INTRODUCTION TO EMBEDDED SYSTEMS
UNIT I

INTRODUCTION

EMBEDDED SYSTEMS AND GENERAL PURPOSE COMPUTER SYSTEMS:

- An embedded system is an electronic/electro-mechanical system designed to perform a specific function and is a combination of both hardware and firmware (software).
- Every embedded system is unique, and the hardware as well as the firmware is highly specialised to the application domain. Embedded systems are becoming an inevitable part of any product or equipment in all fields including household appliances, telecommunications, medical equipment, industrial control, consumer products, etc.

EMBEDDED SYSTEMS vs. GENERAL COMPUTING SYSTEMS

General Purpose Computing System	Embedded System
A system which is a combination of a generic hardware and a General Purpose Operating System for executing a variety of applications.	A system which is a combination of special purpose hardware and embedded OS for executing a specific set of applications.
Contains a General Purpose Operating System (GPOS)	May or may not contain an operating system for functioning.
Applications are alterable(programmable) by the user(It is possible for the end user to re-install the operating system 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(There may be exceptions for systems supporting OS kernel image flashing through special hardware settings)
Performance is the key deciding factor in the 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 the hardware and the 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 behaviour.	Execution behaviour is deterministic for certain types of embedded systems like 'Hard Real Time' systems.

HISTORY:

- Embedded systems were in existence even before the IT revolution. In the olden days embedded systems were built around the old vacuum tube and transistor technologies and the embedded algorithm was developed in low level languages.

- Advances in semiconductor and nano-technology and IT revolution gave way to the development of miniature embedded systems.
- The first recognised modem embedded system is the Apollo Guidance Computer (AGC) developed by the MIT Instrumentation Laboratory for the lunar expedition. They ran the inertial guidance systems of both the Command Module (CM) and. the Lunar Excursion Module (LEM). The Command Module was designed to encircle the moon while the Lunar Module and its crew were designed to go down to the moon surface and land there safely. The Lunar Module featured in total 18 engines. There were 16 reaction control thrusters, a descent engine and an ascent engine. The descent engine was 'designed to' provide thrust to the lunar module out of the lunar orbit and land it safely on the moon. MIT's original design was based on 4K words of fixed memory (Read Only Memory) and 256 words of erasable memory (Random Access Memory). By June 1963, the figures reached 10K of fixed and 1K of erasable memory. The final configuration was 36K words of fixed memory and 2K words of erasable memory. The clock frequency of the. first microchip proto model used in AGC was 1.024 MHz and it was derived from a 2.048 MHz crystal clock. The computing unit of AGC consisted of approximately 11 instructions and 16 bit word logic. Around 5000 ICs (3-input NOR gates, RTL logic) supplied by Fairchild Semiconductor were used in this design. The user interface unit of AGC is known as DSKY (display/keyboard). DSKY looked like a calculator type keypad with an array of numerals. It was used for inputting the commands to the module numerically.
- The first mass-produced embedded system was the guidance computer for the Minuteman-I missile in 1961. It was the 'Autonetics D-l7 guidance computer, built using discrete transistor logic and a hard-disk for main memory. The first integrated circuit was produced in September 1958 but computers using them didn't begin to appear until 1963. Some of their early uses were in embedded systems, notably used by NASA for the Apollo Guidance Computer and by the US military in the Minuteman-II intercontinental ballistic missile.

CLASSIFICATION OF EMBEDDED SYSTEMS

It is possible to have a multitude of classifications for embedded systems, based on different criteria. Some of the criteria used in the classification of embedded systems are:

1. Based on generation
2. Complexity and performance requirements
3. Based on deterministic behaviour
4. Based on triggering.

The classification based on deterministic system behaviour is applicable for 'Real Time' systems. The application/task execution behaviour for an embedded system can be either deterministic or non-deterministic. Based on the execution behaviour, Real Time embedded systems are classified into Hard and Soft. Embedded Systems which are 'Reactive' in nature (Like process control systems in industrial control applications) can be classified based on the trigger. Reactive systems can be either event triggered or time triggered.

