EMBEDDED SYSTEM:

An Electronic/Electro mechanical system which is designed to perform a specific function and is a combination of both hardware and firmware (Software)

EXAMPLES:

Electronic Toys,

Mobile Handsets,

Washing Machines, Air Conditioners,

Automotive Control Units,

Set Top Box, DVD Player etc…

Embedded Systems are:

- Unique in character and behavior
- With specialized hardware and software

History of Embedded Systems:

First Recognized Modern Embedded System: Apollo Guidance Computer (AGC) developed by Charles Stark Draper at the MIT Instrumentation Laboratory. It has two modules

- 1.Command module (CM) 2. Lunar Excursion module (LEM)
- RAM size 256, 1K ,2K words
- ROM size 4K,10K,36K words
- Clock frequency is 1.024MHz
- 5000 ,3-input RTL NOR gates are used
- User interface is DSKY (display/Keyboard)

Embedded Systems Vs General Computing Systems:

General Purpose Computing System	Embedded System
A system which is a combination ofgeneric hardware and General Purpose Operating System for executing a variety of applications	A system which is a combination of special purpose hardware and embedded OSfor executing a specific set of applications
Contain a General Purpose Operating System (GPOS)	May or may not contain an operating system for functioning
Applications are alterable (programmable)by user (It is possible for the end user to re-install the Operating System, and add or removeuser applications)	The firmware of the embedded systemis pre-programmed and it is non-alterable by end-user
Performance is the key deciding factor onthe selection of the system. Always „Faster is Better"	Application specific requirements (like performance, power requirements, memory usage etc) are the key deciding factors
Less/not at all tailored towards reduced operating power requirements, options for different levels of power management.	Highly tailored to take advantage of the power saving modes supported by hardware and Operating System
Response requirements are not time critical	For certain category of embedded systems like mission critical systems, the response time requirement is highly critical
Need not be deterministic in execution behavior	Execution behavior is deterministic for certain type of embedded systems like „Hard Real Time" systems

CLASSIFICATION OF EMBEDDED SYSTEMS:

- **Based on Generation**
- **Based on Complexity & Performance**
- **Based on deterministic behavior**
- **Based on Triggering**

Embedded Systems - Classification based on Generation:

First Generation: The early embedded systems built around 8-bit microprocessors like 8085 and Z80 and 4-bit microcontrollers with simple hardware and firmware.

EX. stepper motor control units, Digital Telephone Keypads etc.

Second Generation: Embedded Systems built around 16-bit microprocessors and 8 or 16-bit microcontrollers, following the first generation embedded systems

EX. SCADA, Data Acquisition Systems etc

Third Generation: Embedded Systems built around high performance 16/32 bit Microprocessors/controllers, Application Specific Instruction set processors like Digital Signal Processors (DSPs), and Application Specific Integrated Circuits (ASICs).The instruction set is complex and powerful.

Ex: Robotics, industrial process control, networking etc.

Fourth Generation: Embedded Systems built around System on Chips (SoC's), Re- configurable processors and multicore processors. It brings high performance, tight integration and miniaturization into the embedded device market

Ex: Smart phone devices, MIDs etc.

Embedded Systems - Classification based on Complexity & Performance

Small Scale:

The embedded systems built around low performance and low cost 8 or 16 bit microprocessors/ microcontrollers. It is suitable for simple applications and where performance is not time critical. It may or may not contain OS.

- washing machine.
- Oven.
- Automatic Door Lock.
- Motion Controlled Home Security System.
- Keyboard controller.
- CD Drive.
- fax machine.

Medium Scale:

Embedded Systems built around medium performance, low cost 16- or 32-bit microprocessors / microcontrollers or DSPs. These are slightly complex in hardware and firmware. It may contain GPOS/RTOS.Various examples of medium scale embedded

systems are routers for networking, ATM (is. Automated Teller Machine for bank transactional machines etc.

Large Scale/Complex:

- Embedded Systems built around high performance 32- or 64-bit RISC processors/controllers, RSoC or multi-core processors and PLD.
- It requires complex hardware and software.
- This system may contain multiple processors/controllers and co-units/hardware accelerators for offloading the processing requirements from the main processor.
- It contains RTOS for scheduling, prioritization and management.

Classification Based on deterministic behavior:

These are 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.

Major Application Areas of Embedded Systems:

Consumer Electronics: Camcorders, Cameras etc.

Household Appliances: Television, DVD players, washing machine, Fridge, Microwave Oven etc.

Home Automation and Security Systems: Air conditioners, sprinklers, Intruder detection alarms, Closed Circuit Television Cameras, Fire alarms etc.

Automotive Industry: Anti-lock breaking systems (ABS), Engine Control, Ignition Systems, Automatic Navigation Systems etc.

Telecom: Cellular Telephones, Telephone switches, Handset Multimedia pplications etc

Computer Peripherals: Printers, Scanners, Fax machines etc.

Computer Networking Systems: Network Routers, Switches, Hubs, Firewalls etc.

