Embedded System Education in Zhejiang University

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Abstract: Embedded system becomes more and more useful in all of the domain of our society. An embedded system education in universities is an urgent requirement. College of Computer Science of Zhejiang University is trying to improve its education in embedded system. This paper describes the achievement Zhejiang University has accomplished since 2002.

Key–Words: Embedded System, Curriculum, Course reformation, Embedded Software

1 Introduction

Since the emergence of embedded system, it has played a more and more important role with the improvement of semiconductor technology. Many kind of embedded systems are used in the cars, cooking machines, video player and a lot of other electronic products. The performance, reliability and durability is the key element of embedded system design and how to improve the design, implementation and development of the embedded systems becomes more and more important in industry and research. Every year, the information technology companies require a great amount of graduated students armed with embedded system developing skills. Thus to educate more and more students with embedded technology development skills is an important task for the universities.

Nowadays, for the universities to teach and design the embedded system curriculum is a difficult job. Although embedded system courses have been designed for more than 30 years, the subject of education in embedded system of the universities is always new, relatively undefined one[1].

The traditional teaching methods do not fit for this new region of embedded system. In a traditional teaching framework, the students go to classroom to listen for the lectures and have very few experiments with embedded evaluation boards. Moreover, if we give students a lot of time to implement their ideas in laboratory. They can compare their ideas with the others and they will obtain deeper understanding of the materials they learned.

In a traditional teaching framework, students read the basic principles and have less opportunities to join a competition. While we give students free time to attend every kind of competitions on embedded software design. In a competition, students enjoy a teamwork and develop their knowledge in more detail.

The embedded system education is a challenging undertaking. It is the same to the universities in Zhejiang University. In this paper, we present the efforts in embedded system education in Zhejiang University.

In this paper, we describe how we construct embedded system courses in Zhejiang University. The paper is organized as follows. Section 2 describes the background of embedded system education in Zhejiang University. Section 3 presents the embedded system curriculum design including theory course design and experiment course design. Section 4 is about the innovations and practices. Section 5 offers the experiences and result from Zhejiang University.

2 Background

As it is known to all that embedded system is the result of the combination of computer science evolution, electronic technology and industrial applications. Embedded system contains many other technologies such as program design, computer organization, computer architecture, concepts of operating system, assembly language, compiler construction technology and object-oriented technology. We teach embedded system course to improve students' skill with all the other courses.

In this course, the students can systematically establish their knowledge with the theories guiding the experiments and experiments emphasizing the theories. Also experiments guided with theories can improve students' research ability and develop their in-

terests in research. The main aim of this course is to train students' skill in embedded system and software design especially the ability of software and hardware co-design, embedded system architecture, real-time operating system and embedded product design. We give them the basic knowledge of using embedded system integrated development environment. After this course, students know how to design software and hardware for embedded system and embedded communication terminals.

These years, the requirement of qualified graduated students in embedded area is growing very fast while embedded system education is in its initial stage. This situation calls for reformation in embedded system education. A lot of other universities also try to configure course plan to fit for such a situation. The nature property of embedded system technology is combining hardware technology and software technology and co-designing with both area. Hardware-software cosimulation has to competing goals: speed and correctness [2].

3 Design of Embedded System Curriculum

In Computing Curricula 2005 report[3], computer science and technology is divided into 5 areas: Computer Engineering(CE), Computer Science(CS), Information Systems(IS), Information Technology(IT), and Software Engineering(SE). CE and CS contains courses of embedded system. Relative performance capabilities of computing graduates by discipline are indicated in table 1.

