Module 5
Embedded Systems and Sensor and Interfacing

Syllabus- Module 5

Embedded Systems

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5.1 Definition of Embedded System

- An embedded system is an **electronic/electro-mechanical** system designed to perform a specific function and a combination of both hardware and firmware (software).
- Every embedded system is unique and the hardware as well as the firmware is highly specialized to the application domain

5.1 Definition cont..

- Embedded systems are becoming an inevitable part of any product or equipment in all fields including:
- household appliances,
- telecommunications (pagers, cellular phones, cable TV terminals, fax and transreceiver, video games),
- medical equipment (ECG recorder, Blood cell recorder, patient monitor system),

- Industrial Instrumentation (Process controller, DC motor controller, robotic systems, CNC machine controller, moisture recorder)
- Scientific (Digital storage system, CRT displays controller, spectrum analyzer)
- consumer products,
- Peripheral controllers of a computer (DRAM controller, printer controller, LAN controller and disk drive controller) etc.
- It may be combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function.

ES is a combination of three components

1. Software
2. Hardware
3. Mechanical component & it is supposed to do only one specific task.

Examples
1) Washing Machine

- **a. Hardware:** Buttons, displays & buzzer, electronic circuitry.
- **b. Software:** It has a chip on the circuit that holds the software which drives controls & monitors various operations possible.
- **c. Mechanical components:** the internals of a washing machine which actually wash the clothes control the input and output of water.

2) Air Conditioner

- **a. Hardware:** Remote, display & buzzer, infrared Sensors, electronic circuitry.
- **b. Software:** It has a chip on the circuit that holds the software which drives control & monitors the various operations possible. The software monitors the external temperature through the sensos and then releases the coolant or suppresses it.
- **c. Mechanical components**: The internals of an air conditioner the motor, the outlet, etc.

3) Automobile Embedded system

- Today high end automobile may have 100 microprocessor
- 4 bit microcontroller checks the seatbelt
- Microcontroller run dashboard devices
- 16/32 bit microprocessor control engine

Embedded System

- Any device that include a computer but is not itself a general purpose computer.
- Hardware and Software of some large system are expected to function without human intervention.
- Respond, monitor, control external environment using sensors and actuators

Characteristics of Embedded System

- Sophisticated functionality
- Restricted memory
- Embedded systems have to be efficient
- The systems are dedicated towards the certain application
- Many embedded systems are hybrid systems in the sense that day include analogue and digital part
- Many embedded system must meet real time constraint
- Lower power

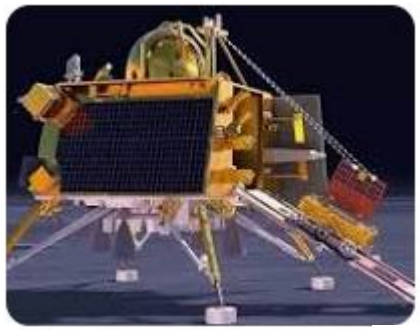
Real Time operation

- Hard Real Time
- Soft Real Time

Examples

- Vending Machine
- 8-bit Microprocessor

- Rover Prgyan to check the moon's Soil
- Lander called Vikram made a soft landing on the moon surface



- NASA Mars Sojourner Rover
- 8-bit Intel 80c85 microprocessor

- GPS receiver

- Mp3 Player 32 bit RISC microprocessor
- DVD Players 32 bit RISC microprocessor
- Sony Aibo ERS-110 Robotic dog 64-bit MIPS RISC

5.2. Embedded systems vs general computing systems

Parameter	General computing	Embedded System
Contents	A system which is a combination of a generic hardware and general-purpose operating system for executing a variety of applications	A system which is a combination of special-purpose hardware and embedded operating system & for executing specific set of applications
OS	It contains a general-purpose operating system (GPOS)	It may or may not contain an operating system for functioning
Alterations	Applications are alterable (programmable) by the user. (It is possible for end user to re-install the OS and also add or remove user applications)	The firmware of the Embedded system is pre-programmed and it is non-alterable by the end user.

5.2. Embedded systems vs general computing systems

Parameter	General computing	Embedded System
Key Factor	Performance is the key deciding factor in the selection of the system. Faster is better	Application specific requirements (like performance, power requirements, memory usage etc) are the key deciding factor.
Power consumption	More	Less
Response Time	Not Critical	Critical for some applications
Execution	Need not be deterministic	Deterministic for certain types of ES like 'Hard real time systems'.