Health Care: Different Kinds of Scanners, EEG, ECG Machines etc.

Measurement & Instrumentation: Digital multi meters, Digital CROs, Logic Analyzers PLC systems etc.

Banking & Retail: Automatic Teller Machines (ATM) and Currency counters, Point of Sales (POS)

Card Readers: Barcode, Smart Card Readers, Hand held Devices etc.

Purpose of Embedded Systems:

Each Embedded Systems is designed to serve the purpose of any one or a combination of the following tasks.

- Data Collection/Storage/Representation
- Data Communication
- Data (Signal) Processing
- Monitoring
- Control
- Application Specific User Interface

Data Collection/Storage/Representation

Performs acquisition of data from the external world. The data may be text, audio, video or any physical quantities. The collected data can be either analog or digital. Data collection is usually done for storage, analysis, manipulation and transmission. The collected data may be stored directly in the system or may be transmitted to some other systems or it may be processed by the system or it may be deleted instantly.

Example: Digital Camera

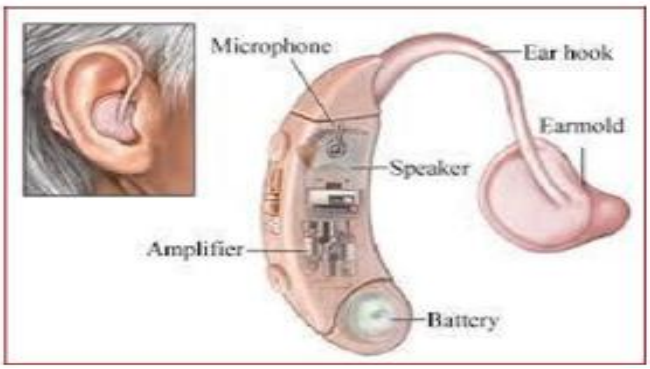
Data Communication:-

Embedded Data communication systems are deployed in applications ranging from complex satellite communication systems to simple home networking systems. Embedded Data communication systems are dedicated for data communication. The data communication can happen through a wired interface (like Ethernet, RS-232C/USB/IEEE1394 etc) or wireless interface (like Wi-Fi, GSM,/GPRS, Bluetooth, ZigBee etc)

- Network hubs, Routers, switches, Modems etc are typical examples for dedicated data transmission embedded systems

Data (Signal) Processing

- Embedded systems with Signal processing functionalities are employed in applications demanding signal processing like Speech coding, synthesis, audio video codec, transmission applications etc
- Computationally intensive systems Employs Digital Signal Processors (DSPs)



4.Monitoring:-

Embedded systems coming under this category are specifically designed for monitoring purpose. They are used for determining the state of some variables using input sensors.They cannot impose control over variables. Measuring instruments like Digital CRO, Digital Multi meter, Logic Analyzer etc used in Control & Instrumentation applications are also examples of embedded systems for monitoring purpose. Electro Cardiogram (ECG) machine for monitoring the heartbeat of a patient is a typical example for this. The sensors used in ECG are the different Electrodes connected to the patient's body

5.Control:

Embedded systems with control functionalities are used for imposing control over some variables according to the changes in input variables. Embedded system with control functionality contains both sensors and actuators. Sensors are connected to the input port for capturing the changes in environmental variable or measuring variable.The actuators connected to the output port are controlled according to the changes in input variable to put an impact on the controlling variable to bring the controlled variable to the specified range

- Air conditioner for controlling room temperature is a typical example for embedded system with „Control" functionality

Air conditioner contains a room temperature sensing element (sensor) which may be a thermistor and a handheld unit for setting up (feeding) the desired temperature.The air compressor unit acts as the actuator. The compressor is controlled according to the current room temperature and the desired temperature set by the end user.

Embedded systems possess certain specific characteristics and these are unique to each Embedded system.

Characteristics of Embedded systems:

- Application and domain specific
- Reactive and Real Time
- Operates in harsh environments
- Distributed
- Small Size and weight
- Power concerns

1.Application and Domain Specific:-

Each E. S has certain functions to perform and they are developed in such a manner to do the intended functions only. They cannot be used for any other purpose.

Ex – The embedded control units of the microwave oven cannot be replaced with AC's embedded control unit because the embedded control units of microwave oven and AC are specifically designed to perform certain specific tasks.

2.Reactive and Real Time: -

E.S are in constant interaction with the real world through sensors and user-defined input devices which are connected to the input port of the system. Any changes in the real world are captured by the sensors or input devices in real time and the control algorithm running inside the unit reacts in a designed manner to bring the controlled output variables to the desired level. E.S produce changes in output in response to the changes in the input, so they are referred as reactive systems.

Real Time system operation means the timing behavior of the system should be deterministic i.e the system should respond to requests in a known amount of time.

Example – E.S which are mission critical like flight control systems, Antilock Brake Systems (**ABS**) etc are Real Time systems.

3.Operates in Harsh Environment :–

The design of E.S should take care of the operating conditions of the area where the system is going to implement. Ex – If the system needs to be deployed in a high temperature zone, then all the components used in the system should be of high temperature grade.Also proper shock absorption techniques should be provided to systems which are going to be commissioned in places subject to high shock.