Computer Engineering 2004[4] is the guideline of computer engineering course design for undergraduate students and also for post-graduate students. Embedded system is mentioned in course category of CE-ESY. CE-ESY Embedded Systems course is occupied 20 core hours:

- CE-ESY0 History and overview
- CE-ESY1 Embedded microcontrollers
- CE-ESY2 Embedded programs
- CE-ESY3 Real-time operating systems
- CE-ESY4 Low-power computing
- CE-ESY5 Reliable system design
- CE-ESY6 Design methodologies
- CE-ESY7 Tool support
- CE-ESY8 Embedded multiprocessors
- CE-ESY9 Networked embedded systems
- CE-ESY10 Interfacing and mixed-signal systems

A lot of universities developed their embedded systems course according Computing Curricula 2005 and Computer Engineering 2004 guideline. The undergraduate embedded system education have been developed by Carnegie Mellon University[5]. P. Koopman et al present the approach of Carnegie Mellon University to organize and teach the embedded systems in variety of subjects. The education of embedded systems is divided into embedded application section and hardware level section. Each section is again divided into different small sub-sections and different teaching method is designed for each subsection according to their characteristics.

At University of California Berkeley, the education design of embedded system based on their strong research on embedded systems[6]. Their curriculum is based on bottom-up aggregation of interests and approaches. The intersection of system theory and computer science is the most important guiding principle for the teaching at this university. The graduate program presented in [6] is divided into three parts: (1) design of embedded systems: models, validation, and synthesis; (2) advanced graduate courses and (3) civil and mechanical engineering. These courses will be arranged according to the grades, abilities and needs of the students to teach their master the knowledge and skills of embedded systems. The detailed curriculum design can be referred to [6] at University of California Berkeley.

There are also many other universities and institutes which construct courses in the education in embedded system such as University of Waterloo [7], Vanderbilt University[8], National Tsing Hua University (Taiwan, China)[9], Royal Institute of Technology[1], The Artist Education Group[10] and so on. They have provide us the experiences and lessons from their embedded system education.

College of Computer Science in Zhejiang University is one of the three top colleges which have a long history in computer science research according to the statistics of Ministry of Education of the People's Republic of China[12]. Zhejiang University has a long history in teaching the essential material of computer science, including digital circuit design, computer organization, concepts of signal and system, concepts of operating system, theory of computation, software engineering, computer architecture and compiler construction. Thus we can design our courses for all kinds of students no matter which domain of computer science they are most familiar with.

The education of embedded system in Zhejiang University is designed in several progressive stages. In such a framework, students can develop their skill in a stable progress. Figure 1 shows that the embedded system courses are divided into two main sections,

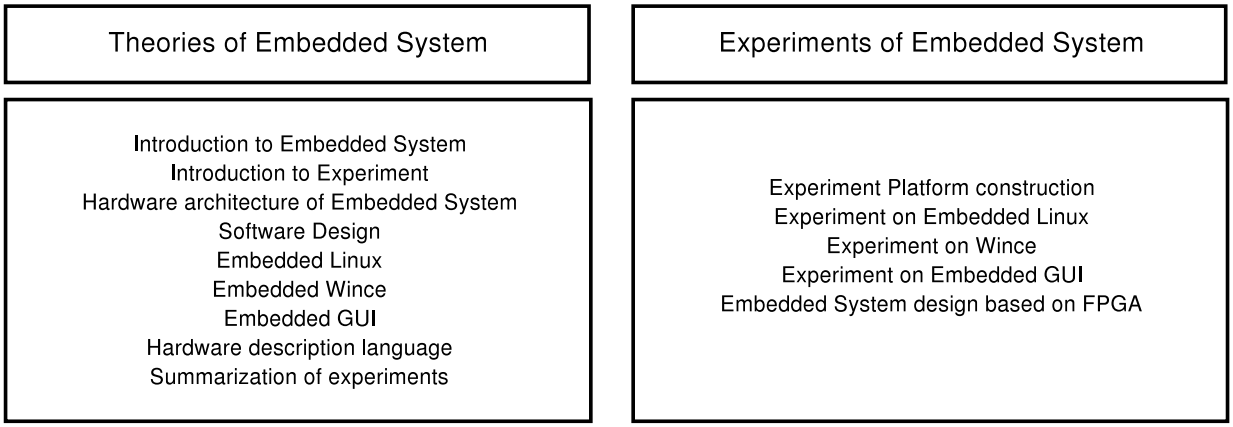

Figure 1: The course structure of embedded system education in Zhejiang University.

