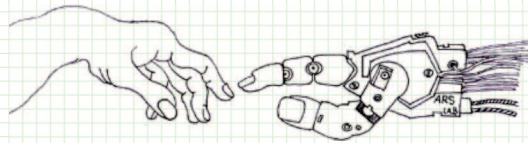# Quick learning guide

Dedicated systems and robotics lab

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Graduate Course in Computer Science, 2013-14

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To acquire and develop the following capabilities:

> model, design and optimal implementation of application-specific information processing systems

> use of harware and software tools, such as development platforms for embedded systems, to design and to implement embedded systems for robotic applications

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The course is organized in two modules: 48-hour lecture and 30-hour robotics lab (lecture room 4, on tuesdays and thursdays, 3-6 pm)

Acquisition of the subject concepts and methods is supported by:

> attendance to lectures and problem solving
> participation to lab experiences
> study of reference readings
> consultation of supplementary readings
> experience with software tools and development platforms for embedded systems
> working out solutions to proposed problems and exercises, see Test area
> writing reports on lab experiences, in the same area
> interaction with teachers, weekly schedule:
>> G. Scollo: room 325 (I block, II floor) [phone]ext.: [095738]3007 on mondays and wednesdays, 2:30-4:30 pm
>> C. Santoro: room M47 (III block) [phone]ext.: [095738]3001 by appointment (via phone or e.mail)
> collaborative interaction with colleagues and teachers

Lectures: the study of the recommended readings sets the methodological grounds for effective application of a technology-transverse, result-holistic design approach:

> versatile design of systems with optimal figure of merit that are dedicated to perform highly specialized tasks

Exercises: starting from a specification of the abstract functionalities of the system, the first problem which is often faced with is to select an architecture wherein to map them out, in order to further proceed to the synthesis of all components: hardware, software, communication interfaces. The proposed exercises deal with the different parts of this process.

Robotics lab: it is envisaged the use of development boards and platforms to implement embedded applications, ranging from on-board assembly to FPGA-based synthesis of components, up to System-on-chip (SoC) implementation. Reports on lab experiences may be outcomes of collaborative group work.

Seminars: as an experimental feature, some lectures (about 1/4 of the total) take the form of seminars that are prepared and delivered by students; one lecture is devoted to the planning of the seminars. Critical evaluation of these as well as of the other educational activities is planned in the form of a written test that is part of the final exam.

Oral exam, project (optional)

- evaluation objectives
- oral exam:
  assessment of the achievement of educational goals
- optional project:
  assessment of conceptual and scientific maturity exhibited in the practice of the subject
- oral colloquies
- subject learning assessment
- evaluation of individual contribution to lab experience reports
- (optional) colloquy on individual use of subject concepts and methods within an <u>original</u> lab project, previously agreed with the teacher, that may be the outcome of a collaborative group effort

Exam success yields the acquisition of 9 credits.

legenda: L = Lecture, E = Lab tutorial lecture, r = reference readings, s = supplementary readings, t.n = tutorial note #

1. Course goals and organization.
   Introduction to design of dedicated systems, codesign and embedded systems
   L01: 11/03, r: VG.01, s: LS.01
2. Architectures and design process of dedicated systems
   L02: 13/03, r: Sch.01, s: BF.01
3. Introduction to microcontroller programming
   E01: 18/03
4. Automated control systems: architectures, analysis, performance features
   L03: 20/03, r: VG.09.1-2, We.1, AM.1-3, s: LS.02, N.01.1-5
5. AD and DA conversion, PWM modulation, sensors, actuators
   L04: 25/03, r: M.3.1-2, M.3.6, VG.4.4-8, s: VGM.13, B (t.1), BF.10.1-2, BF.13
6. LTI discrete control systems, PID control, *tuning of PID controllers*
   L05: 27/03, r: VG.09.3-7, s: VGM.12, We (t.2)
7. Dataflow models, control flow
   L06: 01/04, r: Sch.02, s: LS.06.3, M.2.5
8. Speed control of an electric DC engine
   E02: 03/04
9. Software and hardware implementations of dataflow models
   L07: 08/04, r: Sch.03, s: Sch.04
10. Synchronous systems as finite state machines with datapath (FSMD)
    L08: 10/04, r: Sch.05.1-4
11. Hardware description languages: Gezel, VHDL, Verilog, SystemC
    L09: 15/04, r: Sch.05.5-7, Sch.A.1, s: BF.aB, M.2.7
12. Microcontroller programming with UART and ADC I/O devices
    E03: 17/04