4.Distributed: –

It means that embedded systems may be a part of a larger system. Many numbers of such distributed embedded systems form a single large embedded control unit.

Ex – Automatic vending machine. It contains a card reader, a vending unit etc. Each of them are independent embedded units but they work together to perform the overall vending function.

5.Small Size and Weight:-

Product aesthetics (size, weight, shape, style, etc) is an important factor in choosing a product.

It is convenient to handle a compact device than a bulky product.

6.Power Concerns: -

Power management is another important factor that needs to be considered in designing embedded systems.

E.S should be designed in such a way as to minimize the heat dissipation by the system.

Quality Attributes of Embedded System:

Quality attributes are the non-functional requirements that need to be documented properly in any system design

Quality attributes can be classified as

1.Operational quality attributes

2.Non-operational quality attributes.

1.Operational quality attributes

The operational quality attributes represent the quality attributes related to the embedded system when it is in the operational mode or online mode

The Operational Quality Attributes are

- Response
- Throughput
- Reliability
- Maintainability
- Security
- Saftey

1.Response:

It is the measure of quickness of the system.It tells how fast the system is tracking the changes in input variables. Most of the E.S demands fast response which should be almost real time.

Ex – Flight control application

2.Throughput

It deals with the efficiency of a system. It can be defined as the rate of production or operation of a defined process over a stated period of time.The rates can be expressed in terms of products, batches produced or any other meaningful measurements.

Ex – In case of card reader throughput means how many transactions the reader can perform in a minute or in an hour or in a day.

3.Reliability:

It is a measure of how much we can rely upon the proper functioning of the system.

Mean Time between Failure (MTBF) and Mean Time To Repair (MTTR) are the terms used in determining system reliability.MTBF gives the frequency of failures in hours/weeks/months.

MTTR specifies how long the system is allowed to be out of order following a failure.For embedded system with critical application need, it should be of the order of minutes.

4.Maintainability:

It deals with support and maintenance to the end user or client in case of technical issues and product failure or on the basis of a routine system checkup.Reliability and maintainability are complementary to each other.A more reliable system means a system with less corrective maintainability requirements and vice versa. Maintainability can be broadly classified into two categories. Scheduled or Periodic maintenance (Preventive maintenance), Corrective maintenance to unexpected failures

5.Security:

Confidentiality, Integrity and availability are the three major measures of information security.

Confidentiality deals with protection of data and application from unauthorized disclosure.

Integrity deals with the protection of data and application from unauthorized modification.

Availability deals with protection of data and application from unauthorized users.

6.Saftey:

Safety deals with the possible damages that can happen to the operator, public and the environment due to the breakdown of an Embedded System. The breakdown of an embedded system may occur due to a hardware failure or a firmware failure. Safety analysis is a must in product engineering to evaluate the anticipated damages and determine the best course of action to bring down the consequences of damage to an acceptable level.

Non Operational Quality Attributes:

The quality attributes that needs to be addressed for the product not on the basis of operational aspects are grouped under this category.

The Non Operational Quality Attributes are

- Testability and Debugability
- Evolvability
- Portability
- Time to Prototype and Market
- Per Unit Cost and Revenue

1.Testability and Debugability:

Testability deals with how easily one can test the design, application and by which means it can be done.For an E.S testability is applicable to both the embedded hardware and firmware. Embedded hardware testing ensures that the peripherals and total hardware functions in the desired manner, whereas firmware testing ensures that the firmware is functioning in the expected way

Debug-ability is a means of debugging the product from unexpected behavior in the system

Debug-ability is two level process

1.Hardware level 2.software level

1. Hardware level: It is used for finding the issues created by hardware problems.

2. Software level: It is employed for finding the errors created by the flaws in the software

2.Evolvability:-

- It is a term which is closely related to Biology.
- It is referred as the non-heritable variation.
- For an embedded system evolvability refers to the ease with which the embedded product can be modified to take advantage of new firmware or hardware technologies.

3.Portability: -

- It is the measure of system independence.

An embedded product is said to be portable if the product is capable of functioning in various environments, target processors and embedded operating systems

4.Time-to-Prototype and Market:-

- It is the time elapsed between the conceptualization of a product and the time at which the product is ready for selling.
- The commercial embedded product market is highly competitive and time to market the product is critical factor in the success of commercial embedded product.
- There may be multiple players in embedded industry who develop products of the same category (like mobile phone).

5.Per Unit Cost and Revenue:-

- Cost is a factor which is closely monitored by both end user and product manufacturer.
- Cost is highly sensitive factor for commercial products
- Any failure to position the cost of a commercial product at a nominal rate may lead to the failure of the product in the market.
- Proper market study and cost benefit analysis should be carried out before taking a decision on the per-unit cost of the embedded product.
- The ultimate aim of the product is to generate marginal profit so the budget and total cost should be properly balanced to provide a marginal profit.