5.3. Classification of Embedded system are

- **Based on Generation**
- **Complexity & performances**
- **Based on Deterministic behavior**
- **Based on Triggering**

5.3.1 Classification based on generation

- **First generation** (1G):
  - Built around 8bit microprocessor & microcontroller.(like 8085, Z80, 4-bi microcontroller.
  - Simple in hardware circuit & firmware developed in assembly code .
  - Examples: **Digital telephone keypads, stepper motor control unit**.
- **Second generation (2G)**: These are embedded system
  - Built around 16-bit µp & 8-bit µc.
  - Instruction set more complex and powerful compare to first G µp/ µc.
  - 2G system has embedded operating system for their operation.
  - Examples: **Data acquisition system, SCADA (supervisory control and Data Acquisition) systems**

5.3.2 Classification based on generation

- **Third generation (3G):**
  - with advancement in processor technology, ES developers started making 32-bit microprocessor and 16-bit microcontroller for their design.
  - Concepts like Digital Signal Processors (DSPs), domain specific /Application Specific Integrated Circuits (ASICs) evolved.
  - Instruction set become more powerful and complex pipeline also included.
  - Different vendor produced processor and controller (ex. Intel Pentium, Motorola 68K-gained attention)
  - Dedicated Emdedded real time and general purpose OS entered the market.
  - Examples: **ES is used in Robotics, Media, industrial process control and networking etc**
- **Fourth generation (4G):**
  - Built around 64-bit µp & 32-bit µc.
  - The concept of System on Chips (SoC), reconfigurable processor and Multicore Processors are evolved.
  - Processor are bringing high performance, tight integration and miniaturization into to ES.
  - Highly complex & very powerful. **Examples: Smart Phones, mobile internet device (MIDs).**

5.3.3 Classification based on complexity & performance

- **Small-scale:**
  - It (ES) is suitable for simple applications.
  - Performance not time-critical.
  - Small scale ES may or may not contain OS.
  - Built around low performance & low cost 8 or 16 bit µp/µc.
  - Example: an electronic toy
- **Medium-scale:**
  - ES with slightly complex in hardware & firmware (software) requirement.
  - Built around medium performance & low cost 16 or 32 bit µp/µc or DSPs.
  - Usually contain embedded operating system (GPOS/RTOS) for functioning.
  - Examples: Industrial machines.
- **Large-scale:**
  - Highly complex hardware & firmware.
  - Built around high performance 32- or 64-bit RISC µp/µc or PLDs or RSoC (Reconfigurable System on chip) or Multicore Processors. They may have multiple µp/µc and co-units/hardware accelerators.
  - Decoding/encoding of media, cryptographic function implementation etc are example of processing requirement.
  - It has high performance RTOS for task scheduling, prioritisation, and management.
  - Examples: Mission critical applications.

Classification based on deterministic behavior

- **It is applicable for Real Time systems.**
- The **application/task execution behavior** for an embedded system can be either **deterministic or non-deterministic.**
- These are classified in to two types:
- **Soft Real Time Systems:** Missing a deadline may not be critical & can be tolerated to a certain degree
- **Hard Real Time Systems:** Missing a program/task execution time deadline can have catastrophic consequences (financial, human loss of life, etc.

5.3.5 Classification based on triggering

- (ES which are reactive in nature (like process control systems in industrial control application) can be classified into two types

