A Hardware Lab Anywhere At Any Time

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ABSTRACT

Scientific technical courses are an important component in any student's education. These courses are usually characterised by the fact that the students execute experiments in special laboratories. This leads to extremely high costs and a reduction in the maximum number of possible participants. From this traditional point of view, it doesn't seem possible to realise the concepts of a *Virtual University* in the context of sophisticated technical courses since the students must be "on the spot".

In this paper we introduce the so-called Mobile Hardware Lab which makes student participation possible at any time and from any place. This lab nevertheless transfers a feeling of being present in a laboratory. This is accomplished with a special Learning Management System in combination with hardware components which correspond to a fully equipped laboratory workstation that are lent out to the students for the duration of the lab. The experiments are performed and solved at home, then handed in electronically. Judging and marking are also both performed electronically.

Since 2003 the Mobile Hardware Lab is now offered in a completely web based form.

Keywords: Hardware Lab, Microprocessor, Learning Management System, E-Learning, and Virtual University.

1. INTRODUCTION

The Hardware Lab offered by the Institute of Computer Science at the Albert-Ludwigs-University of Freiburg is a mandatory hardware introduction course for all students in the fourth term (2nd year). The lab consists of three main blocks that try to complement the knowledge gained through the many different theoretical courses the students have taken. These three main blocks are:

Microprocessor Programming
The hardware lab begins by building on the theoretical experiences learnt in the course *Technical Computer Science*. This is accomplished in the lab by programming and testing the PIC16F84 commercial microprocessor. This processor is part of the so-called *PICee System* [5,9] which serves as the basis for all experiments. The *PICee System* consists of a processor board with multiple switches, LEDs, and a double-spaced LCD display (see Figure 2). The primary objective is to provide the students with an opportunity to get familiar with software tools like compilers, simulators, and chip programming software to name only a few.

The implementation of a stopwatch and the development of a pocket calculator are some examples of the more advanced experiments the students perform after they have completed simpler programs like a running LED light.

Designing Combinational and Sequential Circuits
In the second set of experiments, systematic circuit design techniques are put into practice through a series of experiments. These experiments include designing a simple arithmetic logic unit (ALU) which masters the basic arithmetical operations such as addition, subtraction, and multiplication. Other experiments like creating an electronic dice require the students to build smaller components such as decoders, multiplexers, counters, and registers before combining them all into a larger circuit. Even though these circuits are built using discrete logic gates the students learn how to simulate and implement them completely in software just like it is done in modern computer aided design. After the software stage is completed, the circuits will be realised using Altera FPGAs and can be tested using the *PICee System* and corresponding additional hardware (refer to Section 3).

Besides the *full custom* design of circuits with the help of predefined gate libraries, the common hardware description language *VHDL* will be also introduced.

Fundamentals of Analog and Digital Electronics
The concluding section of the lab deals with simple analog and digital circuits – a resistor and capacitor measurement device for example – which are built up with the basic electronic elements like resistors, capacitors and transistors. All the circuits are controlled and evaluated with the help of the *PICee System* in combination with additional extension boards resulting in the so-called *PICee++ System* (see Section 3).

The rest of the paper is structured as follows: Section 2 represents the classic processes of a technical course and shows the changes carried out by us to execute the presented *web based* and *mobile* lab course. In Section 3 the hardware available to every participating group will be discussed. The consequences of the special structure of the Mobile Hardware Lab are discussed in Section 4. After this, a summary of the work done so far will be given.

2. ORGANISATION

Before the summer term 2002, the hardware labs taught by the Chair of Computer Architecture in Freiburg were equivalent to traditional or classic lab courses taught as part of the scientific education at most other universities. At the beginning of the term small groups were formed with three students in each group. These groups had to cope with the following tasks every week:

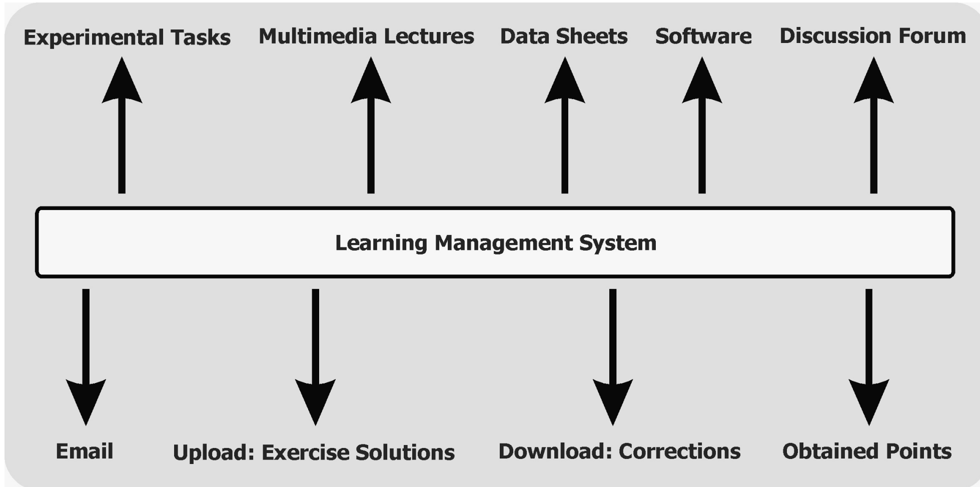

Figure 1. Learning Management System

1) **Preparations for the experiment:** The students receive the next task or problem which they are supposed to solve.
2) **Carrying out of the experiment:** The possible solutions are worked out and demonstrated by the participants or groups in the laboratory.
3) **After the experiment:** The experiences and results gained in the previous step are submitted and then corrected by the organizers.

Originally, the experiments were executed within the laboratory at specially equipped workstations in which every group sits next to a computer, oscilloscope, frequency generator, and various other measurement devices. The costs for such a workstation amount to several 1000 Euro. Mainly for space and reasons of cost a total of only 10 workstations (altogether for at most 30 participants) were equipped in this way.

To make the hardware lab accessible to more participants (particularly students of other universities), the following changes have been carried out since the summer term of 2002: the present lab course has been replaced by a mobile, completely *web based* lab course. The entire course is based on a *Learning Management System* especially tailored to the requirements of the hardware lab in combination with the corresponding hardware components.

The internet portal developed with CGI/PERL and HTML (outlined in Illustration 1) is a variant which is also used in a similar form in other lectures given by the Chair of Computer Architecture. The experiences learnt in these courses result in a comfortable and easy-to-use tool.

With the *Learning Management System* the participants are able to access all experimental tasks, software, documentation, data sheets, as well as the obtained points, corrections, and exercise solutions electronically. Various multimedia based lectures have been created additionally with a *Presentation Recording Tool* [8] and offer helpful information about the usage of the different software tools. For example, a complete VHDL course has been created by the organizers consisting of four multimedia lectures.

The provided experimental tasks are solved by the students or groups, and then handed in electronically over the *Learning Management System* with respect to given deadlines. After this, the solutions are judged by the organizers and then returned electronically. To accomplish this, the programs created by the students are executed and the program code is evaluated by the instructors. The instructors then include any correction and/or notes they feel are relevant with the program. The program and the instructors corrections are then put back into the *Learning Management System* so that the students can view their corrections and the solution. Access to the different parts of the internet portal are protected via student and group passwords.

To introduce and guarantee contact between the organizers and the students (besides voluntary tutorial hours) the so-called *presentations* have been introduced. This is achieved by making some groups present their solutions to the instructors every week instead of always submitting their results electronically. This gives the organizers the chance to get to know all the participating groups personally.

A discussion forum which serves as a knowledge base and makes the exchange of questions and notes possible is additionally offered through the web portal.

3. THE PICee++ SYSTEM

In this section an overview of the *PICee System* and the *PICee++ System* as well is given. The *PICee System* was developed and introduced by the *Elektor* journal and serves as a basis for all the lab experiments [1,5,9]. Represented in Figure 2, the so-called single board computer is based on the PIC16F84 Microchip processor. It is supplemented with input and output devices such as a keyboard, switches, LEDs, and a double-spaced LCD display, which are all directly connected with the corresponding I/O pins of the microprocessor.

Especially the straightforward architecture of the PIC16F84 processor [7] makes it very well suited for an undergraduate course. Some of the features are:

- RISC architecture
- 13 I/O pins with individual direction control
- only 35 single word instructions
- up to 10 MHz operating speed
- 8 Bit data bus
- 15 special function hardware registers
- 4 interrupt sources
- 68 Byte RAM
- 1 kWord program memory

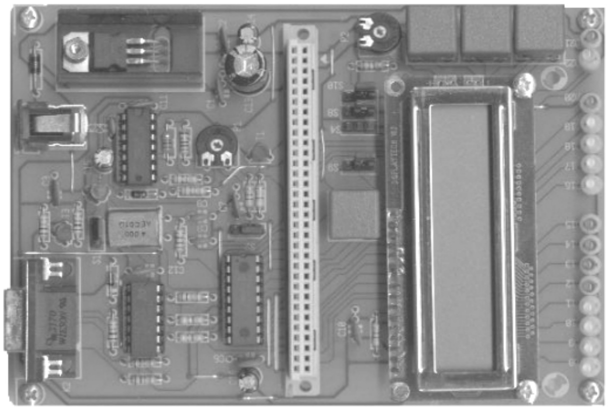

Figure 2. PICee System

The development of the programs, compiling, and then the simulation are all carried out with the software tool *Microchip MPLAB* [7]. The real programming process of the PIC16F84 processor is done with the so-called *IC Programmer* tool [6] using the integrated serial port of the *PICee System*.

