EE443 - Embedded Systems

Lecture 1
Embedded Systems Introduction

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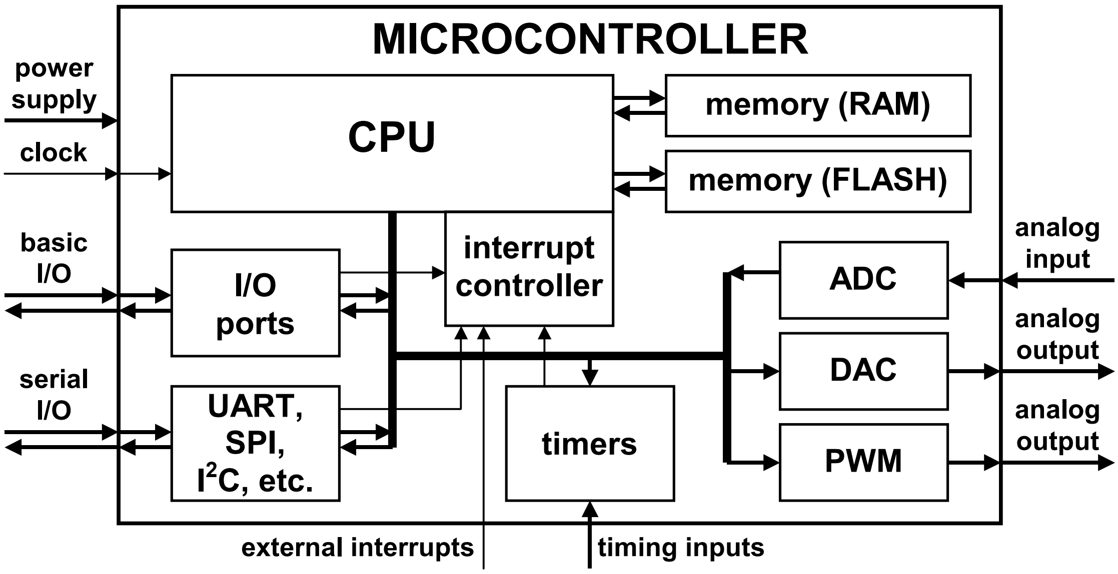
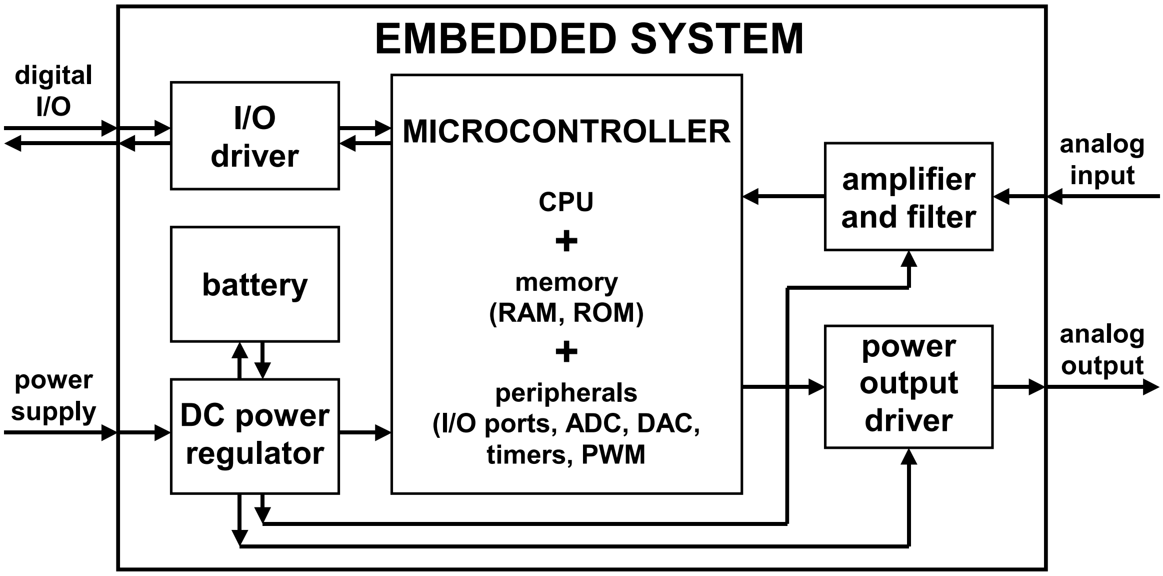
1.1 Microcontroller Organization

Microcontrollers are integrated devices that pack together memory and other functional units around a central processing unit (CPU). Today there are thousands of microcontrollers available in the market, comprising several CPU core architectures, each with a number of different memory and functionality options. It is possible to find a self-sufficient microcontroller to perform a given engineering task with all the necessary interface functions to communicate with the outside physical world.