Table 1: ca2005 divided

Area	Performance Capability	CE	CS	IS	IT	SE
Hardware and devices	Design embedded systems	5	1	0	0	1
	Implement embedded systems	5	2	1	1	3
	Design computer peripherals	5	1	0	0	1
	Design complex sensor systems	5	1	0	0	1
	Design a chip	5	1	0	0	1
	Program a chip	5	1	0	0	1
	Design a computer	5	1	0	0	1
Networking and communications	Design network configuration	3	3	3	4	2
	Select network components	2	2	4	5	2
	Install computer network	2	1	3	5	2
	Manage computer networks	3	3	3	5	3
	Implement communication software	5	4	1	1	4
	Manage communication resources	1	0	3	5	0
	Implement mobile computing system	5	3	0	1	3
	Manage mobile computing resources	3	2	2	4	2

theories of embedded system and experiments of embedded system. Each section then is divided into several sub-sections. We split 32 class hours of theories of embedded system into 15 sub-sections.

The first sub-section of two class hours is the overview of embedded system. It includes the definition of embedded system, the properties of embedded system, the architecture of embedded system, properties of embedded system hardware and properties of embedded system software. This part is important for the beginners, as their interesting is the key to study a course well.

We give detail infumation about experiment platform of embedded system in second two class hours. The students will learn how to use JTAG, how to burn bootloader and how to use minicom to communicate with evaluation board. They will also be familiar with integrated development environment and cross compiler environment after these class hours.

With the basic knowledge about embedded system architecture and development environment, we use 6 class hours to teach students with the most important modules. 4 class hours is used to teach them the up-to-time embedded processors, including processor instruction sets, pipeline structure and memory management unit. The other two class hours is used to teach them the design method for embedded software architecture, mainly about the development process and the construction of embedded development environment.

Then we give a 12 class hours of detail exploration of the embedded Linux and WinCE operating system, as these two operating system are main streams in embedded operating system market.

The last 6 class hours is used to give an introduction about embedded GUI, the hardware description language and summarization of experiments.

We give another 32 class hours for the experiments of embedded system. Students can practise in experiments to verify their knowledge they learned from theory classes. The experiments are designed according the accompanied theory courses. In the experiment time, students construct the development environment, deal with embedded Linux, WinCE and embedded GUI, and make an embedded hardware on FPGA with hardware description language. At last, they are required to use their knowledge to construct a small project.

We can conclude from the embedded system courses design, the main characteristics of this design is that:

- We design the courses in a consecutive form and each parts of the courses is not an independent section. The former part is the base of the later part, and the later part will be the base of another part.
- We keep frequent communication with the industry, teaching and research. Although new innovation in industry always comes from research, only research can not make sense. The key role of the three is teaching. The professors should know as much industry trend as possible. Researching or inventing according industry is important to lead to innovation. Many inventors ignore this most crucial of all questions. Or, starting from the self-evident truth that unless the thing works, no one will buy it, they reason their way to the comforting but spurious conclusion that if and when it works, everyone will want it.[11]. Thus all of the students taught for the industry should keep knowledge up with research and industry.
- An ideal teaching environment is that students are provided with a good communication platform and can freely express their ideas. We also provide students with information of advanced technology all over the world. If some students' ideas are valuable, we give them free time and funds. They can come to Embedded Technology Center[15] in Zhejiang University to develop their projects.

The experiment is important for embedded system education as it is a practical course. College of Computer Science in Zhejiang University has tried its best to introduce as much advanced experiment facilities as possible. From figure 2 indicates that, five years ago in 2002, we developed a suit of embedded evaluation boards based on ARM7TDMI architecture. With the good effect on the students' skill improvement, we introduced new facilities every year since 2002. In 2003, we bought 15 Intel XScale Sitsang evaluation boards, 15 Intel EIA Pentium M evaluation boards and 180 HP Pocket PC h5500 evaluation boards to satisfy variety of embedded application development needs. In 2004, we upgraded the experiment facilities with 30 Intel XScale PXA255 evaluation boards, and in 2005, we upgraded again with 10 Intel XScale PXA2272 evaluation boards. In 2006, we bought 50 Xilinx Virtex-II PRO evaluation boards. Education of embedded system in Zhejiang University go farther to teach configurable and programmable hardware level.

