Developing and integrating lab projects as important learning components in an embedded systems course

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Abstract

This paper describes the process of developing and the experience in teaching the practical component of a course in modern embedded systems at Instituto Superior Técnico, the engineering school of the Technical University of Lisbon (Portugal). The course mainly addresses electrical engineering students, covering both hardware and software aspects in a theoretical and practical integrated perspective. The results achieved in the last two years show that students significantly benefit from this new lab environment and projects, both in achieved skills and students' satisfaction.

1 Introduction

Modern computer-based embedded systems demand increasing performance at moderate cost and low power consumption. Therefore, education and training of computer and electrical engineers should reflect this reality [2].

The School of Engineering of the Technical University of Lisbon has a long experience teaching embedded systems. Because of the Bologna process towards an European higher education and also due to the decreasing number of students that select the "Computer Electronics" course, we have decided to review the course in the winter semester of 2005/06. Although the designation is maintained we reviewed and redesigned it towards a modern embedded system course. It was decided in the course to cover the fundamental aspects of both hardware and software components of the embedded systems in an integrated way, and practical projects as well as lab assignments were prepared to expose students to the challenge of designing embedded systems in an academic environment but simulating company conditions. This paper is focused in the experience of the authors in designing, implementing and applying these projects during two consecutive academic years.

2 Course organization and characteristics

This embedded system course is intended for the first year master program according to Bologna protocol, continuing the three year bachelor studies where Electrical and Computer Engineering students get background knowledge on Digital Systems at the first year course and Computer Architecture and Digital electronics on subsequent years. All the material for the course and extra class communication between teachers and students happen via the FenixEDU electronic information system developed at TULisbon.

From the students's perspective, the course has three main components: *lectures* and *lab assignments* in a total of 28 hours each and about 100 hours of *self study*. The grading system includes two tests and two lab projects with equal weight in the final grade.

The lecture contents is loosely based on [3], but also makes use of [1] and notes specifically prepared as complementary study material. Covered topics in the lectures include: *i*) general purpose processors, covering the instruction set, microarchitecture, interrupts and DMA; *ii*) dedicated embedded processors, namely design methodologies, controllers, datapaths and interfaces; *iii*) memory, including the technology aspects and the organization of memory systems; *iv*) buses and peripherals, namely electrical characteristics, protocols and standards; and *v*) software aspects, related with basic compilation techniques, code analysis and optimization, and device drivers.

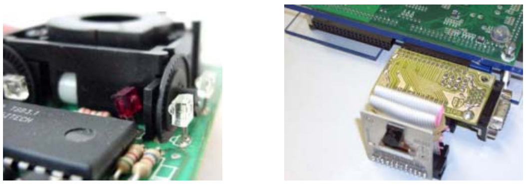
3 Practical projects and lab assignments

We prepared the projects with mainly two objectives in mind: to motivate students to regularly study the main topics of the course and to improve their skills to design complex embedded systems. The practical component of the course is embodied in lab assignments that are presented to the students aiming to provide an example on how an engineering project should be planned and organized.

In the PI project, students have to design and implement an input peripheral for a Personal Computer (PC). This peripheral is a mechanical mouse that has to be interconnected with the PC using the Universal Serial Bus (USB). This work includes the acquisition circuits, the communication software and the device driver hosted on the PC.

In the PII project, students have to design and implement a very demanding video embedded system. This is a system based on specialized processors implemented on a FPGA and a video camera.

Basic development boards were provided and some devices were implemented to support students work. For the PI,the PICDEM FS USB Demonstration Board (PIC18F4550) and the MPLab programming environment from the Microchip, and the mechanical set-up of a mouse, namely with two rollers and the optical encoding disk with 36 holes around its outer edge (see fig. 2(a)). For the PII, apart from a board with the XC3S1000 Xilinx FPGA (Digilent Spartan 3 Starter Kit) and the software also from Xilinx (EDK 8.1 and ISE 8.1), we also provide two hardware modules for video acquisition and display. The camera module is based on the Omnivision OV9650 CMOS image sensor and the display module generates the signals necessary for a standard VGA monitor (see fig. 1(b)).



(a) Mouse anatomy (b) Video devices

Figure 1. Devices prepared and provided to the students to perform the projects

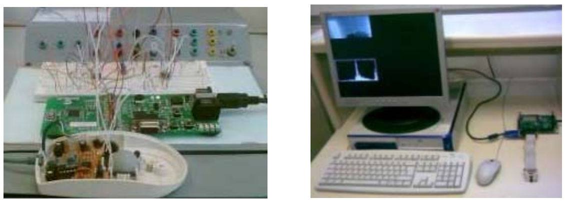
The lab assignments enable the students to learn the practices and steps used in typical engineering projects such as: problem statement, tool selection, design procedure, hardware and software implementation, debugging, demonstration of the final product and report preparation.

Lab assignment for PI consists on the following main steps: *i*) disassembling a computer mouse, identification of its electronic components, and development of the hardware to interface the optical position sensors with the PIC; *ii*) development, using MPLab, of the PIC firmware to implement the input peripheral functionality; *iii*) programming in C++ (Borland C++ Builder) the PC driver for the developed input peripheral; *iv*) demonstration of the input peripheral in action and reporting of the different stages of the work carried out, the difficulties encountered and the devised solutions.

The lab assignment for PII consists on the following main steps: *i*) creation of a new project for the FPGA using the EDK Base System Builder which allows the showcase of the peripherals available in the FPGA Board; *ii*) development, using Borland C++ Builder, of image processing algorithms for edge detection and histogram equalization; *iii*) porting of the developed algorithms to the EDK environment where the FPGA is programmed with a MicroBlaze core processor; *iv*) development of the same two algorithms using the MicroBlaze assembly language; *v*) experimental determination of the frame rate achieved; *vi*) demonstration of the video system operating on real-time images.

4 Assessment of the results and conclusions

Fig. 2 present pictures illustrating two of the systems developed by the students in PI and PII. The majority of the students in the last two years showed great interest and commitment in the projects that were carried out which lead into excellent success rates, close to 97%.



(a) Input peripheral (b) Video system

Figure 2. Examples of prototypes developed by the students in the projects

The number of students increased from about 20 in 2004/05 to about 45 in each of the following two academic years, when the new version of the course was offered. On the contrary, the fail rates for the last three years have decreased from 38% to 9% and to 8% in 2006/07. Tracking the student evaluation of the course, from its last offering in its old form until its two subsequent offerings in its reviewed form, a significant improvement can also be identified.

References

[1] V. P. Heuring and H. F. Jordan. *Computer Systems Design and Architecture*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1996.

[2] S. Nooshabadi and J. Garside. Modernization of teaching in embedded systems design-an international collaborative project. *IEEE Transactions on Education*, 49(2):254–262, May 2006.

[3] F. Vahid and T. Givargis. *Embedded System Design: A Unified Hardware/Software Introduction*. John Wiley & Sons, Inc., New York, NY, USA, 2001.