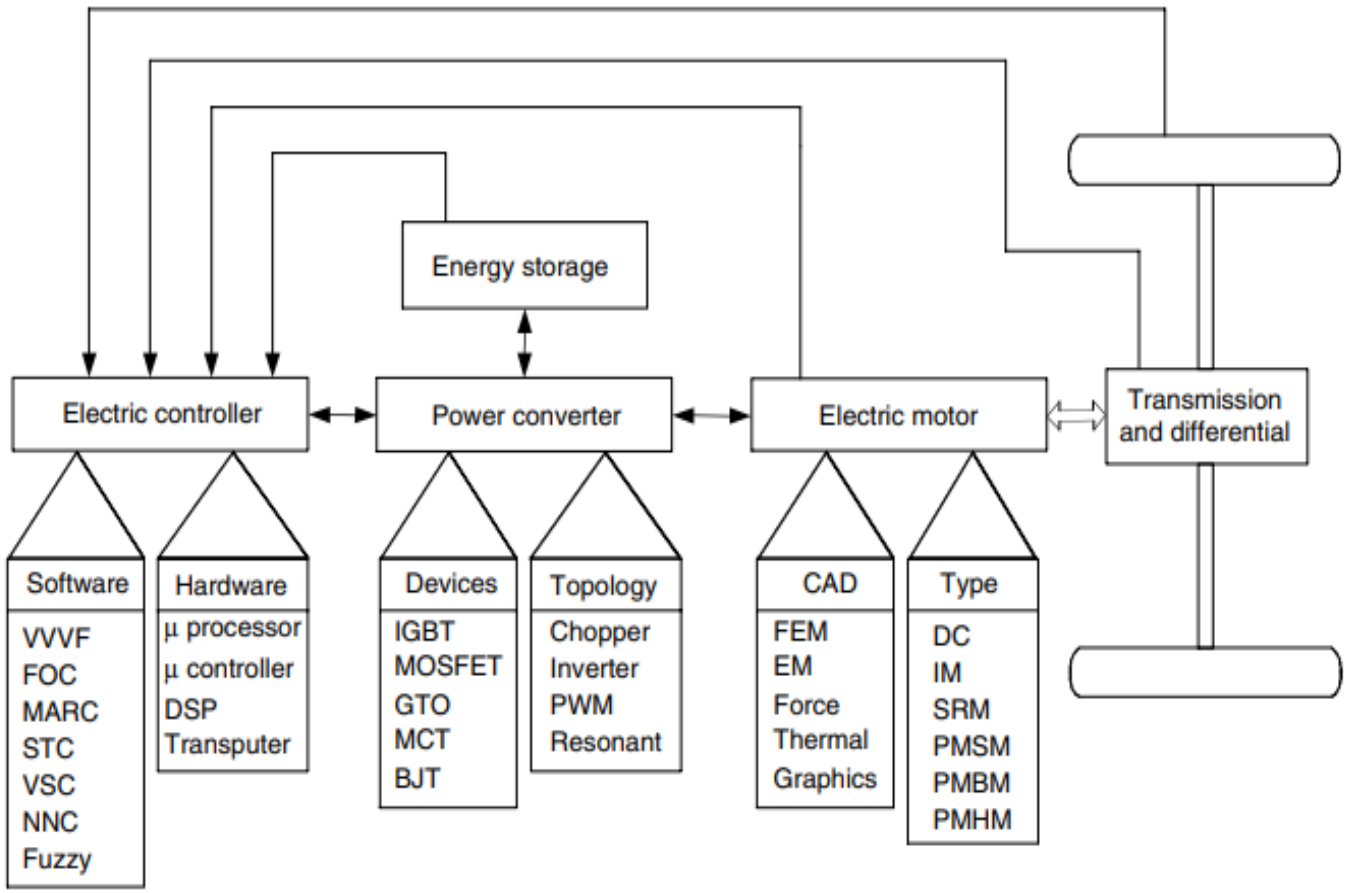
3. Brake System - Anti-lock Brakes and Power Brakes

4. Steering, Suspension and Tires

5. Electrical System – Battery, Fuses and Connectors, Car Computer(ECU)

6. Exhaust System - Catalytic Converter, Silencer

7. Car Cooling System - water pump, thermostat, radiator, fan and other smaller components.



Sensor translate measurable quantities (current, voltage, temperature, speed, torque, and flux) into electric signals through the interface circuitry.

Signals conditioned to the appropriate level before fed into processor.

Then amplified via the interface circuitry to drive power devices of the power converter

What To Understand?

- **SYSTEMS:** Know the system operation and control parameters.
- **ENVIRONMENT AND SITUATIONS:** Translate the situation(s) to respective signal using sensor(s) & transducer(s).
- **CAPABILITY to COMMUNICATE:** Design for capability to communicate the translated signal using signal conditioning devices to controller.
- **CONTROLLER:**  Which controls communication and coordination among all components through computation and comparison to issue command signal to implement action.
- **ACTION/OUTPUT:** Implement controller command using actuator(s).

'SMART (INTELLIGENT) SYSTEM'

Mechatronics represents a process that blends mechanics and electronics with use of precision engineering, computer science, information technology, control system theory, and sensor and actuator technology to design improved products and processes.

Classification of Mechanistic Systems

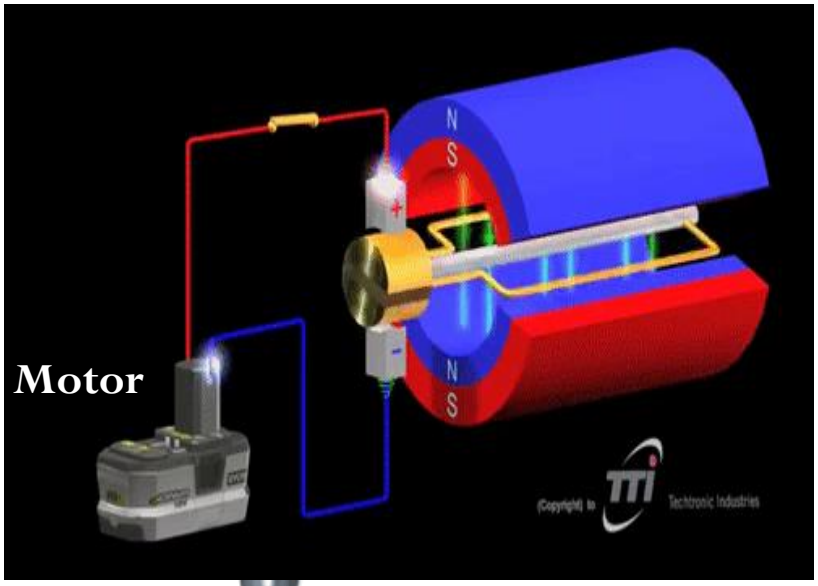
Based on type of input energy, type of control applied, mathematical model used, and level of Intelligence.

1. Input Energy based Classification

- Type of input energy - Electrical, hydraulic, pneumatic, mechanical, chemical, nuclear and optical

- Electrical System
- Thermal System
- Mechanical System
- Fluid System
- Chemical System
- Nuclear System