With the upgrading of experiment hardware, we also responsible for several education projects. We are responsible for the following education projects:

- From September 2004 to January 2005, Personal Communication Architecture(PCA) Embedded System Course constructed together with Intel Corporation[13].
- From January 2005 to January 2006, embedded system course of Zhejiang University appointed by

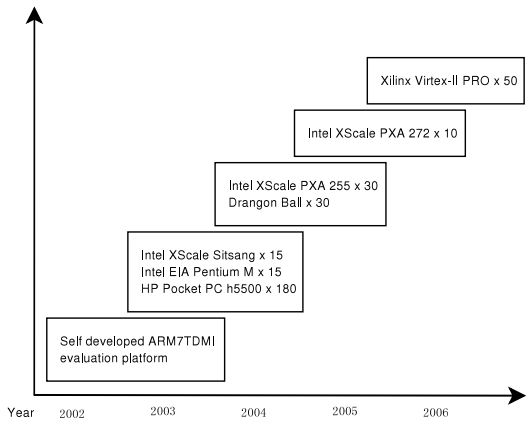

Figure 2: The facilities for embedded system experiments we introduced to Zhejiang University every year since 2002 when we began to give embedded system curriculum. As we can see from the figure, that the facilities is upgrading distinctly in recent years.

Ministry of Education of the People's Republic of China[12] as national level excellent course.

- From March 2005 to March 2006, Principle of Microcomputer Course co-funded by Ministry of Education of the People's Republic of China and Intel Corporation.
- From July 2005 to January 2006, Embedded Intel Architecture(EIA) Embedded course funded by Intel University Project.
- From July 2005 to December 2005, WinCE embedded system teaching kits funded by the Ministry of Education of the People's Republic of China.
- From January 2006 to October 2006, XScale272 teaching experiment board development course funded by Shanghai Forward Technology Co Ltd.[14]
- From September 2006 to September 2007, Intel Embedded Technology Center(ETC)[15] training courses funded by 2006 high-tech zones cooperation with the Zhejiang University and District school collaborative software and IC professionals training projects.
- From December 2006 to December 2007, embedded system course funded by Ministry of Education as national level excellent course.
- From January 2007 to January 2008, Embedded System funded by Intel university embedded and communication project.
- From June 2007 to May 2008, Java-based mobile communications and multimedia GPRS handsets course funded by National students innovation training program.

4 Innovation of Embedded System Curriculum

With these several years practice in embedded system education, we have accumulated a lot of experiences. Based on these experiences, we also have some innovation.

Every year, we employ about six doctoral or postgraduate students as a high-grade teaching assistant who research in embedded system. The main speaker teachers and teaching assistants offer undergraduate students with learning and experimental guidance. The teaching teams educated totally 840 students in 4 years and on average each teacher educated 10 students, the teacher-student ratio is 1:10.

In addition to the teachers from Zhejiang University, we also invited globally famous experts in embedded system to give lectures. Since 2005, we have invite professors from Japanese Thammasat University teach a total of 48 hours of courses. In 2006, we invite professors from San Jose State University to give lecture courses. In 2005 and 2007 we invited CMU professor of Zhejiang University to give lectures.