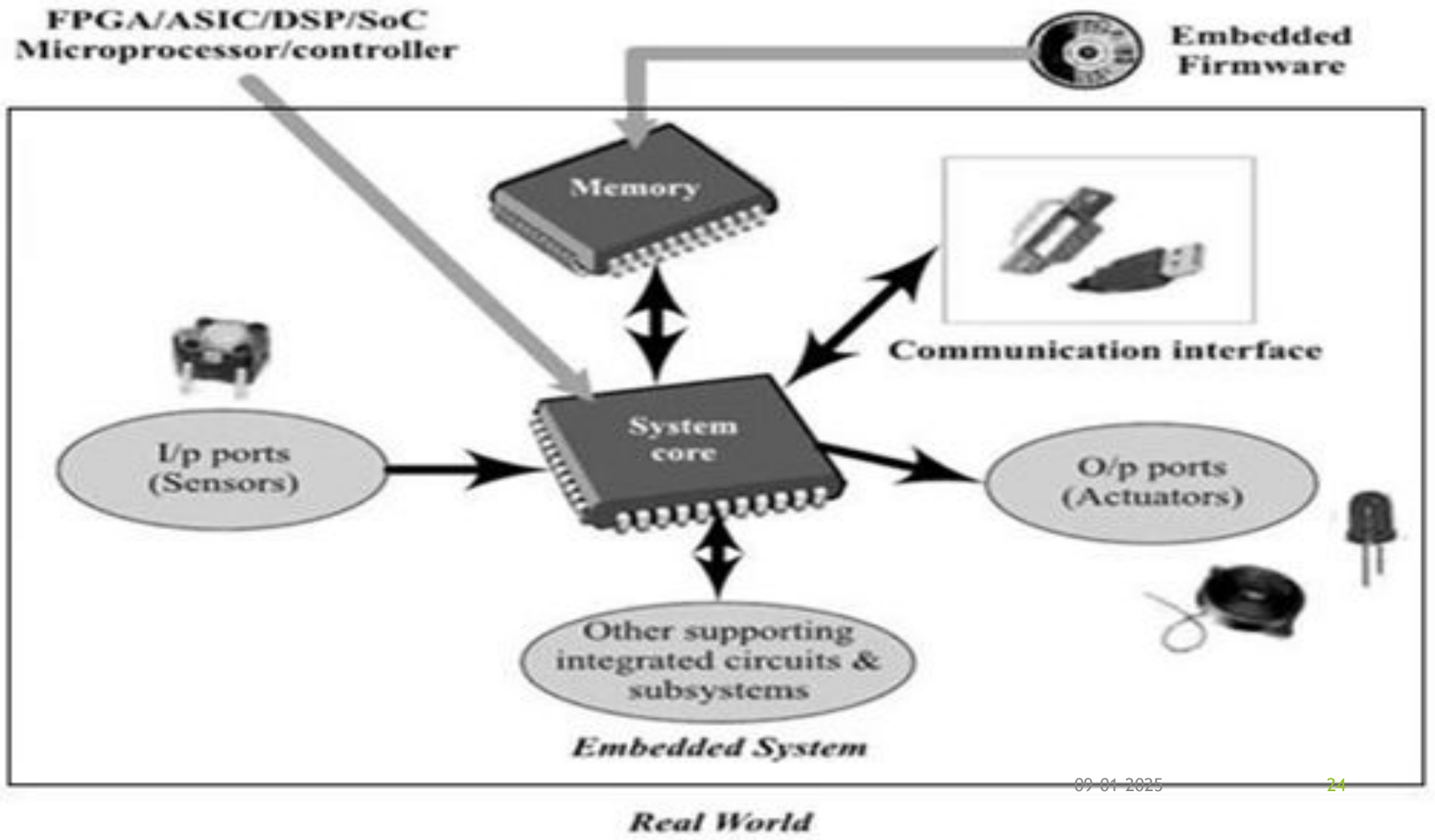
- **Event triggered:** Activities within the system (e.g., task run-times) are dynamic and depend upon occurrence of different events.

- **Time triggered:** Activities within the system follow a statically computed schedule (i.e., they are allocated time slots during which they can take place) and thus by nature are predictable

5.4. Major applications areas of ES.

1. **Consumer electronics:** Camcorders, cameras, etc.
2. **Household appliances:** Television, DVD players, washing machine, fridge, microwave oven, etc.
3. **Home automation and security systems:** Air conditioners, sprinklers, intruder detection alarms, closed circuit television cameras, fire alarms, etc.
4. **Automotive industry:** Anti-lock braking systems (ABS), engine control, ignition systems, automatic navigation systems, etc
5. **Telecom:** Cellular telephones, telephone switches, handset multimedia applications etc.
6. **Computer peripherals:** Printers, scanners, fax machines, etc.
7. **Computer networking systems:** Network routers, switches, hubs, firewalls, etc.
8. **Healthcare:** Different kinds of scanners, EEG, ECG machines etc.
9. Measurement & Instrumentation: Digital multi meters, digital CROs, logic analyzers, PLC systems, etc.
10. **Banking & Retail:** Automatic teller machines (ATM) and currency counters, point of sales (POS)
11. **Card Readers:** Barcode, smart card readers, hand held devices, etc
12. **Wearable devices:** health and fitness trackers smartphone screen extension notification etc
13. **cloud computing and Internet of things (IoT)**

5.5. Elements of an Embedded System



5.5. Elements of an Embedded System

- System core (Brain-Single chip Controller)
- System core can processor, controller, FPGA, ASIC, DSPs, RSoC
- Sensor input signal sensing
- System processes the signal and Provide control signals to the output ports (Actuators)
- Common user interface input devices are keyboards, push button, switches
- Common user interface output devices are LED, LCD, Piezoelectric buzzers.
- Other supporting IC and Subsystem
- Communication interface
- Memory connected embedded firmware.
- Control Algorithm storage memory OTP (one time Programmable), PROM, UVEPROM, EEPROM, and FLASH.

Why Microcontroller ??????????

