



UNIVERSITÀ  
DEGLI STUDI DI MILANO-BICOCCA

## SYLLABUS DEL CORSO

### Sistemi Embedded

2425-3-E3101Q124

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#### Aims

Understanding of the major issues in real-time embedded systems. Ability to develop simple real-time embedded applications on micro-controllers in assembly and C, with and without OS.

#### Contents

Embedded systems: features and requirements. The structure of embedded systems: micro-controllers, DSP, FPGA, memories and their organization, communication systems. Peripherals, sensors and actuators. Real-time scheduling theory. Software architectures and libraries for real-time, fail-safe and safety-critical programming. Real-time operating systems. Laboratory activity with micro-controller programming in assembly and C. Laboratory activity with PC-like machines in C under Linux with scheduling classes RT - deadline.

#### Detailed program

1. Embedded systems: features and requirements
  1. General features of embedded systems; application domains; market value and diffusion.
  2. Basic requirements: timing, reliability, efficiency.
  3. Design choices vs requirements.
  
2. The structure of embedded systems
  1. Small recap of digital and analog electronics.

2. Scale levels: IC, PCB, network.
3. Processing units: CPU, microcontrollers, DSP, GPU, ASIC. Programmable logic: FPGA.
4. Memories: SRAM and DRAM, non-volatile memories; interactions between processor and memory: Von Neumann and Harvard architectures, memory hierarchies.
5. Communication systems: GPIO, Pulse Width Modulation, RS-232, USB, I2C, SPI, CAN bus, JTAG.
6. Systems with a high degree of integration: SoC e NoC.
7. Examples of micro-controllers.

### 3. Peripherals, sensors and actuators

1. Timers.
2. DMA.
3. Fundamentals of sampling theory: Nyquist theorem, aliasing, quantization noise; Comparators and A/D and D/A converters.
4. Models of sensors and actuators: Affine models, saturation, harmonic distortion, dynamic range.
5. Sensors: Accelerometers and gyroscopes.
6. Actuators: Linear solenoids and DC motors.

### 4. Real-time scheduling theory

1. Basic definitions: periodic, aperiodic e sporadic tasks, utilization, valid and feasible schedules, optimality.
2. Cyclic schedule.
3. Static priority scheduling: rate-monotonic and deadline-monotonic schedule, schedulability analysis.
4. Dynamic priority scheduling: earliest-deadline-first and least-slack-time-first schedule.
5. Scheduling for aperiodic and sporadic jobs.
6. Blocking time analysis.
7. Critical sections, scheduling anomalies (priority inversion and deadlock), priority inheritance and priority ceiling protocols.

### 5. Software architectures and libraries

1. Main architectures: Round-robin, round-robin with interrupts, function-queue-scheduling.
2. (hints) POSIX.4, Ada Real-Time and Ravenscar, Real-Time and High-Integrity Java.
3. (hints) real-time operating systems.

### 6. Laboratory activity on micro-controllers programming.

1. Software development toolchain and IDE.
2. Assembly programming and development of some basic programs.
3. C programming.
4. Team project development.

## Prerequisites

1. Basic knowledge of computer architecture and what is assembly.
2. Basic skills in C programming.
3. Basic knowledge of operating systems and concurrent programming.

#### 4. Software design principles with UML.

### Teaching form

- erogative classes;
- laboratory interactive practices, with development of projects in small groups; such activities will base on HW STM from the Nucleo family as well as compatible shields, and on the small robot Coderbot (Raspberry Pi).

### Textbook and teaching resource

relevant

- G. C. Buttazzo. Hard Real-Time Computing Systems, Predictable Scheduling Algorithms and Applications, 3rd Edition. Springer, 2011

less relevant

- J. W. S. Liu. Real-Time Systems. Prentice-Hall, 2000.
- E. A. Lee, S.A. Seshia. Introduction to Embedded Systems: A Cyber-Physical Approach. Second Edition, MIT Press, 2017.
- D. E. Simon. An Embedded Software Primer. Addison Wesley, 1999.
- C. Brandolese, W. Fornaciari. Sistemi Embedded: Sviluppo Hardware e Software per Sistemi Dedicati. Pearson, 2007.

### Semester

Second semester

### Assessment method

- Written examination with exercises and/or open questions on topics not covered by the laboratory activities;
- written report on the laboratory activities;
- possible oral examination about the laboratory report.

### Office hours

Send email for an appointment.

# Sustainable Development Goals

INDUSTRY, INNOVATION AND INFRASTRUCTURE

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