We also frequently cooperation with domestic and overseas universities and colleges to construct the embedded system curriculum. The curriculum group has organized the Chinese university courses embedded system seminar in Xi'an, Chengdu, Harbin, Guangzhou, Shanghai and other places, and we discussed with the local college teachers about the content of courses Embedded framework and construct mutual promotion system of the curriculum with them. The curriculum group as the key member of the Chinese Institute of embedded computer professionals has invited Ministry of Education of People's Republic of China to join the seminar to discuss how to improve embedded system education. We also actively communicate with other countries and we have participated in the organization of 2005 Shanghai Asian Embedded academic forums and attended Asia Embedded academic forums in India. We also share the teaching curriculum results with the National University of Singapore, Hong Kong University of Science and Technology, University of Hong Kong, Malaysia Multimedia University, University of the Philippines and the Indian Institute of Technology and other universities in Southeast Asia.

With the support of Intel American University

Cooperative Department, we cooperate with world famous universities CMU and Georgia Polytechnic University to build embedded systems. The English versions of Embedded System course ware and video will be constructed with the support of University Institute of Intel.

The curriculum group has frequent cooperation with international famous enterprises. We have constructed the "Zhejiang University-IBM Technology Center", "Zhejiang University HP Joint Lab," and "Zhejiang University-Intel Embedded Joint Lab". In 2006 the "Zhejiang University-Intel Embedded Joint Lab" upgraded to "Zhejiang University-Intel Embedded Technology Center," becoming the world's only embedded technology center, and in 2007 upgraded once again as "Zhejiang University-Intel Technology Centers."

We give students a lot of time in practice after courses. They can discuss in the project team of the courses and we encourage students to develop their own research programs. For the innovative programs, we provide them with some support from Embedded Technology Center and support them to participate in Student Research Training Projects(SRTP) and Embedded competition. We also offer certain funds to support the scientific research. These policies greatly stimulate the enthusiasm of practice of students. Zhejiang University organized and implemented SRTP for undergraduates. The main objectives are: (1), to provide undergraduate the research training opportunities, to lead the students as soon as possible into the field of professional research; (2), to make full use of curriculum, teaching resources and talents advantages, and to improve management efficiency; (3), to train students in integrating theory with practice and innovation ability in practice to work independently; (4) to improve the teamwork of teachers and students and the ability of expression; (5) to encourage the early research results to implemented into industry.

College of Computer Science in Zhejiang University has a totally established 247 SRTP of which 82 project are embedded technology related, accounting for about one-third. The SRTP project "Java based and GPRS communication multimedia mobile phone" guided by Professor Tianzhou Chen titled with national students innovative training program.

The curriculum group also actively encourage students to follow their own interests to team up to participate in a variety of embedded competition and provide students with guidance and equipment. The students have participated and successes in the global Linux Challenge, the National Electronic Design Contest. Intel plan for the future contest, Microsoft Embedded Software Design Competition, the United States Cup and many other prizes. They also join a team to participated in Intel third Cup National Undergraduate Electronic Design Contest of Embedded topic. In 2007, Some students participate "Third Shanghai Embedded System Design and Application innovation contest", "2007 IEEE standard computer mouse Maze Tournament". In 2004, we encouraged students to participate in the "IBM Global Linux tournament" and got second place. In the same year, we encouraged students to participate in the "National Electronic Design Contest" and got third place. Student Jiangwei Huang participated "Intel plans for the future contest" and got an excellent reward. In 2004, students participated "IBM Global 2004 College Linux Challenge" and got second place.

What's more? We encourage students to join technology clubs. We have Intel Technology Club, IBM Technology Club and Nokia Technology Club and some other technology clubs are planning to establish. In these clubs, students can enjoy many kind of technology activities. The technology clubs may invite experts to give lectures or have some projects keep students busy.

Zhejiang University held more than 10 training in Hangzhou, Shanghai, Xi'an, Harbin, Chengdu and Wuhan, and totally trained more than 1,000 teachers. Through teacher training we effectively promoted the embedded system courses in the colleges. More than 47 colleges used our embedded course as part of the training curricula. We used Intel XScale in 35 colleges and these colleges trained a total of 3,837 students. We use Embedded Intel Architecture in 12 colleges and universities and totally trained 1,315 students. In the training activities, we trained non-Zhejiang University students up to 5,152, of which 3,797 undergraduates, 1,355 graduate students.