- **Classification Based on Generation**
  This classification is based on the order in which the embedded processing systems evolved from the first version to where they are today. As per this criterion, embedded systems can be classified into:
    - **First Generation** The early embedded systems were built around 8bit microprocessors like 8085 and Z80, and 4 bit microcontrollers. Simple in hardware circuits with firmware developed in Assembly code. Digital telephone keypads, stepper motor control units etc. are examples of this.
    - **Second Generation** These are embedded systems built around 16bit microprocessors and 8 or 16 bit microcontrollers, following the first generation embedded systems. The instruction

set for the second generation processors/controllers were much more complex and powerful than the first generation processors/controllers. Some of the second generation embedded systems contained embedded operating systems for their operation. Data Acquisition Systems, SCADA systems, etc. are examples of second generation embedded systems.

- **Third Generation** With advances in processor technology, embedded system developers started making use of powerful 32bit processors and 16bit microcontrollers for their design. A new concept of application and domain specific processors/controllers like Digital Signal Processors (DSP) and Application Specific Integrated Circuits (ASICs) came into the picture. The instruction set of processors became more complex and powerful and the concept of instruction pipelining also evolved. The processor market was flooded with different types of processors from different vendors. Processors like Intel Pentium, Motorola 68K, etc. gained attention in high performance embedded requirements. Dedicated embedded real time and general purpose operating systems entered into the embedded market. Embedded systems spread its ground to areas like robotics, media, industrial process control, networking, etc
- **Fourth Generation** The advent of System on Chips (SoC), reconfigurable processors and multicore processors are bringing high performance, tight integration and miniaturisation into the embedded device market. The SoC technique implements a total system on a chip by integrating different functionalities with a processor core on an integrated circuit. The fourth generation embedded systems are making use of high performance real time embedded operating systems for their functioning. Smart phone devices, mobile internet devices (MIDs), etc. are examples of fourth generation embedded systems.

- **<u>Classification Based on Complexity and Performance</u>**
  This classification is based on the complexity and system performance requirements. According to this classification, embedded systems can be grouped into:
  - **Small-Scale Embedded Systems** Embedded systems which are simple in application needs and where the performance requirements are not time critical fall under this category. An electronic toy is a typical example of a small-scale embedded system. Small-scale embedded systems are usually built around low performance and low cost 8 or 16 bit microprocessors/microcontrollers. A small-scale embedded system may or may not contain an operating system for its functioning.
  - **Medium-Scale Embedded Systems** Embedded systems which are slightly complex in hardware and firmware (software) requirements fall under this category. Medium-scale embedded systems are usually built around medium performance, low cost 16 or 32 bit microprocessors/microcontrollers or digital signal processors. They usually contain an embedded operating system (either general, purpose or real time operating system) for functioning.
  - **Large-Scale Embedded Systems/Complex Systems** Embedded systems which involve highly complex hardware and firmware requirements fall under this category. They are employed in mission critical applications demanding high performance. Such systems are commonly built around high performance 32 or 64 bit RISC processors/controllers or Reconfigurable System on Chip (RSoC) or multi-core processors and programmable logic devices. They may contain multiple processors/controllers and co-units/hardware accelerators for offloading the processing requirements from the main processor of the system. Decoding/encoding of media, cryptographic function implementation, etc. are examples for processing requirements which can be implemented using a co-processor/hard- ware accelerator. Complex embedded systems usually contain a-high performance Real Time Operating System (RTOS) for task scheduling, prioritization and management.

APPLICATIONS AND PURPOSE OF EMBEDDED SYSTEMS:

MAJOR APPLICATION AREAS OF EMBEDDED SYSTEMS

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 breaking 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.

PURPOSE OF EMBEDDED SYSTEMS:

1.Data collection/Storage/Representation
2. Data communication
3. Data (signal) processing
4. Monitoring
5. Control
6. Application specific user interface.

1. **Data Collection/Storage/Representation**

- Embedded systems designed for the purpose of data collection performs acquisition of data from the external world.
- Data collection is usually done for storage, analysis, manipulation and transmission. The term “data” refers all kinds of information, viz. text, voice, image, video, electrical signals and any other measurable quantities. Data can be either analog (continuous) or digital (discrete).
- Embedded systems with analog data capturing techniques collect data directly in the form of analog signals whereas embedded systems with digital data collection mechanism converts the analog signal to corresponding digital signal using analog to digital (A/D) converters and then collects the binary equivalent of the analog data. If the data is digital, it can be directly captured without any additional interface by digital embedded systems.
- The collected data may be stored directly in the system or maybe transmitted to some other systems or it may be processed by the system or it may be deleted instantly after giving a meaningful representation. These actions are purely dependent on the purpose for which the embedded system is designed.
- Embedded systems designed for pure measurement applications without storage, used in control and instrumentation domain, collects data and gives a meaningful representation of the collected data by means of graphical representation or quantity value and deletes the collected data when new data arrives at the data collection terminal. Analog and digital CROs without storage memory are typical

examples of this. Any measuring equipment used in the medical domain for monitoring without storage functionality also comes under this category.