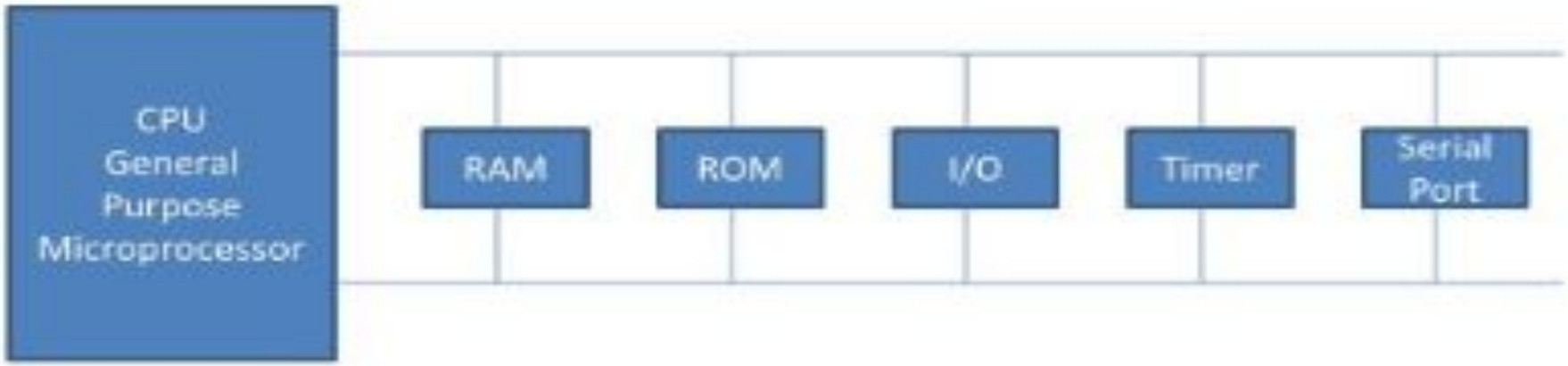
- Low cost, Small packaging
- Low power consumption
- Programmable , re-programmable
- Easy integration with circuits
- For applications in which cost, power and space are critical.
- Single purpose.

5.6. The core of the Embedded System

1. General purpose and Domain specific Processor
   a. Microprocessors
   b. Microcontrollers
   c. Digital Signal Processors
2. Programmable Logic devices (PLDs)
3. Application Specific Integrated Circuits (ASICs)
4. Commercial off the shelf Components (COTS)

5.7. Microprocessor

- CPU for Computer
- No RAM,ROM, I/O on chip itself
- Example Intel's x86, Motorola's 680x0



5.7. Microprocessor

1. A silicon chip representing a CPU.
2. It performs Arithmetic and logical operations.
3. CPU has AU, control units and working registers.
4. Microprocessor is a dependent unit and it requires the combination of hardware like memory, timers and interrupt controller etc. for proper functioning.

Microprocessor

- Developers of microprocessors:
  - Intel – Intel 4004 – November 1971(4-bit)
  - Intel – Intel 4040.
  - Intel – Intel 8008 – April 1972.
  - Intel – Intel 8080 – April 1974(8-bit).
  - Intel – Intel 8085 – 1976.

Microcontroller

- A highly integrated silicon chip containing a CPU, scratch pad RAM, Special and General-purpose Register Arrays, On Chip ROM/FLASH memory for program storage, Timer and Interrupt control units and dedicated I/O ports.
- Microcontrollers can be considered as a super set of Microprocessors.
- Since a microcontroller contains all the necessary functional blocks for independent working, they found greater place in the embedded domain in place of microprocessors.
- Microcontrollers are cheap, cost effective and are readily available in the market.
- Texas Instruments TMS 1000 is considered as the world's first microcontroller.

Microprocessor	Microcontroller
Microprocessor are widely used in computer systems.	Microcontroller is widely used in embedded systems.
A silicon chip representing a Central Processing Unit (CPU) embedded into it, which is capable of performing arithmetic and logical operations.	It is a highly integrated chip that contains a CPU, scratch pad RAM, special and general-purpose register arrays, on chip ROM/ FLASH memory for the program stage, timer and interrupt control units and dedicated I/O ports.
It is a dependent unit. It requires the combination of other chips like timers, program and data memory chips, interrupt controller for its functioning.	*It is a self-contained unit* and does not require external interrupt controller, timer UART etc. for functioning.

Microprocessor	Microcontroller
It consumes more power.	It consumes less power than a microprocessor.
Most of the time general purpose in design and operation.	Mostly application oriented or domain specific.
Does not contain built in lower ports will stop the input output port functionality needs to be implemented with the help of external programmable peripheral interfaces like 8255.	most of the processor contain multiple built in lower ports which can be operated as a single aid or 16 or 32 bit 4 or as individual port pins
Limited power saving options compared to micro controllers	Includes lot of power saving features

Microprocessor	Microcontroller
Targeted for high and market where performance is important	Targeted for embedded market where performance is not so critical (now it's not valid)
Relatively slower in speed.	Relatively faster in speed.
Access time for memory and input devices are more.	Access time for memory and input devices are less.