In 2006, the embedded system course was appointed as national level excellent course by the Ministry of Education of People's Republic of China and promoted to the national higher education. Since then, we have accomplished 13 teaching duties, for a total of nearly 2,000 students been trained.

After several consultations with Intel Corporation, on July 21, 2005, the curriculum group signed the agreement of Intel certification authority with the Intel software college manager Mary Allisini, as shown in figure 3 and the example of an Intel Training Certification in figure 4. This is the first certification authority agreement signed on Chinese mainland so far.

We also published several excellent textbooks about embedded system:

- Tianzhou Chen et al. "Embedded Intel Architecture Experimental Guide", Beijing University of Aeronautics and Astronautics Press, 2006.8.

Figure 3: The curriculum group representation is signing the agreement of Intel certification authority with the Intel software college manager Mary Allisini.


Profession certification program from
Intel Zhejiang University Embedded Technology Center (ETC)
In recognition of the commitment to achieve professional excellence, this certifies that
Ye Minjiao
has successfully completed the technical trainings consisting of
Intel Xscale 255/272
Intel Xscale Linux/Wince
Intel EIA
Intel Xscale
Signature
Date
Provided by ETC

Figure 4: An example of the Intel Training Certification.

- Wenzhi Chen, "Embedded System Development Theory and Practice", Qinghua University Press, 2005.8.
- Tianzhou Chen, Qingsong Shi, "Theory of Embedded System Design" Qinghua University Press, 2007.8.

5 Conclusion

Embedded system has a wide range of technology from semiconductor technology to embedded software development. Embedded system education curriculum group in Zhejiang University is searching the methods to improve its teaching practice all the time. Practice is designed to link the theory to reality. As the progress of embedded technology, embedded systems will be more important than ever, and embedded education will be more interesting. Embedded education in Zhejiang University will evolve with the advance of embedded system.

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References:

[1] M. Grimheden and M. Törngren. What is embedded systems and how should it be taught?-results from a didactic analysis. *ACM Trans on Embedded Computing Systems (TECS)*, Volume 4, Issue 3, pp: 633 - 651.

[2] Gajski, D.D.; Vahid, F. Specification and design of embedded hardware-software systems, *Design & Test of Computers, IEEE* Spring 1995, Volume: 12, Issue: 1 pp. 53–67

[3] The Joint Task Force for Computing Curricula 2005, Computing Curricula 2005, *A cooperative project of The Association for Computing Machinery (ACM) The Association for Information Systems (AIS) The Computer Society (IEEE-CS)*,30 September 2005

[4] Joint Task Force on Computer Engineering Curricula, Computer Engineering 2004, *IEEE Computer Society Association for Computing Machinery*, 2004 December 12

[5] P. Koopman, H. Choset et al. Undergraduate embedded system education at carnegie mellon. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 500 - 528.

[6] Alberto. L. SV and A. Pinto. An overview of embedded system design education at Berkeley. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 472 - 499.

[7] Rudolph E. Seviora. A curriculum for embedded system engineering. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 569 - 586.

[8] J. Sztipanovits, G. Biswas et al. Introducing embedded software and systems education and advanced learning technology in an engineering curriculum. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 549 - 568.

[9] Tai-Yi Huang, Chung-Ta King et al. The embedded software consortium of Taiwan. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 612 - 632.

[10] P. Caspi, A. Sangiovanni-Vincentelli and et al. Guidelines for a graduate curriculum on embedded software and systems. *ACM Trans on Embedded Computing Systems*, Volume 4, Issue 3, pp: 587 - 611.

[11] From Invention to Innovation *Science* 21 May, 2004, Vol. 304. no. 5674, pp. 1117 - 1119

[12] The web site of Ministry of Education of the People's Republic of China, http://www.moe.edu.cn/english/index.htm

[13] The web site of Intel Corporation, http://www.intel.com/

[14] The web site of Shanghai Forward Technology Co Ltd. http://www.forwardahead.com/

[15] The web site of Embedded Technology Center. http://embedded.zju.edu.cn