13. Program design and analysis for dedicated systems
    L10: 29/04, r: Sch.07
14. VHDL tutorial
    E04: 06/05
15. VHDL tutorial
    E05: 08/05
16. Example of 8-bit SoC design
    E06: 13/05
17. Planning of student seminars
    L11: 15/05
18. UART example in VHDL
    E07: 20/05
19. System-on-Chip (SoC) design
    L12: 22/05, r: Sch.08
20. HW/SW architecture of an autonomus mobile robot: a case study
    E08: 27/05
21. HW/SW communication, on-chip bus systems
    L13: 30/05, r: Sch.09-10
22. Real-time (RT): features, performance, RT operating systems
    L16: 03/06, r: BF.08.3-6, s: M.4.1, M.6.2
23. Microprocessor interfaces
    L14: 10/06, r: Sch.11, s: BF.12
24. Hardware interfaces, communication protocols
    L15: 12/06, r: Sch.12, BF.11.1-2, s: VG.06.7-11

Reference textbooks

N.B. The recommended parts are displayed in the lecture program, for each lecture, in the short form A.C.S., where: A = initials of textbook author(s), C = chapter, S = section(s)

C. Brandolese, W. Fornaciari: *Sistemi embedded: sviluppo hardware e software per sistemi dedicati*
Pearson, Milano (2007)

P.R. Schaumont: *A Practical Introduction to Hardware/Software Codesign*
2nd Ed., Springer (2012)

P. Marwedel: *Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems*
2nd Edition. Springer (2011)

F. Vahid & T. Givargis: *Embedded System Design: A Unified Hardware/Software Introduction*
Wiley (2002)

Textbooks

E.A. Lee & S.A. Seshia: *Introduction to Embedded Systems – A Cyber-Physical Systems Approach*
1st Ed, Version 1.08 (2011)

R. Siegwart, I.R. Nourbakhsh, D. Scaramuzza: *Introduction to Autonomous Mobile Robots*
2nd Edition, The MIT Press (2011)

K.J. Åmström & R.M. Murray: *Feedback Systems: An Introduction for Scientists and Engineers*
v. 2.11b, Princeton University Press (2012) (freely available on the second author's wiki at Caltech)

N.S. Nise: Control Systems Engineering, 6th Ed., Wiley (2011)

T. Wescott: *Applied Control Theory for Embedded Systems*, Elsevier (2006)

G.P. Starr: *Introduction to Applied Digital Control* (link path to textbook: Faculty / Starr / ME 581)
2nd Ed., ME 581 textbook, Dep't of Mechanical Engineering, University of New Mexico (2006)

F. Vahid, T. Givargis & B. Miller: *Programming Embedded Systems: An Introduction to Time-Oriented Programming*, Version 4.0.
Uniworld (2012)

M. Wolf: *Computers as components: Principles of embedded computing system design*
3rd Edition, Morgan Kaufmann (2012)

Tutorials and other consultation notes

1. M. Barr: Introduction to Pulse Width Modulation, *Embedded Systems Programming* 12, Sep. 2001
2. T. Wescott: PID without a PhD, *Embedded Systems Programming* 13, Oct. 2000

Any further consultation notes will be mentioned along lecture progress

Lab activities take place in the framework of the ARS Lab

They consist of a series of experiences with the following topics:

- FPGA programming in VHDL
- specification and synthesis of peripheral devices (PWM, Input capture, SPI, I2C)
- device driver programming on SoC/Linux-embedded
- servomotor control (speed and position)
- high-level control of autonomous robotic systems

Forum, Moodle, Galileo: what goes where?

- Forum: discussions about
  - course organization, news, FAQ
  - problems with use of on-line services, software tools etc.
  - discussions about *ideas* of dedicated system projects

- Moodle (restricted access services):
  - access to educational support materials
  - development of proposed problems and exercises
  - discussions about topics relating to lectures, lab experiences and learning materials
  - group collaboration, delivery of lab experience reports
  - discovery and discussion of possible errors in learning materials (this may award *bonus points* !)

- Galileo:
  - development of dedicated systems projects
  - documentation and dissemination of results in the public domain