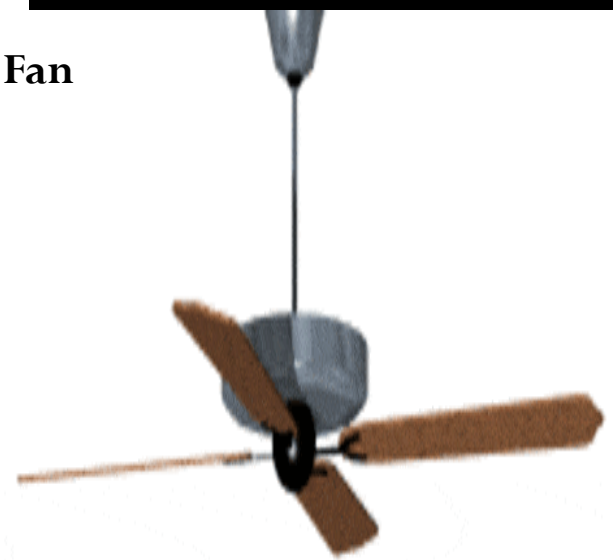
Electrical Systems



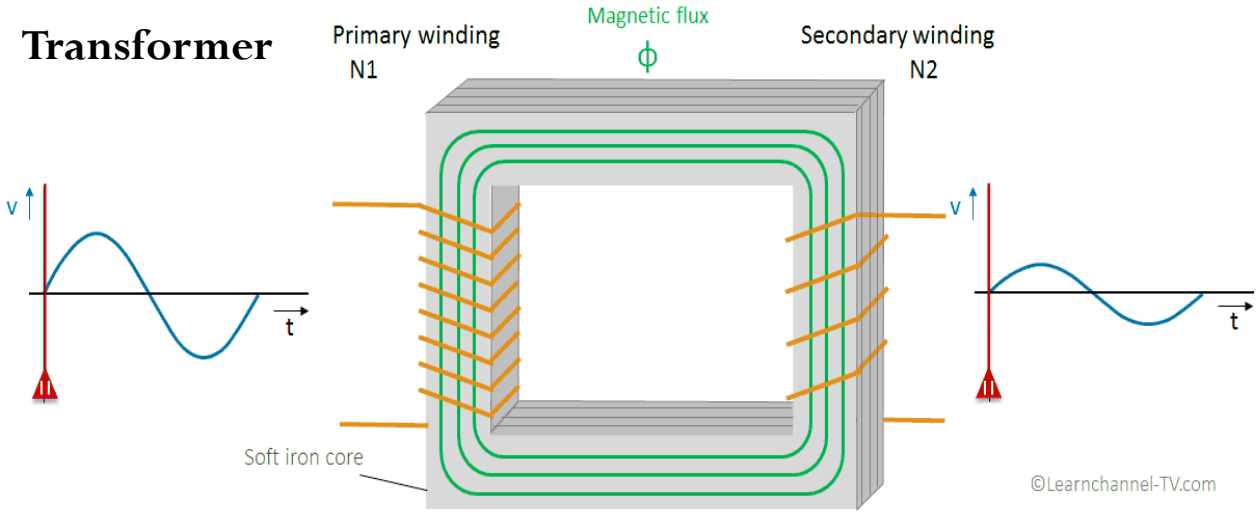
Motor

- Input is Electrical Energy
- Output may be mechanical, electrical, chemical, etc.

Fan

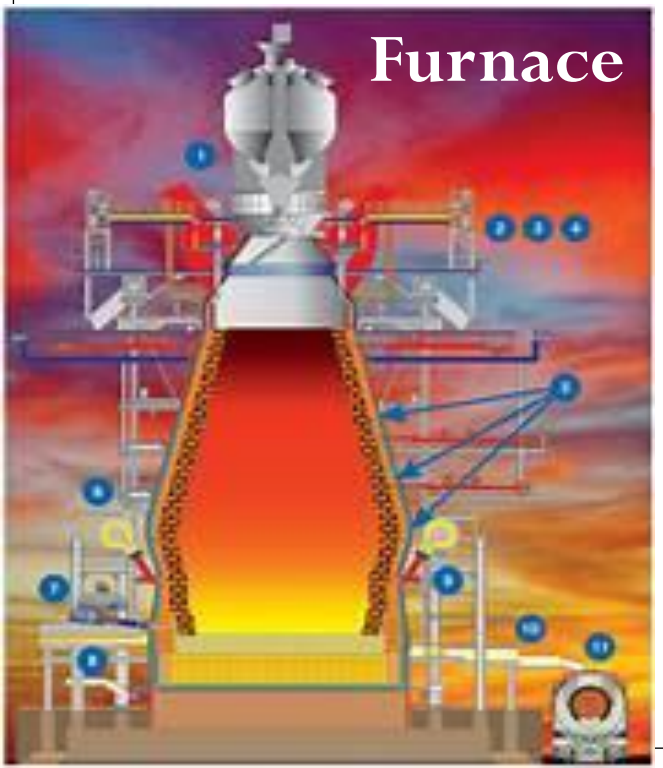


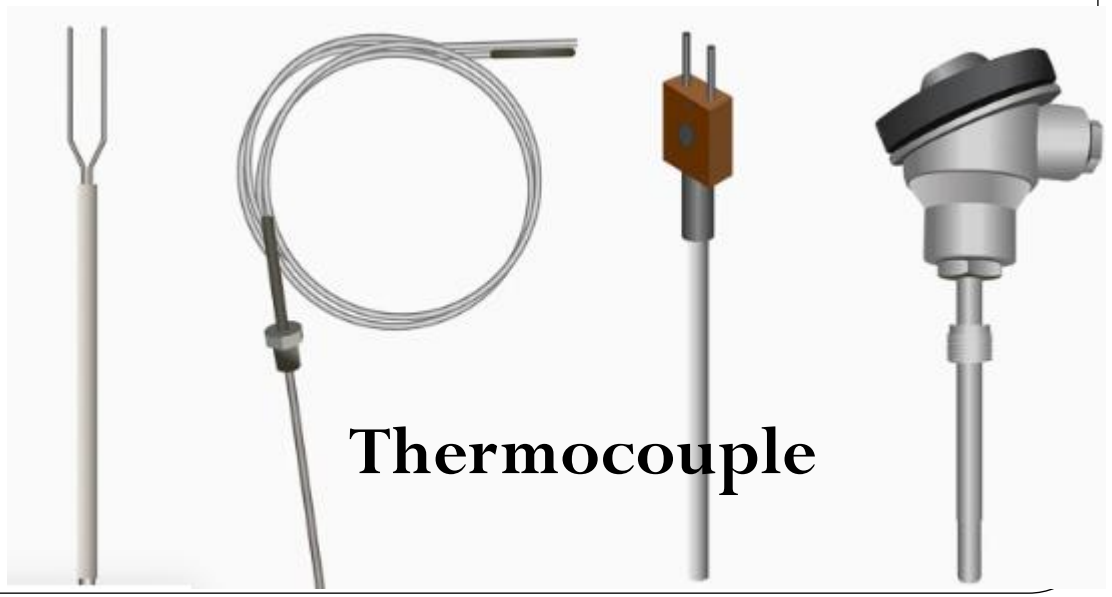
Transformer



Thermal Systems

- Input is Thermal Energy
- Output may be mechanical, electrical, chemical, etc.





Mechanical Systems

- Input is mechanical Energy
- Output may be mechanical, electrical, etc.

Lathe machines

Turbines

Automobiles

Nuclear Systems

- Input is nuclear Energy
- Output may be mechanical, electrical, heat, motion etc.

Electricity generation through nuclear fission heat, Nuclear weapons atomic bomb

Fluid Systems

- Input is fluid Energy
- Output may be mechanical, electrical, etc.

Pelton wheel turbine

Air compressor

Water jet cutting

Chemical Systems

- Input is chemical Energy
- Output may be mechanical, electrical, etc.

Battery

Electrolytic process

2. Mathematical Model based Classification

Behaviour of system is described with the help of mathematical model (s). **Equations to establish input-output relationship**

- Dynamic System
- Static System
- Linear System
- Nonlinear
- Distributed
- Lumped
- Probabilistic
- Deterministic

- **Static System** - the components and system are represented to give an output without any time constraint.
- In a static system, the variables or properties of the system do not vary or change with time.

- E.g. **calculation of mechanical stress in a bridge**

- **Dynamic System** – A dynamic system model is a mathematical representation of the dynamics between the inputs and outputs of a dynamic system. Represented by integral or differential equation. E.g. moving objects, systems undergoing chemical reactions, evolving populations etc.

Dynamic system models are either **time-variant or time-invariant.**

- ✓ The **parameters of a time-variant model change with time**. E.g. time-variant model to describe the mass of an automobile. **As fuel burns, the mass of the vehicle changes with time.**
- ✓ The parameters of a time-invariant model do not change with time. E.g. a simple robot. Generally, the dynamic characteristics of robots do not change over short periods of time.

