

## CMPE 101 - COMPUTER ENGINEERING AS A DISCIPLINE

### Modules 4-5:

#### 4- Introduction to Embedded Systems

#### 5- Overview of integrated circuits and microcontrollers

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### Lesson Title: Introduction to Embedded Systems

#### Learning Objectives:

By the end of the lesson, students will be able to:

1. Define what an embedded system is.
  2. Understand the basic components of an embedded system.
  3. Identify real-world applications of embedded systems.
  4. Differentiate between general-purpose and embedded systems.
  5. Explore career opportunities related to embedded systems.
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### I. Introduction to Embedded Systems

#### 1. Definition:

- **Embedded System:** A combination of hardware and software designed to perform a dedicated function or task. Unlike general-purpose computers, they are optimized for specific tasks.
- **Examples:** Washing machines, microwave ovens, cars' anti-lock braking systems (ABS), smartwatches, etc.

#### 2. Key Characteristics of Embedded Systems:

- **Task-Specific:** Performs only one task or a set of related tasks.
  - **Real-Time Performance:** Many embedded systems need to operate in real-time (e.g., medical devices, industrial automation).
  - **Reliability:** Must be dependable, as failures can have serious consequences.
  - **Size and Power Constraints:** Often small in size and designed to consume minimal power.
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### II. Components of an Embedded System (20 minutes)

#### 1. Hardware Components:

- **Microcontroller** (or Microprocessor): The brain of the embedded system, responsible for executing the software.

- **Memory:** Used to store the program and data. It can be ROM (Read-Only Memory) or RAM (Random Access Memory).
- **Input/Output (I/O):** Devices that allow the system to interact with the external environment (e.g., sensors, displays, buttons).
- **Power Supply:** Provides the necessary voltage to the components.

## 2. Software Components:

- **Firmware:** Software written for embedded systems, typically stored in non-volatile memory.
- **Operating System (Optional):** Some complex embedded systems use real-time operating systems (RTOS) to manage hardware and run multiple tasks.

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## III. Real-World Applications of Embedded Systems (15 minutes)

1. **Consumer Electronics:** Mobile phones, digital cameras, smart TVs.
2. **Automotive Industry:** Engine control systems, GPS navigation, airbags.
3. **Healthcare:** Heart rate monitors, insulin pumps, MRI machines.
4. **Industrial Automation:** Robotic arms, conveyor belt systems.
5. **Aerospace:** Flight control systems, satellite control.
6. **Smart Homes:** Thermostats, security systems, smart appliances.
7. **Telecommunications**
8. **Internet of Things (IoT)**
9. **Transportation**
10. **Retail Systems**

## Real-world applications of embedded systems, along with examples:

### 1. Consumer Electronics

Embedded systems are integrated into many household and personal devices to perform dedicated functions.

- **Smartphones:** The processor inside a phone is an embedded system responsible for handling tasks like managing calls, camera functions, and sensors.
- **Digital Cameras:** Image processing, focus, and exposure settings are controlled by embedded systems.
- **Smart TVs:** Manage streaming services, display, and internet connectivity.

### 2. Automotive Industry

Modern vehicles have multiple embedded systems that control various functions, improving safety and performance.

- **Anti-Lock Braking System (ABS):** Prevents the wheels from locking up during braking by rapidly adjusting brake pressure.
- **Engine Control Units (ECU):** Manages engine functions like fuel injection, emission controls, and performance optimization.
- **Airbags:** Embedded systems detect collisions and deploy airbags instantly for passenger safety.
- **GPS Navigation Systems:** Provide real-time location tracking and directions.

### 3. Healthcare Devices

Embedded systems are essential for medical devices that monitor health, perform diagnostics, or assist in treatment.

- **Heart Rate Monitors:** Continuously track heart rate and alert patients to irregularities.
- **Insulin Pumps:** Automatically adjust and deliver insulin doses for diabetes management.
- **MRI Machines:** Embedded systems control imaging processes and patient diagnostics in complex medical equipment.

### 4. Industrial Automation

Embedded systems play a critical role in controlling machines and processes in manufacturing and industrial settings.

- **Robotic Arms:** Used in factories for precision tasks like assembling products, welding, and painting.
- **Conveyor Belt Systems:** Automatically move materials or products through a manufacturing process based on sensor inputs.
- **Temperature Controllers:** Embedded systems maintain specific temperatures for industrial processes like chemical production or food manufacturing.

### 5. Aerospace and Defense

Embedded systems are used in both aircraft and space exploration to perform critical functions.

- **Flight Control Systems:** Manage aircraft stability, navigation, and safety.
- **Satellites:** Use embedded systems to manage communications, data collection, and position adjustments.
- **Unmanned Aerial Vehicles (UAVs):** Embedded systems control drone flight, navigation, and camera operation.