RISC	CISC
Lesser number of instructions.	Greater number of instructions.
Instruction pipelining and increased execution speed.	Generally, no instruction by planning feature
Orthogonal instructional set allows each instruction to operate or any register and use any addressing mode.	Non orthogonal Instruction set (all instructions are not allowed the operate on any register and use any addressing mode. It is instructions specific)
Operations are performed on registers only; the only memory operations are load and store.	operations are performed on registers on memory depending on the instruction
A large number of registers are available	Limited number of general-purpose registers

Programmer needs to write more code to execute task since the instructions are simpler ones.	Instructions are like macros in C language. A programmer can achieve the desired functionality with the single instruction which in turn provides the effect of using more simpler single instruction in RISC.
Single fixed length instruction.	Variable length instructions.
Less Silicon usage and pin count.	More Silicon usage since more additional decoder logic is required implement the complex instruction decoding.
With Harvard architecture.	Can be Harvard or Von-Neumann architecture.
Example: ATMEL AVR microcontroller 32instcrutions	Example: ATMEL 8051 (AT89C51), 255 instructions

5.9. Instrumentation and control systems:

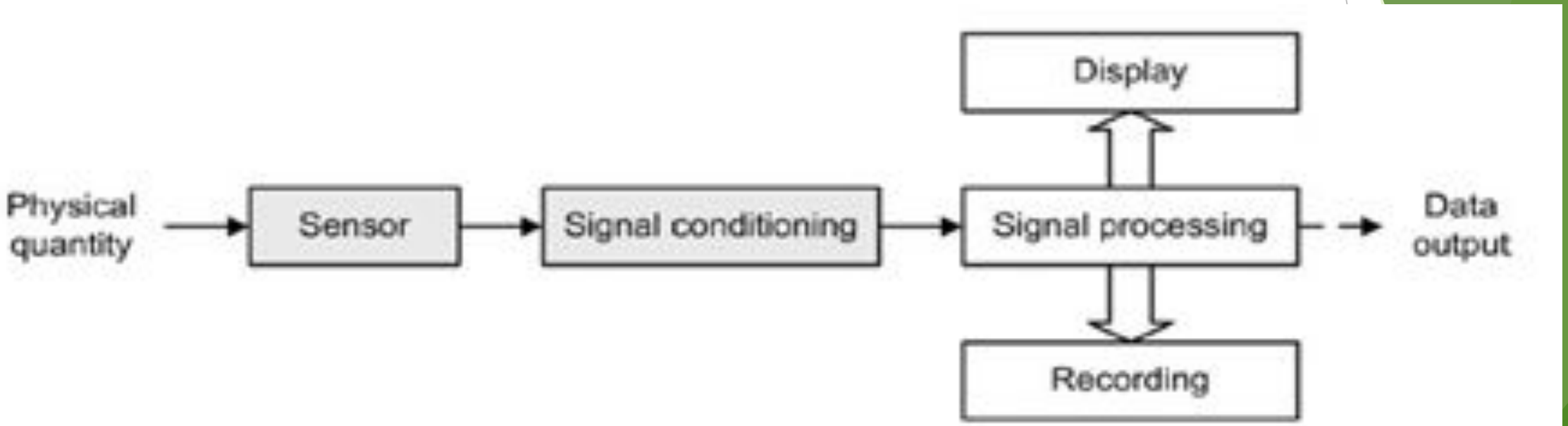


Figure: Control systems