- Some embedded systems store the collected data for processing and analysis. Such systems incorporate a built-in/plug-in storage memory for storing the captured data. Some of them give the user a meaningful representation of the collected data by visual (graphical/quantitative) or audible means using display units [Liquid Crystal Display (LCD), Light Emitting Diode (LED), etc.] buzzers, alarms, etc. Examples are: measuring instruments with storage memory and monitoring instruments with storage memory used in medical applications. Certain embedded systems store the data and will not give a representation of the same to the user, whereas the data is used for internal processing.
- A digital camera is a typical example of an embedded system with data collection/storage/ representation of data. Images are captured and the captured image may be stored within the memory of the camera. The captured image can also be presented to the user through a graphic LCD unit.

2. **Data Communication**
    - Embedded data communication systems are deployed in applications ranging from complex satellite communication systems to simple home networking systems.
    - The data collected by an embedded terminal may require transferring of the same to some other system located remotely. The transmission is achieved either by a wire-line medium or by a wireless medium.
    - Wire-line medium was the most common choice in all olden days embedded systems.
    - As technology is changing, wireless medium is becoming the de-facto standard for data communication in embedded systems. A wireless medium offers cheaper connectivity solutions and make the communication link free from the hassle of wire bundles.
    - Data can either be transmitted by analog means or by digital means. Modem industry trends are settling towards digital communication.
    - The data collecting embedded terminal itself can incorporate data communication units like wireless modules (Bluetooth, ZigBee, Wi-Fi, EDGE, GPRS, etc.) or wire-line modules (RS-232C, USB, TCP/IP, PS2, etc.).
    - Certain embedded systems act as a dedicated transmission unit between the sending and receiving terminal's, offering sophisticated functionalities like data packetizing, encrypting and decrypting. Network hubs, routers, switches, etc. are typical examples of dedicated data transmission embedded systems. They act as mediators in data communication and provide various features like data security, monitoring etc.
3. **Data (Signal) Processing**
    - The data (voice, image, video, electrical signals and other measurable quantities) collected by embedded systems may be used for various kinds of data processing.
    - Embedded systems with signal processing functionalities are employed in applications demanding signal processing like speech coding, synthesis, audio video codec, transmission applications, etc.
    - A digital hearing aid is a typical example of an embedded system employing data processing. Digital hearing aid improves the hearing capacity of hearing impaired persons.
4. **Monitoring**
    - Embedded systems falling under this category are specifically designed for monitoring purpose.
    - Almost all embedded products coming under the medical domain are with monitoring functions only.
    - They are used for determining the state of some variables using input sensors. They cannot impose control over variables.
    - A very good example is the Electro Cardiogram (ECG) machine for monitoring the heartbeat of a patient. The machine is intended to do the monitoring of the heartbeat. It cannot impose control

over the heartbeat. The sensors used in ECG are the different electrodes connected to the patient's body.

- Some other examples of embedded systems with monitoring function are measuring instruments like digital CRO, digital multimeters, logic analyzers, etc. used in Control & Instrumentation applications. They are used for knowing (monitoring) the status of some variables like current, voltage, etc. They cannot control the variables in turn.

5. **Control**
   - Embedded systems with control functionalities impose control over some variables according to the changes in input variables.
   - A system with control functionality contains both sensors and actuators.
   - Sensors are connected to the input port for capturing he 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 system used in our home to control the room temperature to a specified limit is a typical example for embedded system for control purpose. An airconditioner contains a room temperature sensing element (sensor) which may be a thermistor and a handheld unit for setting up (feeding) the desired temperature. The handheld unit may be connected to the central embedded unit residing inside the airconditioner through a wireless link or through a wired link. 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. Here the input variable is the current room temperature and the controlled variable is also the room temperature. The controlling variable is cool air flow by the compressor unit. If the controlled variable and input variable are not at the same value, the controlling variable tries to equalise them through taking actions on the cool air flow.
6. **Application Specific User Interface**
   - These are embedded systems with application-specific user interfaces like buttons, switches, keypad, lights, bells, display units, etc.
   - Mobile phone is an example for this. In mobile phone the user interface is provided through the keypad, graphic LCD module, system speaker, vibration alert, etc.

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