### 6. Smart Homes

Embedded systems are a key part of home automation, making daily life more convenient and energy-efficient.

- **Smart Thermostats:** Automatically adjust home temperature based on user preferences and patterns to save energy.
- **Security Systems:** Control door locks, cameras, and alarms, allowing remote monitoring and access via smartphone.
- **Smart Appliances:** Devices like refrigerators, washing machines, and ovens with sensors and connectivity features for better performance and remote control.

## 7. Telecommunications

Embedded systems are crucial in communication devices that support networking and data transmission.

- **Routers and Modems:** Manage internet connectivity and data traffic for homes and businesses.
- **Base Stations:** Control wireless communications and signal transmission in mobile networks.

## 8. Internet of Things (IoT)

IoT devices rely heavily on embedded systems to sense, process, and communicate data over the internet.

- **Smart Watches:** Monitor fitness levels, heart rate, and daily activity while connecting to a smartphone.
- **Home Assistants (e.g., Alexa, Google Home):** Embedded systems process voice commands and control smart devices.

## 9. Transportation

Public and private transportation systems use embedded systems to optimize safety, efficiency, and user experience.

- **Traffic Lights:** Use embedded systems to control traffic flow and timing based on real-time data.
- **Train Control Systems:** Automatically manage train speeds, braking, and signal systems for safe operations.

## 10. Retail Systems

Retail and point-of-sale systems often rely on embedded systems for quick and efficient operations.

- **Point-of-Sale (POS) Systems:** Embedded systems in cash registers and credit card machines process transactions securely and swiftly.
- **Barcode Scanners:** Embedded systems enable the fast identification and processing of products at checkout.

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## IV. Comparison: Embedded Systems vs General-Purpose Systems

### 1. **Embedded Systems:**

- Optimized for specific tasks.
- Less flexible but highly efficient.
- Limited memory and processing power.

### 2. **General-Purpose Systems:**

- Capable of performing a wide range of tasks (e.g., laptops, desktops).
- Highly flexible but may require more power and resources.

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## V. Career Opportunities in Embedded Systems

1. **Embedded System Developer:** Design and implement embedded software.
2. **Firmware Engineer:** Focuses on low-level programming and optimization.
3. **IoT Developer:** Specializes in embedded systems for Internet of Things devices.
4. **System Architect:** Designs the hardware and software architecture for embedded systems.
5. **Testing Engineer:** Ensures that embedded systems work reliably and efficiently.

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## VI. Summary and Q&A

- Recap key points:
  - Definition of embedded systems and key components.
  - Real-world applications.
  - Career paths related to embedded systems.
- Open the floor for questions.

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## Homework/Assignment:

Research and present an example of an embedded system you use daily. Explain its components, purpose, and how it functions.

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This lesson introduces students to the fundamental concepts of embedded systems and opens the door for more technical discussions in future classes.

1. **Marwedel, P. (2021).** *Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things* (3rd ed.). Springer.

This updated edition covers modern topics like the Internet of Things (IoT) and cyber-physical systems, providing insights into the latest embedded system applications.

2. **Wolf, W. (2020).** *Computers as Components: Principles of Embedded Computing System Design* (4th ed.). Morgan Kaufmann.

A comprehensive reference on the design and integration of embedded systems, featuring real-world applications in areas like automotive systems and IoT.

3. **Saponara, S., & De Gloria, A. (Eds.). (2021).** *Applications in Electronics Pervading Industry, Environment, and Society: APPLEPIES 2020*. Springer.

A collection of recent research and case studies, highlighting the role of embedded systems in modern industries and IoT applications.

4. **Zhu, Q., Di Natale, M., & Sangiovanni-Vincentelli, A. (2022).** *Design Automation of Cyber-Physical Systems: A Passive Perspective*. Springer.

This book discusses embedded systems in the context of cyber-physical systems, focusing on modern design and automation techniques, including real-time embedded applications.

5. **Chattopadhyay, S., Banerjee, A., & Mall, R. (2022).** *Embedded Systems* (2nd ed.). Oxford University Press.

A recent textbook that provides an up-to-date overview of embedded systems design, including hardware-software co-design and real-time systems.

6. **Vemu, S., & Gurumurthy, B. (2021).** *Secure Embedded Systems: Enabling Security in Embedded Systems*. CRC Press.

A timely reference that explores the security challenges in modern embedded systems, especially in IoT devices and applications, which are increasingly critical.

7. **Fahmy, S. A. (2019).** *Introduction to Embedded Systems: Using Microcontrollers and the MSP430* (2nd ed.). Springer.

This book is great for students, offering practical examples with microcontrollers and recent applications, such as low-power embedded systems.

8. **Hsieh, Y.-T. (2019).** *Embedded Systems Design with the Texas Instruments MSP432 32-bit Processor*. Springer.

A detailed guide to embedded systems design with the MSP432, a popular microcontroller used in IoT devices and applications.