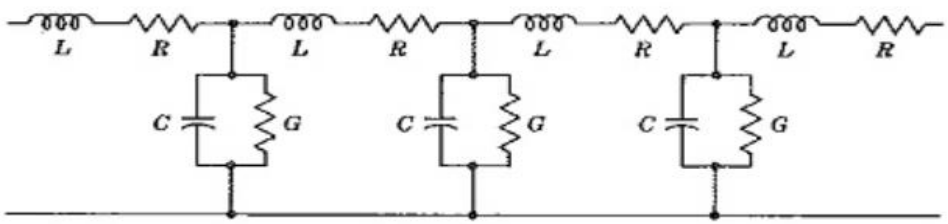
- **Linear System** - linear relationship between input and output. A system is said to be a linear system if it obeys the principle of homogeneity and principle of superposition. E.g. Filter circuits, communications channels, a network that is solely resistive and has a steady DC source
- **Nonlinear** – does not show linear relationship between input and output. E.g. A magnetization curve or the no load curve of a DC machine

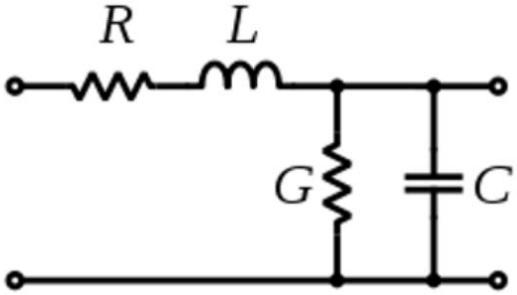
**The superposition theorem states that the response in a linear circuit with multiple sources is the sum of the responses from each source considered separately.

The homogeneity property requires that if the input (also called the excitation) is multiplied by a constant, then the output (also called the response) is multiplied by the same constant.

➢**Distributed** – parameters are distributed along space and time. Developed using partial differential equation.

➢**Lumped** – parameters are functions of time and are concentrated at a singular point. Developed using differential equation. Homogeneous and consistent system can be lumped not heterogeneous.





- **Probabilistic / stochastic** – Constituted by random variables' states instead of unique set of values. Represented using probabilistic distribution.
- **Deterministic** – Constituted by a unique set of variable system parameters with previous state values. Its results are dependent on the initial values of the variables.

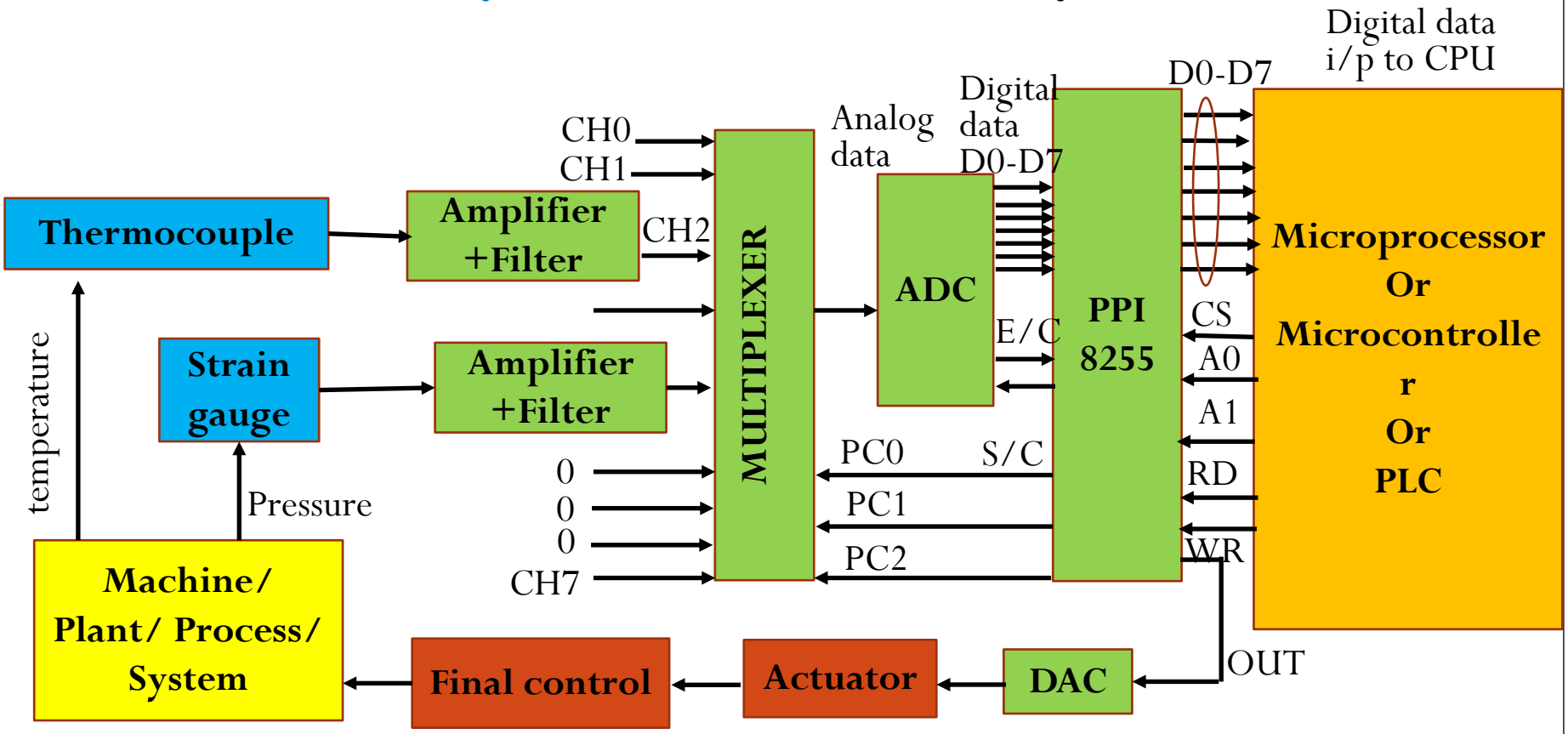
3. Function based Classification

- A system can be classifies based on the functions that it performs.
- A system can be made up of –

a measurement system and /or a control system

3. Function based Classification

- Measurement system and control system



S/C : Start Conversion

E/C : End Conversion

Programmable Peripheral Interface (PPI) chip

PPI 8255 *is a general purpose programmable I/O device designed to interface the CPU with its outside world such as ADC, DAC, keyboard etc.*

- **Sensor** responds to the energy received from physical quantity. The output is converted to an electrical analog signal by a transducer.
- **Signal conditioner** amplification, filtering, rectification, analog to digital converter (ADC)/ Digital to analog (DAC), etc.
- **Data transmitter** data received after signal conditioning are transmitted to components/device for further processing for measurement or control. Important for computer control or remote control.

- **Data Processor** (calculation, calibration, comparison, etc) done by computer / calculating device for displaying an output or performing computer control.
- **Data presentation** data are presented for interaction through display devices such as monitors, LCD, prints, etc.

- **Open-loop system:**

✓An open-loop system is defined as a system in which the output signal is not fed back for comparison with the input signal.

✓Thus the output is not affected by the changes in the input. E.g heating of a room

- **Closed-loop system:**

✓A closed-loop system is defined as a system in which the output signal is fed back for comparison with the input signal.