The microcontroller is the brain of an embedded system. Similar analogies can be made between the system components and other body parts. Input receivers can be thought as eyes and ears and output drivers can be the mouth, arms, and legs. The DC power regulator is the digestive system that makes the food received from outside world utilizable by the other system components.



It is not possible to put all the embedded system components on a single silicon chip because of the IC manufacturing limitations. We cannot place a +/-12V output driver on the same silicon chip with a microcontroller that works with +1.5..+3.3V DC supplies. The ICs manufactured using +1.5..+3.3V technology cannot handle voltages as high as +/-12V. On the other hand, if we try to manufacture a microcontroller using +/-12V technology, then a much larger silicon chip is required, wasting silicon area and increasing manufacturing cost.

1.2 Embedded Systems Not Defined

There are several definitions of embedded systems that can be found in different contexts. The following two definitions are suitable for our engineering purposes.

Definition 1:
Information processing systems embedded into enclosing products such as cars, telecommunication or fabrication equipment. -- Main reason for buying is ***not*** *information processing.* [Peter Marwedel, T. U. Dortmund]

Definition 2:
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems. [Edward A. Lee, U. C. Berkeley]

The first definition draws a wider boundary for the embedded systems category whereas the second definition states that integration with physical processes is required for a system to be considered as embedded. We can argue for example, whether the cellular phones are embedded systems or not. If we were asking this question in 1990s, then the answer would more likely to be "yes". Early cellular phones were 100% phones mostly dealing with challenges of receiving and transmitting audio signals in real-time. Most of the today's cellular phones however, are equipped with several additional features, so that sometimes less than 10% of the price paid goes into the phone functionality. The remaining 90% buys a color screen, a camera, an Internet browser, an audio/video player, and more. A $499 cellular phone sold today is an embedded system according to the first definition. According to the second definition, it is only 10% embedded system where the remaining 90% can be categorized as a miniaturized PC.

The second definition is a more precise categorization of embedded systems as they are seen from the electrical engineering perspective. **Within the scope of this course, an embedded system is a device that answers the design challenges related to one or more of the characteristics listed in the following section. It is not really important how many of these design challenges we must deal with while working on a project. The hardware and software development methods discussed in this course are all helpful design techniques whether we call the end product an embedded system or not.**

1.3 Embedded System Characteristics

Common examples of embedded systems include processors used in manufacturing equipment, transportation vehicles, telecommunication equipment, and consumer electronics. Following are the characteristics of these systems:

1. Interaction with the physical processes: Sensors acquiring information about processes and actuators (or actors) controlling those processes are the connections between the most common embedded systems and the outside physical world. Signal conditioning, data acquisition, driver electronics and transducers are important parts of these systems.

2. Real-time constraints: Failure to complete system tasks within a specified time frame may result in harm to the user or degradation of system performance. Such failures may be life-threatening in transportation vehicles. This is a consequence of the embedded systems' interaction with the physical world.

Performance of a PC is not critical while editing a document or browsing Internet. A user can spend 100 seconds waiting in front of a PC where it may take only 5 seconds to complete the same task in ideal operating conditions. An embedded system controlling a process on the other hand, must execute the specified computations with the required frequency and precision. We can find average performance of a PC satisfactory even if it appears to be too slow from time to time. Unlike a typical PC application, averaged performance is not a meaningful measure when we consider real-time systems. An embedded system must work within specifications **every time, all the time,** and its performance must be guaranteed without statistical arguments.

3. Reliability: Embedded systems can be safety-critical as another natural consequence of being connected to the physical environment. Following are the major requirements of a reliable system.

- **Availability:** An embedded system must work within specifications as long as the system power is on. Keeping wide tolerance limits (temperature, supply voltage, noise immunity, etc.) and implementing the necessary failure recovery procedures provide a high availability.

- **Handling exceptions:** Failure of a temperature sensor on a boiler should not cause a blast. A dirty speed sensor should not result in a runaway wheel in the ABS system of a vehicle. All similar failures of system components must be handled in the least harmful way.
- **System start-up and recovery:** Initial start-up and recovery after a power failure should be safe and consistent.
- **Security:** If necessary, access to the system controls must be restricted to the authorized users. User data should be kept confidential whenever it is required and external communications should be protected.