5.9. Instrumentation and control systems:

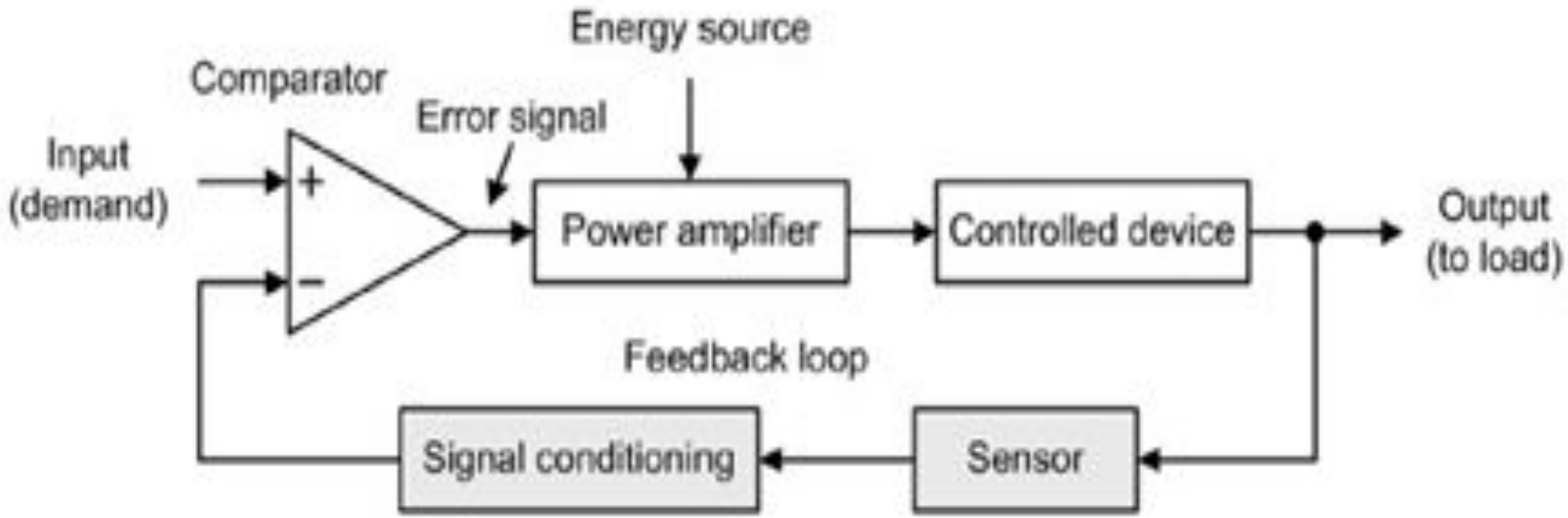
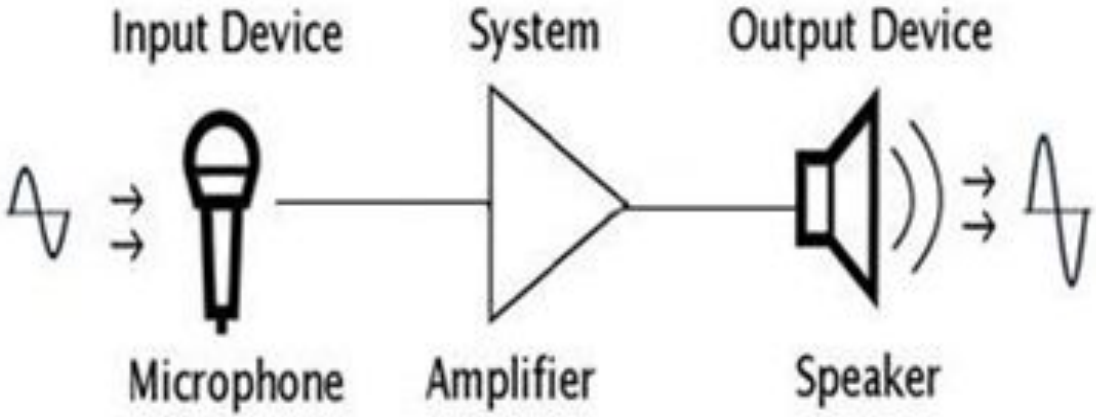


Figure: Instrumentation systems

5.10 Transducers

- Transducers are devices that convert energy in the form of sound, light, heat, etc., into an equivalent electrical signal, or vice versa.
- Ex: A loudspeaker is a transducer that conver low frequency electric current into audib sounds.
- A microphone, on the other hand, is transducer that performs the reverse function i.e., that of converting sound pressure variations into voltage or current.



5.11 Sensors

- A sensor is a special kind of transducer that converts energy from one form to another for any measurement or control purpose.
- Ex. A Temperature sensor. The signal produced by a sensor is an electrical analogy of a physical quantity, such as distance, velocity, acceleration, temperature, pressure, light level, etc.
- The choice of sensor is governed by a number of factors including accuracy, resolution, cost and physical size.
- Sensors can be categorized as either active or passive. An active sensor generates a current or voltage output. A passive transducer requires a source of current or voltage and it modifies this in some way (e.g. by virtue of a change in the sensor's resistance).
- Sensors can also be classed as either digital or analog. The output of a digital sensor can exist in only two discrete states, either 'on' or 'off', 'low' or 'high', 'logic 1' or 'logic 0', etc.