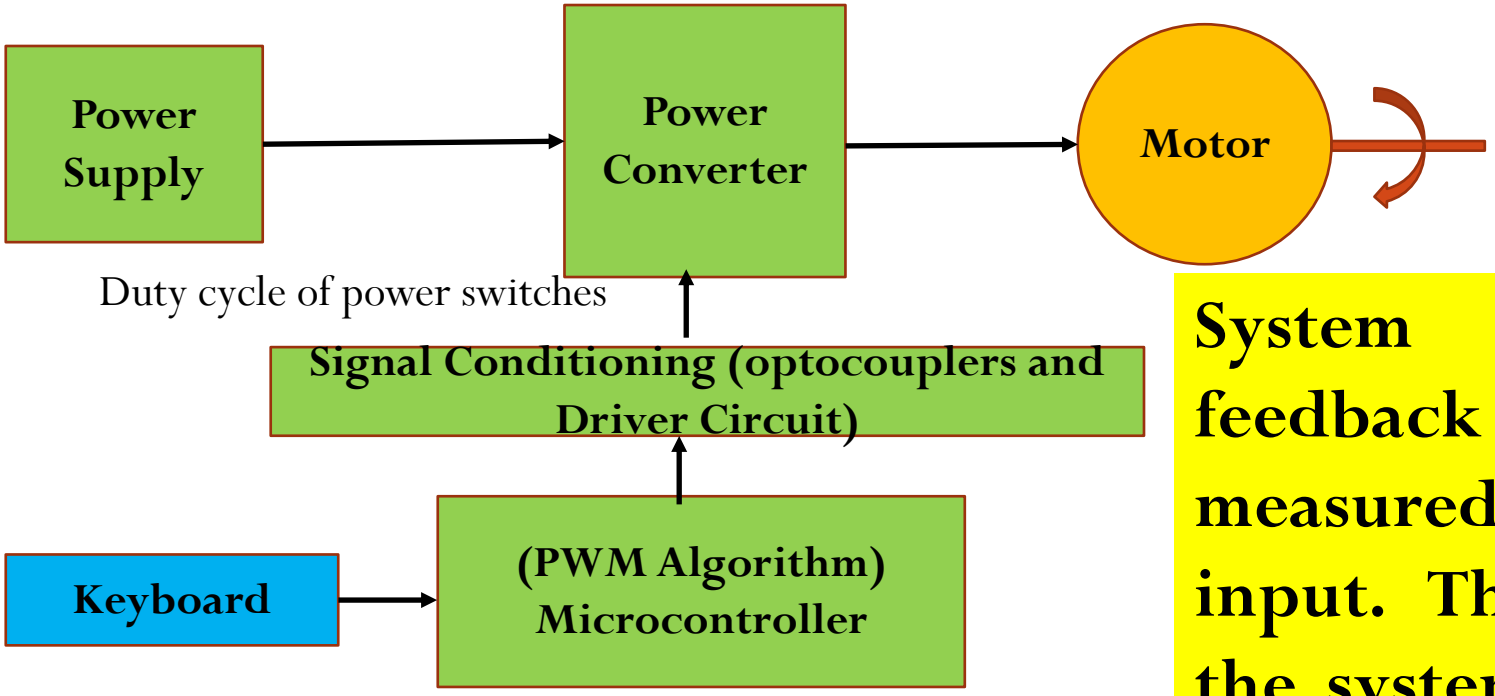
✓Thus the output is affected by the changes in the input.

- Measurement system and **control system**

used to control some phenomenon or action

Types – Open loop or Closed loop system

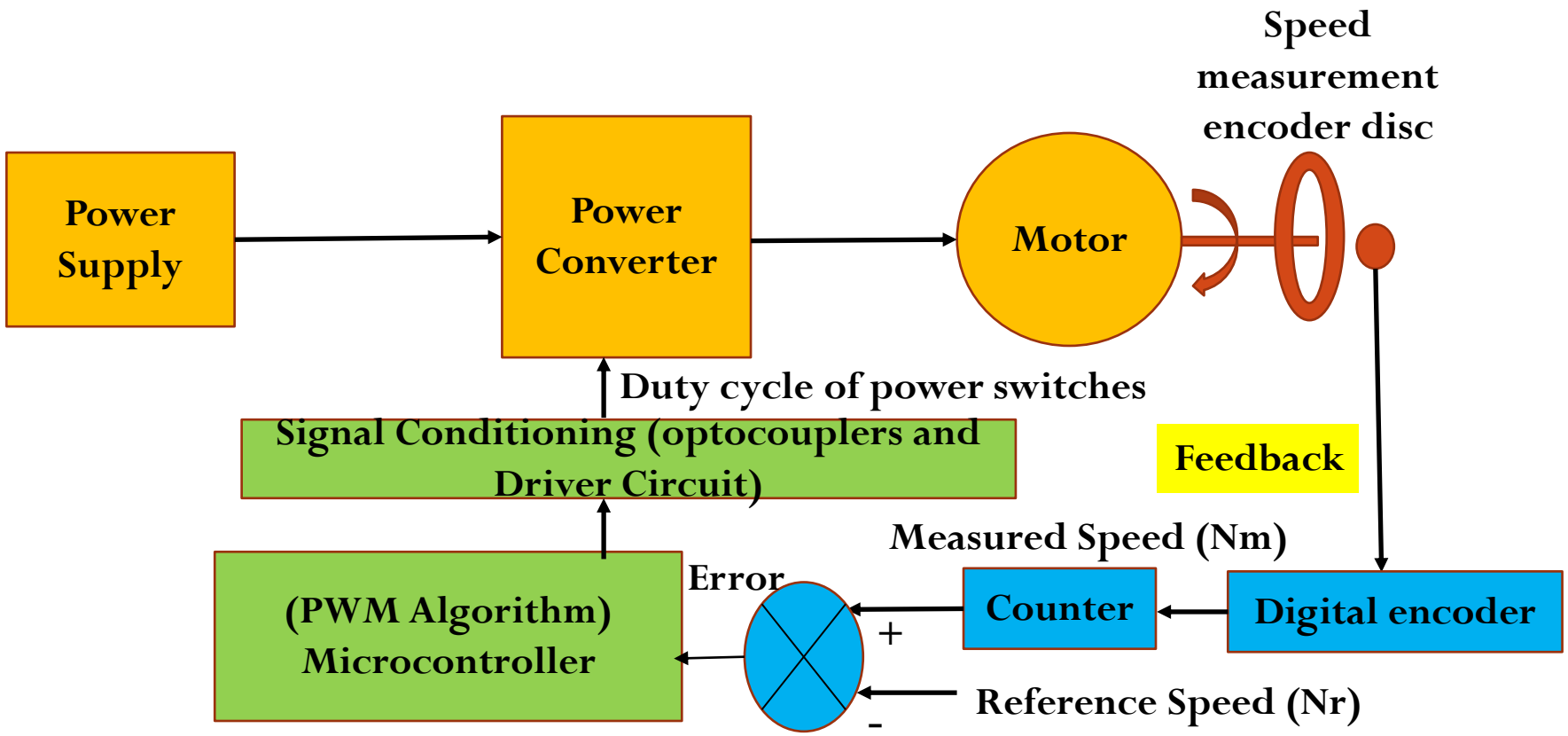
(i) Open loop system



System has no feedback of actual measured value to input. Thus o/p of the system does not affect the i/p.

- **Open-loop control** is **often used with processes that require the sequencing of events by on–off signals**, e.g. washing machines which require the water to be switched on and then, after a suitable time, switched off followed by the heater being switched on and then, after a suitable time, switched off.

(ii) Closed loop system



The o/p from the system is fedback to the input level of the system such that the error is reduced.

Automatic and intelligent mechatronics system are closed loop and feedback control systems (FCS)

- Closed loop system regulates the output to a certain value based on the feedback provided by a measuring device.
- A self regulating system is fully automatic.
- **Elements of closed Loop system**

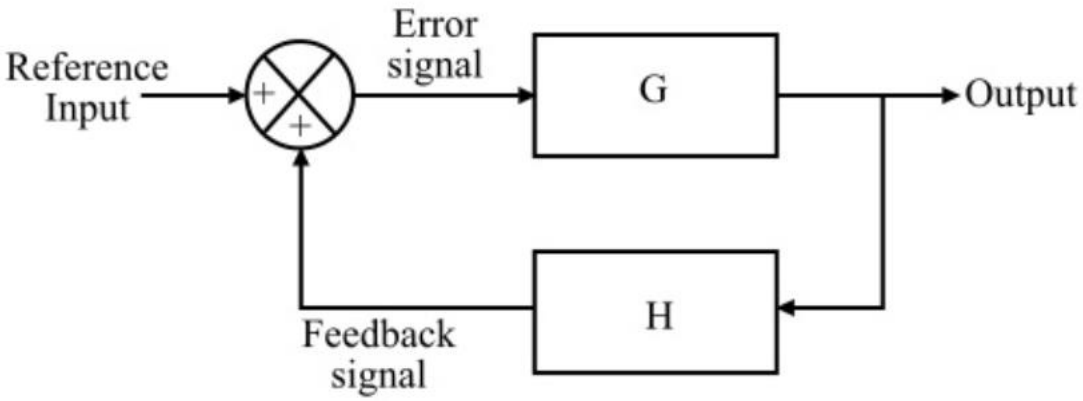
  i) Elements for comparison :

Error = Desired/set/reference value – measured value

- Error is generated by negative feedback, positive feedback and bipolar feedback.
- Negative feedback is used to control a system.

