UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Embedded Systems

2627-3-E3101Q124

Aims

Understanding of the major issues in real-time embedded systems. Ability to develop simple real-time embedded applications on micro-controllers and SBC (Single Board Computer) in languages near to the hardware, e.g., 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 C. Laboratory activity with PC-like machines in C under Linux with scheduling classes RT and 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.
2. Basic skills in C programming.

3. Basic knowledge of operating systems and concurrent programming.

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