Actuators

- Actuator is used for output. It is a transducer that may be either mechanical or electrical which converts signals to corresponding physical actions (motion).
- Actuators acts as an output device.
- Example: Wearable device: Certain smartwatches used ambient light sensor to detect the surrounding light intensity and uses and electrical or electronic actuator circuit to adjust the screen brightness for better readability

LED

- LED is a p-n junction diode and contains a CATHODE and ANODE for functioning the anode is connected to positive terminal of power supply and cathode is connected to negative terminal of power supply.
- There are two ways to interface an LED to a microprocessor/microcontroller
- First approach, the anode of LED is directly connected to the port pin and cathode to ground and Port pin drives the LED.
- In the second approach, the cathode of LED is connected to the port pin of processor/controller and anode to supply voltage (Vcc) through a current limiting resistor.

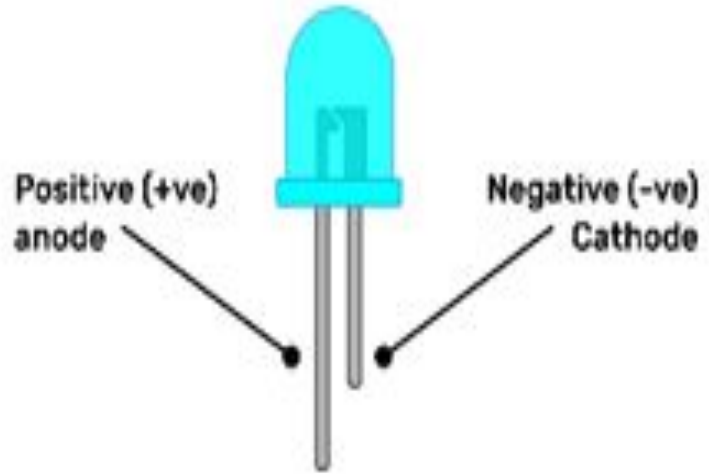


Fig (a). LED

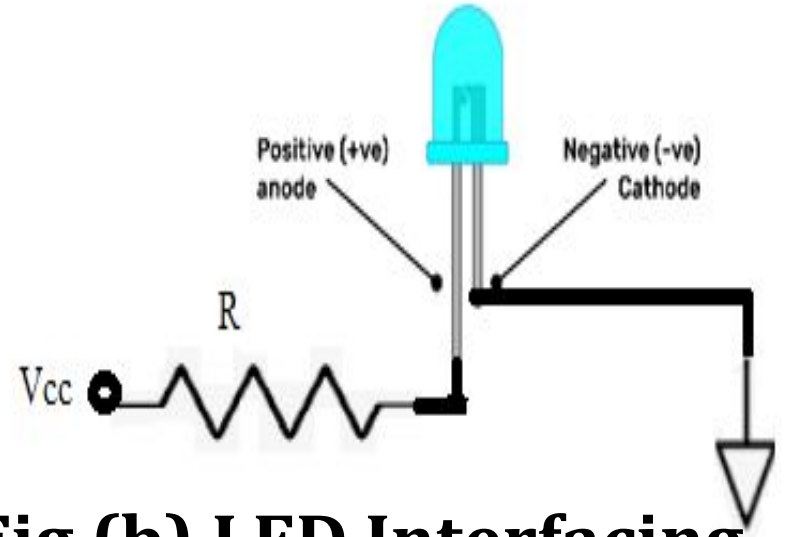


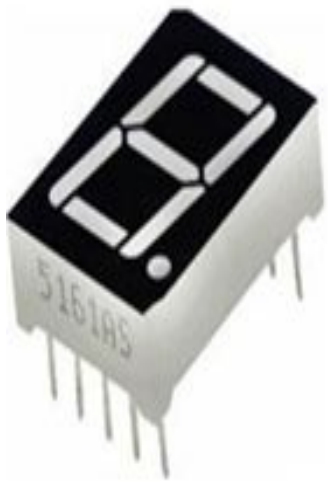
Fig (b) LED Interfacing

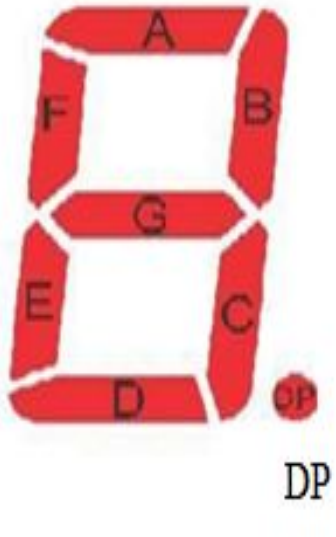
7 Segment LED Display

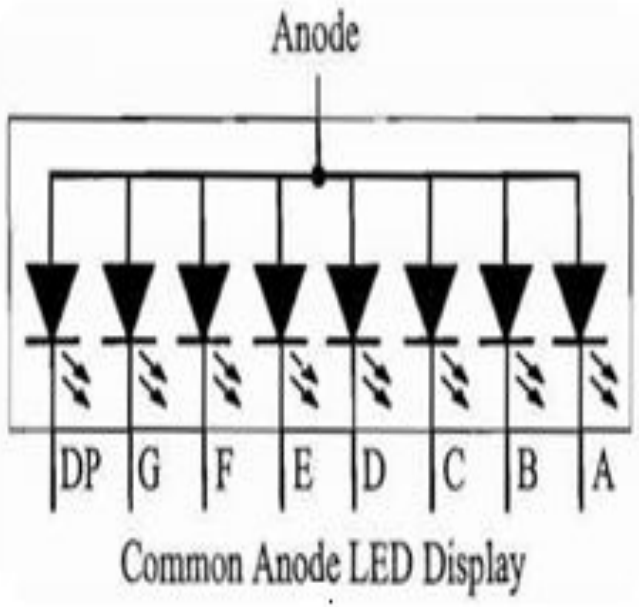
- A seven-segment display (SSD), or seven-segment indicator, is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot matrix displays.
- Seven-segment displays are widely used in digital clocks, electronic meters, basic calculators, and other electronic devices that display numerical information