Positive Feedback

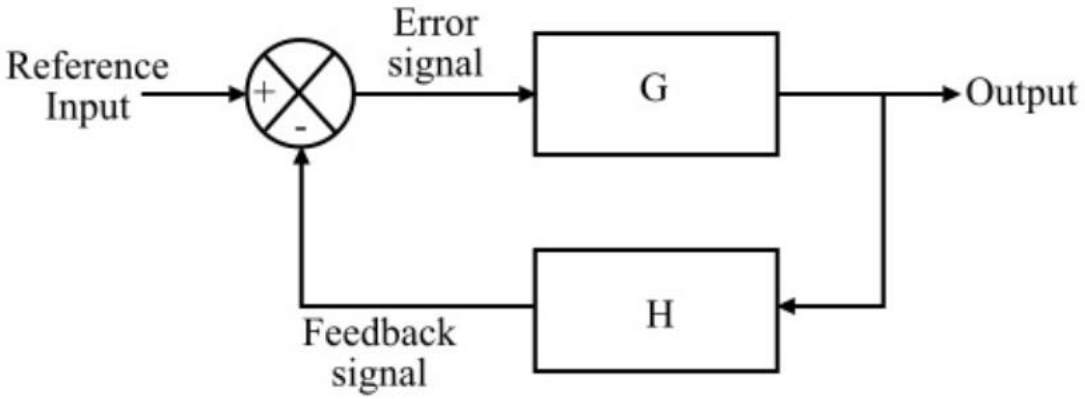
- A feedback in which **the reference input signal and the feedback signal are added together** is called a positive feedback. The positive feedback is also called a regenerative feedback.



- Application: oscillator circuits

Negative Feedback

- When the **reference input signal and the feedback signal are subtracted at the input of the system**, then the feedback is known as negative feedback.



- Application: amplifier circuits, motor control system etc.

**Most widely used type of feedback in the control systems.

ii) Control Elements: Take an action based on the error signal. Controls the process according to algorithm.

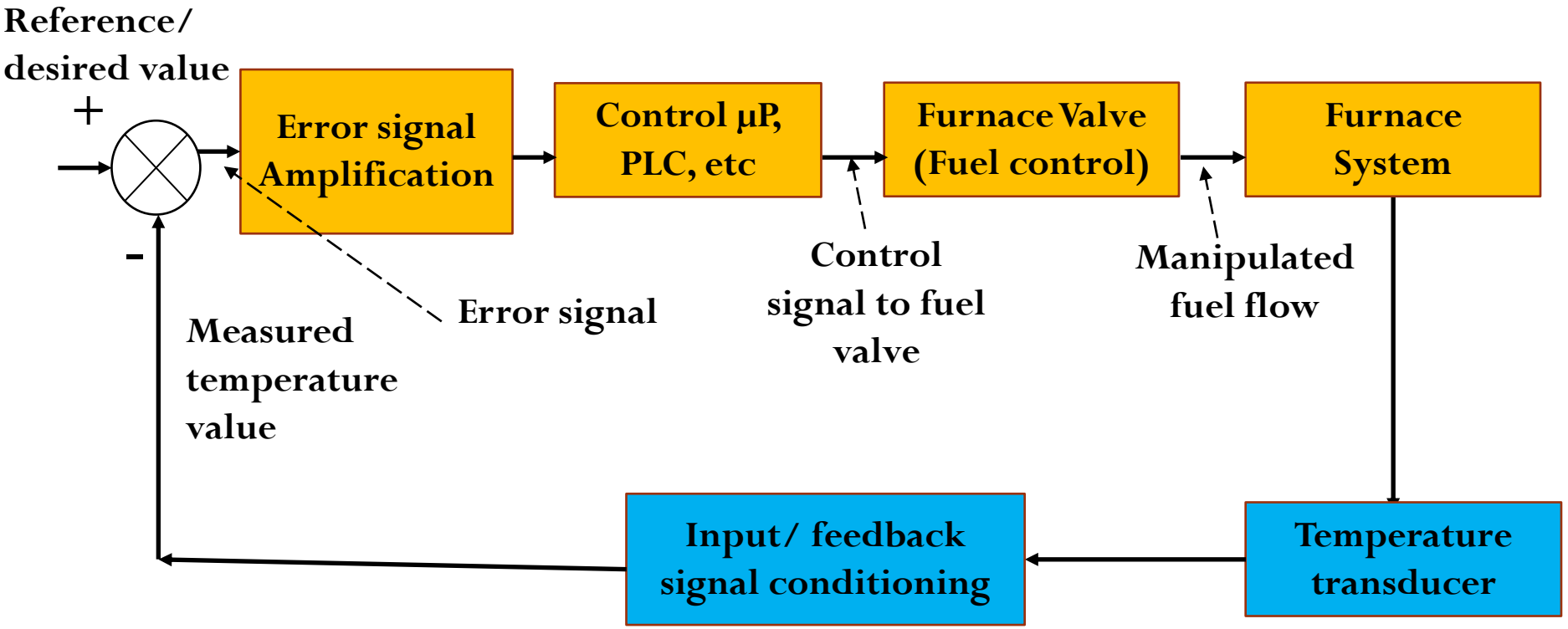
iii) Correction element : Minimize the error based on the control signal issued by controller. A switch (effector/ actuator/ final control element) to turn ON or OFF AC/fan for cooling room.

iv) Process element : Combination of various functions of different system controlled using closed loop control.

v) Measurement element : Output a value of signal corresponding to input physical variable parameter under measurement. Measured value is compared with required value. Error processed to issue control signal command for correction.

Developing closed loop system from open loop system

Temperature control of furnace



- **Reference Value:** Desired furnace temperature
- **Controlled value :** It is the furnace temperature
- **Error Signal :** Difference between reference and measured value of temperature.

In closed loop human is replace by computer / PLC/ µP, µC, etc.

Elements of Closed Loop System

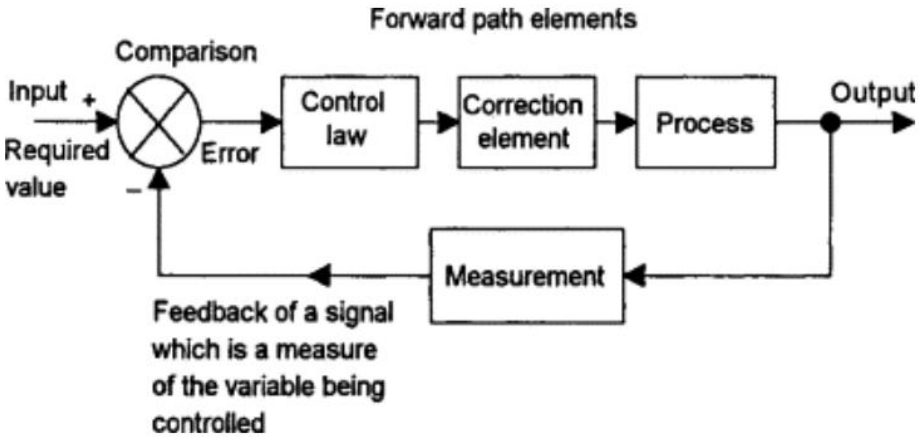
1) Comparison element :

This element compares the required value of the variable being controlled with the measured value of what is being achieved and produces an error signal:

Error = reference value signal− measured actual value signal

- ✓ In open loop, the operator compares.
- ✓ In closed loop feedback control is required

2) Control Unit: Control unit analyses the error signal and decides what action is to be taken. Operator behave like a control unit and control the temperature (in furnace example).