4. Efficiency: The following measures can be used for evaluating the efficiency of embedded systems:

- **Power consumption:** Many embedded systems run on batteries or they may rely on limited supplies provided through other system components.
- **Code efficiency:** In most cases the entire code of an embedded system is stored with the system. The code-size to implement the required functionality should be as small as possible especially for the systems to be manufactured in large quantities.
- **Run-time efficiency:** The minimum amount of resources should be used for implementing the required functionality. We should be able to meet time constraints using the least amount of hardware resources and energy.

Weight, compactness, and manufacturing costs can be the other efficiency factors in embedded systems applications. Weight of a mobile consumer electronics device may not be critical, but usually there are strict limits for the systems used on aircrafts and military equipment.

5. Dedicated application: Embedded systems are dedicated towards a certain application. User interfaces are also specialized and optimized for that application.

1.4 Applications

The following list summarizes the key areas in which embedded systems are used:

- **Industrial process control:** Control systems used in manufacturing environments are the most typical examples of embedded systems. Reliability of these systems is critical.

- **Household and consumer electronics:** Home appliances, air conditioning equipment, and home security systems are the growing application areas for embedded systems. Simple electrical or electromechanical control units have been replaced by more reliable and efficient digital controllers.

  Consumer electronics which constitutes the major part of the electronics industry relies on embedded processors. The processing capability integrated into video and audio equipment is growing progressively with addition of high-performance digital signal processing (DSP) and memory units. Mobile phone manufacturers have been pushing DSP and storage capabilities to the limits set by the power efficiency requirements in a very competitive market.

- **Medical equipment:** Medical equipment used for diagnostic, therapeutic, and surgical purposes in hospitals have always been a traditional application area for embedded systems. Home-care medical equipment and wearable devices or implants for patient monitoring and therapy purposes have growing potential for improving the quality of medical care. Information processing power combined with the data storage and remote communication capabilities makes the embedded systems critical components of all modern medical devices .

- **Automotive electronics:** Cars and trucks that have been sold during the last few decades contain a number of electronic control units. A few examples are engine and emission control systems, air bag controllers, anti-lock braking systems (ABS), navigation computers with GPS. Reliability of these systems are critical for user safety. Embedded systems also have an important place in other transportation vehicles such as trains and all kinds of boats where user safety is critical.

- **Avionics equipment:** All airplanes used for civil aviation or military purposes rely on electronic control and safety systems most of which can be classified as embedded systems. An essential fraction - in some cases more than half - of the total cost of airplanes goes into the electronic components.

- **Robotics:** Embedded systems are the essential parts of robots or robotic actuators as a natural consequence of their interaction with the physical environment.

- **Military applications:** In many sections of the electronics industry, military applications led the development of electronic systems mainly due to the availability of financial resources for R&D. Embedded systems have been used heavily in the military equipment for telecommunication, navigation, remote sensing, targeting, and several other applications.

1.5 Future

The cost of digital electronic components have been decreasing steadily while the integration density is rising as a result of well-known trends in the semiconductor manufacturing industry. Digital systems replaced their analog or electromechanical counterparts mainly because of their reliability and flexibility. In addition, advancements in the electronic assembly and packaging technologies facilitated miniaturization of devices such as the medical implants that seemed impossible to produce ten years ago. Most people encounter embedded processors in their daily lives more often than they can realize. There may be several appliances with embedded processors in our homes, and our cars are likely to contain tens of microprocessors depending on their age and luxury level.

Some market analysts predict that the embedded system market will be much larger than the market for PCs and similar systems in the near future. It has been estimated that nearly 80% of the processors manufactured today are used in embedded systems [1]. In terms of variety of the components available in the market, most of the microcontrollers or embedded processors contain 8-bit processors. On the other hand, 75% of all 32-bit processors are integrated into embedded systems. Also, the complexity of embedded software is expected to increase, doubling the length of code every two years in the area of consumer electronics.

The marketing estimates on the number of processors are dictated by the expectations of the consumer electronics market. Most consumer electronics products, such as mobile phones and portable audio/video players, heavily focus on the information processing capabilities. These are high-volume products, so that the sales of every designed system can easily reach thousands or millions. The number of embedded system designs in the other application areas is higher, but the sales of these products is much lower compared to consumer electronics products. From a design engineer's point of view, future trends in embedded systems should not be tied solely to the development of processors. Development of new sensor and actuator technologies and driver electronics will result in a growing number of applications for embedded systems.

[1] Marwedel, Peter, "*Embedded System Design*" Springer, Boston, MA, 2006.