- The seven elements of the display can be lit in different combinations to represent the Arabic numerals. Often the seven segments. Figure show the 7 segment LED display.

7 Segment LED Display

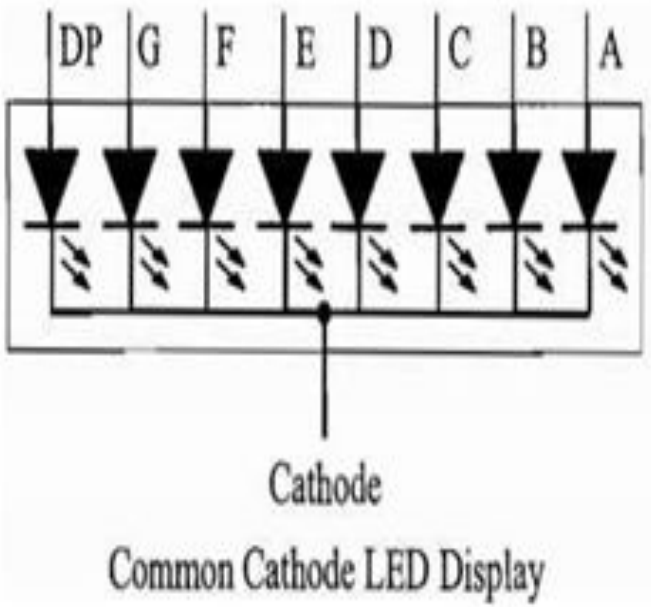
DP: decimal point







Common Anode LED Display



Common Cathode LED Display

For example, for displaying the number 4, the segments F, G, B and C are lit.

For displaying 3 the segments A, B, C, D, G and DP are lit.

For displaying the character ‘d’ the segments B, C, D, E and G are lit.

7 Segment LED Display

- The seven segment LED displays are available in two different configurations, namely:
  - Common Anode
  - Common cathode
- Seven segment LED display is a popular choice for low-cost applications like, public telephone call monitoring devices, point of sale terminal etc.

For common cathode displays		
Digit	**binary input value**	**hex input value**
0	11111100	FC
1	01100000	60
2	11011010	DA
3	11110010	F2
4	01100110	66
5	10110110	B6
6	10111110	BE
7	11100000	E0
8	11111110	FE
9	11110110	F6

For common anode displays		
Digit	**binary input value**	**hex input value**
0	00000011	03
1	10011111	9F
2	00100101	25
3	00001101	0D
4	10011001	99
5	01001001	49
6	01000001	41
7	00011111	1F
8	00000001	01
9	00001001	09

DIGIT	HEX Value	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0
		D0	D1	D2	D3	D4	D5	D6	D7
		8	4	2	1	8	4	2	1
0	0x03	0	0	0	0	0	0	1	1
1	0x9F	1	0	0	1	1	1	1	1
2	0x25	0	0	1	0	0	1	0	1
3	0x0D	0	0	0	0	1	1	0	1
4	0x99	1	0	0	1	1	0	0	1
		www.alselectro.com							
5	0x49	0	1	0	0	1	0	0	1
6	0x41	0	1	0	0	0	0	0	1
7	0x1F	0	0	0	1	1	1	1	1
8	0x01	0	0	0	0	0	0	0	1
9	0x09	0	0	0	0	1	0	0	1
		a	b	c	d	e	f	g	dot