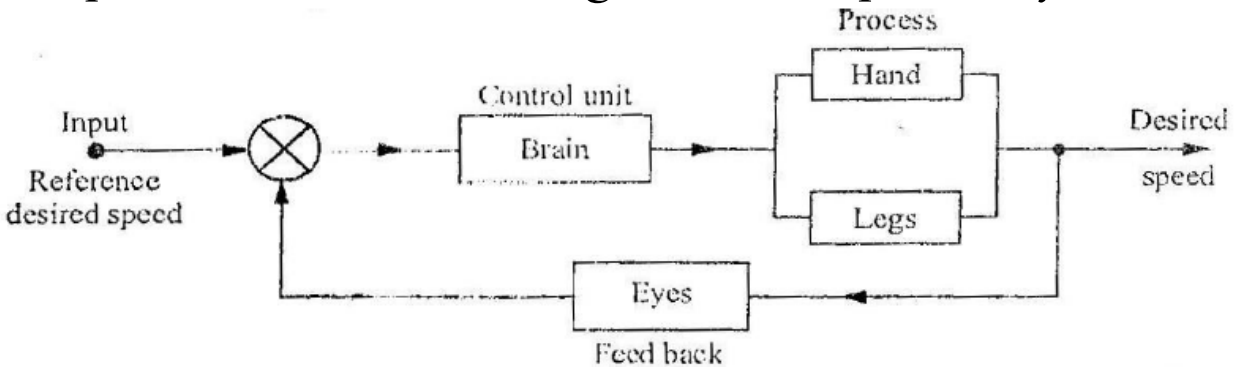


Elements of Closed Loop System

3) **Correction unit:** the modified signal from the control unit will be received by the correction unit which produces a change in the process to correct or change the controlled condition. Switch to be made ON/OFF of heating process (in furnace example)
4) **Process unit:** The process is the system in which **there is a variable that is being controlled,** e.g. it might be a room in a house with its temperature being controlled or heating of Furnace using fuel
5) **Measurement element or measuring device:** The measurement element produces a signal related to the variable condition of the process that is being controlled. E.g it might be a temperature sensor with suitable signal processing, Thermocouple/ Thermistor, etc.

Speed control of an automobile

- The driver observes the speedometer, and based on the speed shown by the speedometer he decides whether the fuel supply should be increased or decreased or gear change is to be made.
- Here **speed shown a speedometer is a feedback**. A **feedback signal from the eye compares the desired speed in the memory of the driver.**
- Error signals are given to brain**. Brain manipulates the error signals** and gives it to hand and leg and increase the fuel supply if the speed is less than the desired speed, otherwise decrease the fuel supply.
- Changing of gear and increase or decrease of fuel supply, depends on whether it an upward or downward gradient respectively.



What type of control is used in traffic light system?

How can we convert it from one form of control to another form?

What are the input and output of a toaster? Is it an open loop or closed loop system? How can we transform an open loop system to closed loop system?

Inputs- bread and time setting

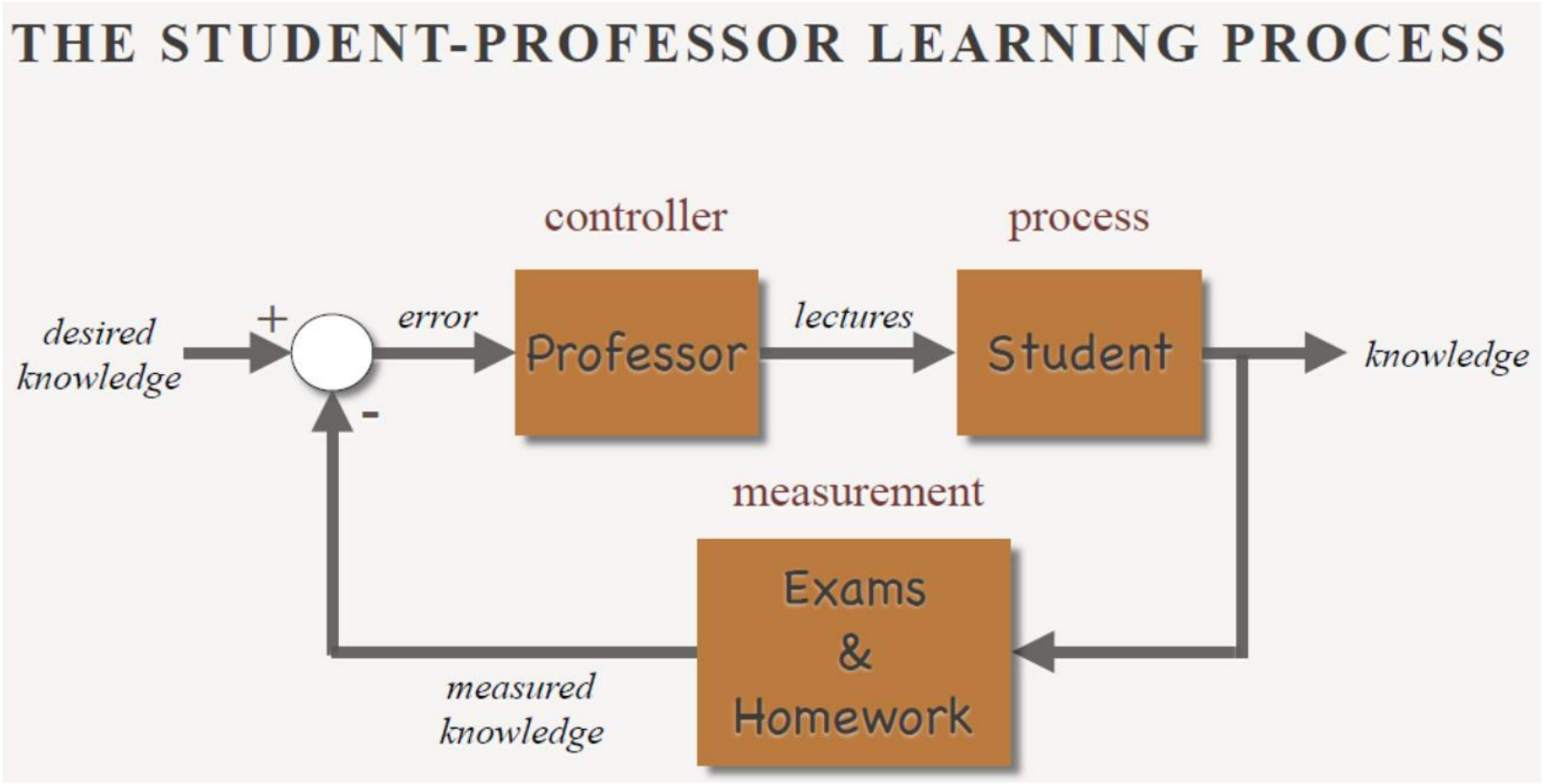
Depending on the time setting, bread is simply heated in the system. The toast quality is judged by the user and has no effect on the input, therefore, the output has no effect on the input. Hence the automatic toaster is an open-loop system.

To make it closed loop system:

- Sensors to measure the color
- Actuators to adjust the timer based on the measured color.

- If voltage stabilizer is an open loop or closed loop system?
- A servo voltage stabilizer is a closed-loop control mechanism that serves to maintain balanced 3 or single-phase voltage output despite fluctuations at the input owing to unbalanced conditions.
- TV remote control!!!
- The operation of the TV remote does not get affected by the usage of TV, hence it is an open-loop system.

- Give any example of closed loop system


THE STUDENT-PROFESSOR LEARNING PROCESS
controller
process
desired knowledge
+
-
error
Professor
lectures
Student
knowledge
measurement
Exams & Homework
measured knowledge

Advantages and Disadvantages of closed loop control systems

- **Advantages:**

More accurate, More flexible control, easier to use, more informative, more intelligent, more useful than manual control

- **Disadvantages:**

More complex mechanism, complex hardware, More prone to breakdown or damage, Newly developed components may outdate existing one.

Sequential Control System

- Control of sequences of operations in a sequence is called as a sequence control system.
- Working of washing machine is a sequential control system wherein control is exercised based on event, or parameter etc., i.e. control action will be executed one after another event.
- The events to be carried out in a domestic washing machine are soaking, washing, rinsing and drying.
- Each of these operations involves a number of steps.

Mechatronic System Intelligence

- Advancement in **Semiconductor technology and IT** led to new generation equipment and machinery – **smart or intelligent product/ device/ system**
- Intelligent systems are made of sensing devices, memory, data-processing devices, reasoning devices, communication devices and effectors/ actuators to develop intelligence and knowledge.
- Intelligent systems are capable of perceiving reasons, learning and acting intelligently using **artificial intelligence (AI)**

- AI can make major contributions to designing intelligent machines in the areas of perception and cognition, and also to actuators such as 'intelligent' grippers on robot arms.

Properties of Intelligent System

- Unique identification
- Capability to communicate effectively with its devices and environment
- Capability to store, inform, and use data/information regarding its components, system, and environment
- Facility to display its features, requirements, etc.
- Communicate and coordinate with its users, components and environment for decision making
- Continuously monitor their status and environment

Why build intelligence into machines?

- machine intelligence offers new possibilities
- machine intelligence can give better solutions to problems
- software is relatively inexpensive to mass produce
- software can often be changed more easily than hardware

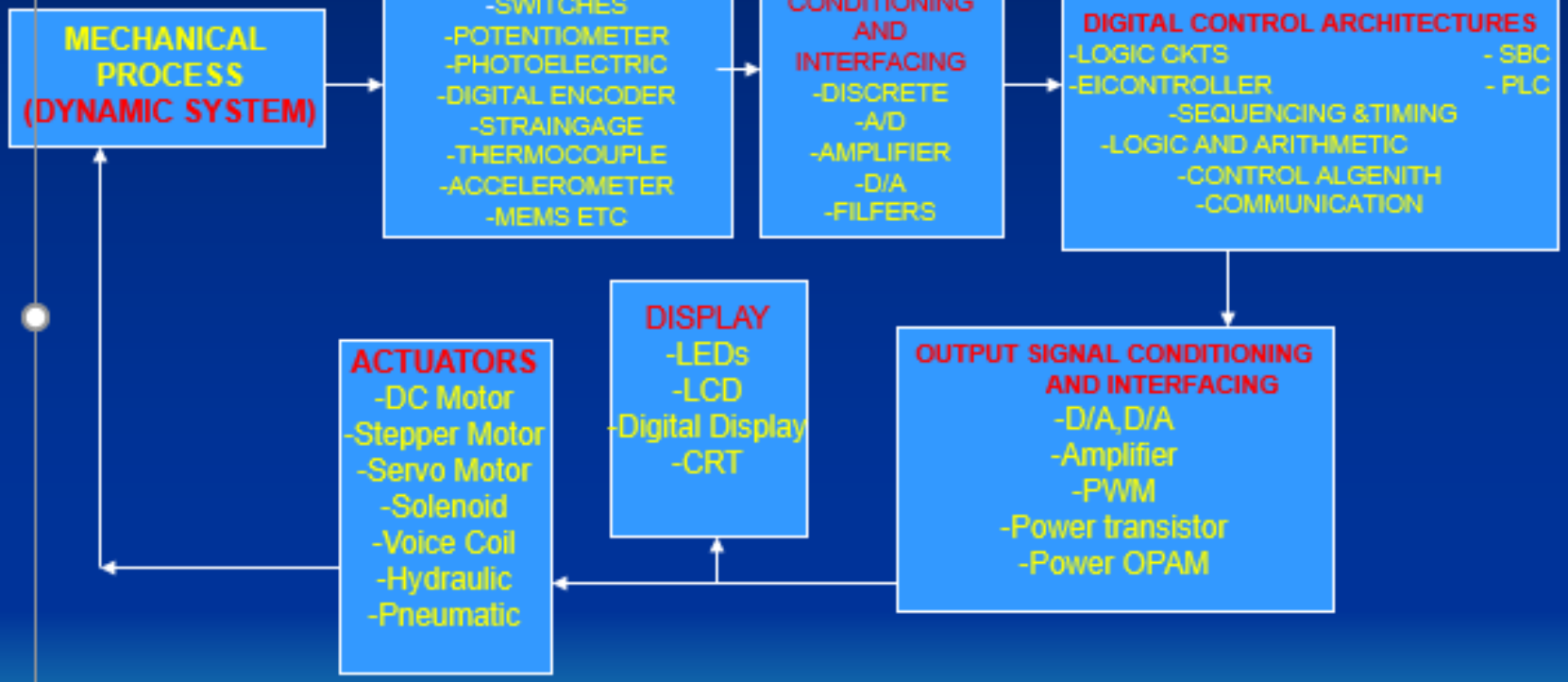
Mechatronic system intelligence varies from dumb to wisdom levels, similar to human brain.

Level of Intelligence	**Intelligent system class**	**Sub system**	**System ability**	**Components**	**Examples**
Level 0	Dumb		Cannot interact with self or environment	No components (e.g. sensors, data processing devices, software)	Table, glass of water
Level 1	Self regulating	Perception + execution	Identification (analog and digital signal as information)	Sensors, decision mechanism (Opamps, logic gates, flip flops and timers) + effector **No software**	Automatic iron, Auto focusing camera
Level 2	Small SDs/ Lower Intelligence	Perception + execution with knowledge	Identification +reasoning for accessing knowledge	Sensors, decision mechanism + effector	refrigerator with thermostat, washing machine

Level 3	Big SDs/ Lower Intelligence	Perception + cognition+ execution	Identification +reasoning for accessing knowledge +Learning+ communication	Sensors, decision by processor (Hardware and software)+ effector	Cars with an electronic transmission system (ETS) [changing road condition, ice, obstacles etc]
Level 4	Advance intelligence/ Wisdom level	Perception + cognition+ execution	Identification +reasoning for accessing knowledge +Learning+ communication + history track for pattern recognition	Sensors, decision by processor (Hardware and software)+ANN + Deep Learning effector	Anthropoid robots (ASIMO) **A**dvanced **S**tep **i**n **I**nnovative **Mo**bility

Level 4: It has capability to interact with its components , systems and environment by tracking and retaining history to identify and control the situation with reasoning before making decisions for communicating/implementing the same.

Generalized Intelligent Mechatronics System



A TYPICAL INTELLIGENT MECHATRONIC SYSTEM

Dr. Tilak, PEC, CHD.

Human Intelligence System

A human intelligence system is embedded with components like sensors, and data sophisticated information devices.

Hardware components:

Sensing elements : eyes for seeing, ears for hearing, nose for smelling, tongue for tasting (sweet, sour, salty, bitter, etc.), and skin for feeling touch, temperature, pressure, etc

Data (information)-processing elements: Neurons carry information to our computer, i.e. brain. The output of the brain (computer) after making a decision is communicated through motor nerves to the decision effectors.

End effectors legs for walking, hands for performing specific tasks, mouth for eating, etc.

Human Intelligence System

Software components The software components in human beings to develop knowledge and intelligence is in progress since one is born using sensing components such as eyes, nose, and ears .

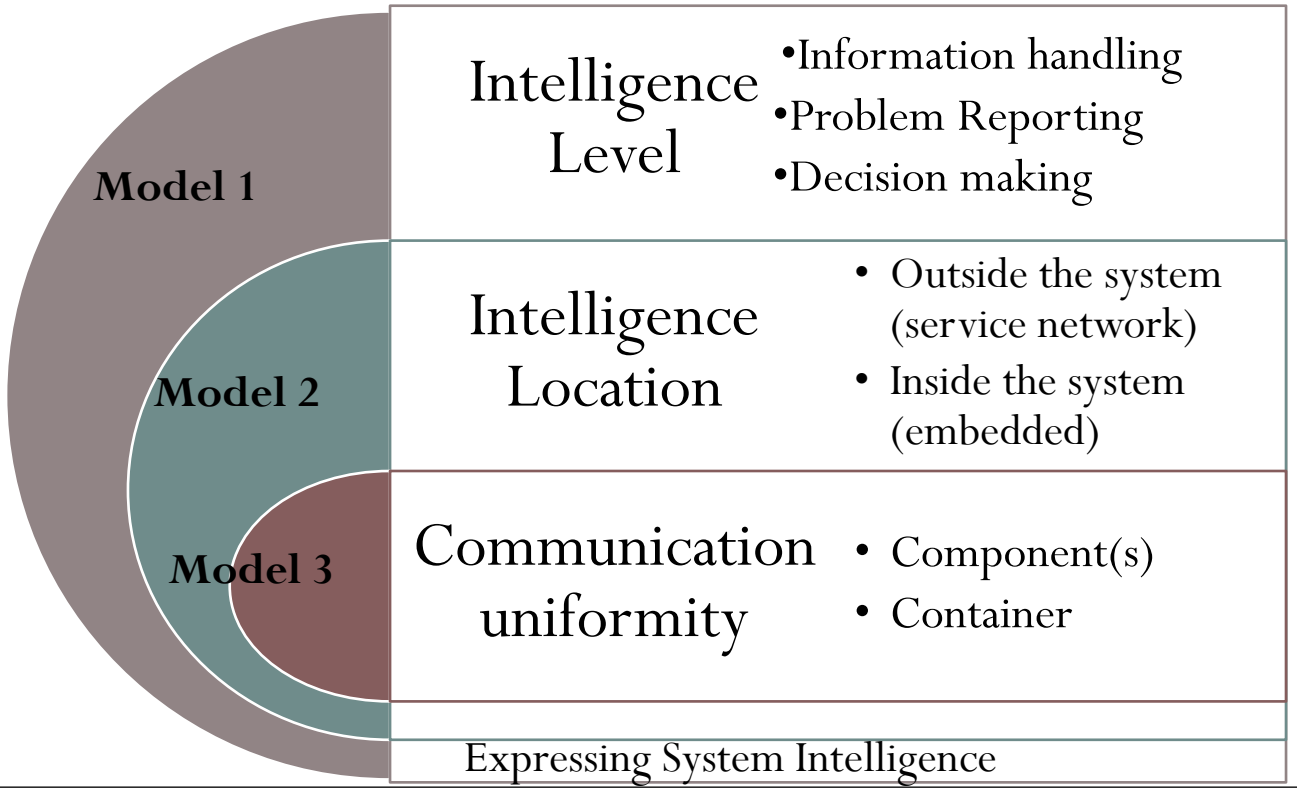
Further **brain is updated through the environment**, in which one lives and interacts with parents, family friends, teachers, books, Internet, and others.

The brain is capable of **remembering past events and comparing them with facts to develop reasoning before making a decision.**

Training and updating of the result in learning.

Future Generation System Intelligence Level - IoT

Models Expressing System Intelligence



Components Involved in Intelligent System Design and Development

Type 1 : Mechanical system incorporated with electronic components in order to increase the functional aspects of product – Variable speed Drive, CNC machine

Type 2 : Mechanical product working on traditional concept, but their internal components were updated by electronic parts – sewing machines and automated manufacturing systems.

Type 3: Products and systems whose functionality remained similar to those of traditional, even after replacing internal part by electronic components – digital clocks

Type 4: Products and systems working through synergistic integration with mechanical and electronic components – photocopiers, intelligent washers and dryers, rice cookers, and automatic ovens.

Class category based on JSPMI – Japan society for promotion of machine Industry (1970)

- Mechanical components and systems- used in design and development of a mechatronic system

Mechanical components		Machines		Vehicles		Precision mechanics		Micro-mechanics	
Basic mechanics	Force and motion generating	Power Producing	Power consuming	Automobiles and trains	Aircrafts	Precision components	Precision devices	Micro-components	Micro-systems
Bearing linkage	Kinematic chains, drive chains, hydraulic components, electromechanical components, pneumatic components	Electric motors, piston engines, turbines	Electric generators, turbo generators, piston compressors, machine tools, manufacturing machines, agriculture machines	Cars, trucks, tractors, military vehicles, trains	General aviation, passenger, military	Switches, relays, sensors, actuators, drive chains, linkage, bearing	Recorders, printers, communication devices, consumer devices, optical and medical devices	Drive chains, linkage, bearing	Motors, pumps, sensors, actuators

• Electrical Components and Systems

Basic electrical/electronic components and devices				Integrated circuits (IC)			Supporting devices and system	
Active components	Passive components and devices			Analog	Digital		Auxiliary devices	Power sources
	Resistive	Inductive	Capacitive					
Amplifiers, operational amplifiers (Op Amps), transistors	Resistors, trimmers, potentiometers, rheostats, heaters, thermistors, varistors, etc.	Inductors, chokes, coils, transformers, motors, generators, solenoids, speakers, microphones, etc.	Capacitors, Varicap diodes	Op Amps, SCRs, DIACs, transistors, Hall effect sensors, current sensors, modulators, opto-couplers, vacuum tubes, oscillators, comparators	Logic gates, flip-flops, registers, latches, timers, adders, subtractors, tri-state logic, RAM, ROM, EPROM, buffers/drivers, encoders, decoders, multiplexers, demultiplexers, counters	Highly integrated devices: microprocessor, microcontrollers, digital signal processors(DSPs), field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs)	Protective: circuit breakers, voltage regulators, spark gaps, surge absorbers, transformers Switching: diodes, transistors, SCRs, relays, thermostats, limit switches, centrifugal switches, mercury switches, keypads *Sensing*: sensors and transducers Display: LEDs, LCDs, monitors	Batteries, fuel cells, photovolta cells, thermoelec tric generators, power supplies

Information processing components and systems

Basic components	Hardware	Software	Soft computing tool
Data, information, policies, procedures, purposes, communication networks	µP, µC, DSP, FPGA, Computer Computing devices, data processors, etc	Machine language program (simple systems), assembly language program (smart and intelligent systems; 8085, 8086, 8051, etc. microprocessors), high-level language program (intelligent complex systems; 8086, 386, 486, Pentium I, II, III, IV), data processors FORTRAN, PASCAL, COBOL, BASIC, C, C++, MATLAB, LabVIEW, DSpace, etc.	For advanced intelligent systems : Fuzzy Logic, NN, GA, PSO, etc.

Mechatronics for all (Applications of Mechatronics)

- Mechatronics has bridged the gap between traditional/conventional mechanical, electrical, and control engineering after **advances in semiconductor technology, especially microchips and computer technology.**
- It responds to the industries' increasing demand for engineers **who are able to work across boundaries of conventional engineering**.
- Mechatronic engineers identify and utilize the interdisciplinary knowledge and proper combinations of technologies **to provide optimal solutions for increasing engineering problems.**

- Application of such knowledge and technology leads to the **development of more efficient, intelligent, cost-effective product designs to meet the growing market demand**.
- In particular, **the development of microprocessors and microcomputers encouraged engineers to integrate interdisciplinary areas and apply them to various products from all walks of life**, such as in the fields of consumer product design, manufacturing, instrumentation, motion control, industrial processes, robotics, aircraft, traction, defence, automated diagnostic systems, medicines, and biotechnology

Application of Mechatronics

- Robotics
- Defence
- Biomedical and Surgery
  - Robotic Surgery
  - Laparoscopy
- Agriculture – Automatic Weed controller
- Automation
  - Industrial Automation
  - Automation in Automobile Industry

Civil Engineering: Electric Shovel, Building material mixing and loading ,etc

Metallurgical: Automatic and intelligent control of metallurgical processes ,etc.

Aerospace: Flight control ,Drone design ,etc.

Chemical: Automatic and intelligent control of chemical processes, etc

Architecture: Automatic design of a structure ,3D Printing ,etc.

Medical : Robotic surgery, Biomedicine,etc

Robotics: Snake, ASIMO, SOFIA (social humanoid robot),etc.

Defense: Guided missile ,tank ,unmanned vehciles ,etc

Agriculture: Automatic weed controller, crop plantation ,etc

Role of Mechanical ,Electrical & Electronics and Computer Engineering in Intelligent product design

- Mechanical :Sensors, Actuators design, mechanics etc.
- Electrical :Sensors, Actuators design, etc.
- Electronics: Sensors, Controllers ,Communication and switching, interfacing ,networking, etc.
- Computer :Controller , communication, software design, intelligent control, etc.

Bio-mechatronics

- Application of mechatronic approaches in the field of bio-engineering to design and develop SMART and Intelligent devices and system for diagnostics purposes and human/animal organ replacement and control .
- Doctors and engineers work together to design and develop such devices and systems

Some Examples of Mechatronic Systems

Today, mechatronic systems are commonly found in homes, offices, schools, shops, and of course, in industrial applications.

Common mechatronic systems include:

- Domestic appliances, such as fridges and freezers, microwave ovens, washing machines, vacuum cleaners, dishwashers, cookers, timers, mixers, blenders, stereos, televisions, telephones, lawn mowers, digital cameras, videos and CD players, camcorders, and many other similar modern devices;
- Domestic systems, such as air conditioning units, security systems, automatic gate control systems;

Some Examples of Mechatronic Systems

- Office equipment, such as laser printers, hard drive positioning systems, liquid crystal displays, tape drives, scanners, photocopiers, fax machines, as well as other computer peripherals;
- Retail equipment, such as automatic labeling systems, bar-coding machines, and tills found in supermarkets;
- Banking systems, such as cash registers, and automatic teller machines;
- Manufacturing equipment, such as numerically controlled (NC) tools, pick and-place robots, welding robots, automated guided vehicles (AGVs), and other industrial robots;
- Aviation systems, such as cockpit controls and instrumentation, flight control actuators, landing gear systems, and other aircraft subsystems.

QUERIES??