With directly connected input and output devices (like for example the keyboard and the LCD display) complex experiments are possible and can be realised in short periods of time (topic block *Microprocessor Programming*).

To cover the complete spectrum of tasks performed in a classic hardware lab, the *PICee System* was extended with two extra boards (see Figures 3 and 4) to the so-called *PICee++ System* [9]. These two boards were designed by the Chair of Computer Architecture group and can be attached to the connector strip of the main *PICee* board (the connector strip is placed in the middle of the board, refer to Figure 2). All important signals of the PIC16F84 processor like Reset, VCC, or CLK are also available on the two extension modules (the corresponding pins are placed in the lower part of Figures 3 and 4).

The first extension board (Figure 3) consists of an Altera FPGA EPM7128SLC84-15 which can be directly programmed with the integrated parallel port using the *Altera MAX+PLUS II Baseline* software package [4]. As can be seen in Figure 3 all the I/O pins of the FPGA can be easily accessed using the corresponding pins on the board. With the use of small wires a connection to the connector strip can be made enabling connection between all components of the *PICee System* and the extension board. Using the *PICee++ System* all circuits developed in the topic block *Designing Combinational and Sequential Circuits* can be embedded in a *real* development environment.

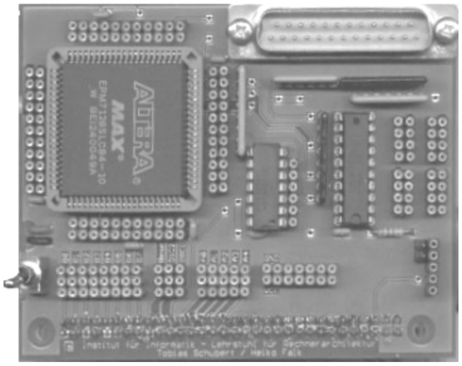

Figure 3. Extension Module I

The second extension module (Figure 4) corresponds to a freely configurable experimental board which is used in many technical courses to build up, control, and measure circuits with other devices (oscilloscope or frequency generator for example). The same applies when using the extension board to connect with the available I/O pins on the PIC16F84 processor to make a measuring device. This is done for example in the topic block *Fundamentals of Analog and Digital Electronics*.

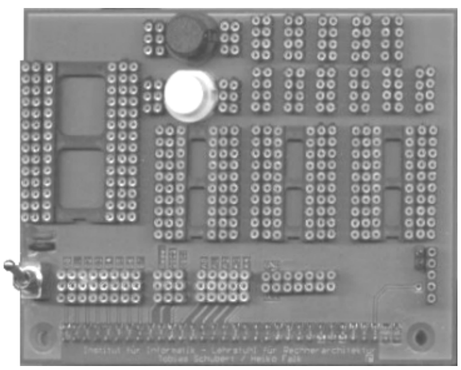

Figure 4. Extension Module II

In both cases the students not only have to design the circuit, but the corresponding wiring and various data interchange routines to be able to use one or more of the *PICee++ System's* components.

4. CONSEQUENCES OF A WEB BASED LAB

Revising established structures usually inherits severe implications. In the following we discuss pros and cons of our mobile course we observed so far, justified by means of qualitative and quantitative methods of evaluation:

Mobility
One great milestone is the opening of the practical course to remote participants and the rise of students – now only limited by the amount of provided *PICee++ Systems*, since space is no longer a topic: Currently more than 100 students (formerly 30) attend the course every year. However, we assume students have access to a PC. Thus, a mandatory course has to take into

account that e.g. social standings may hinder a student to attend due to the lack of this requirement. Fortunately – in particular in technical faculties – the percentage of students equipped with a computer is remarkably high (in our case 97%). Furthermore, many universities force concepts concerning notebook supplies for students based on e.g. rentals as is the case in our environment. Thus, we can guarantee full notebook supply.

Flexibility
Getting familiar with tools needed for laboratory work is an important aspect, usually handicapped due to narrow slots of laboratory access times. The Mobile Hardware Lab eliminates pressure of time. Moreover the gained flexibility yields the potential for more intense collaborations and efficient studies. Citation: "We ran *secondary* experiments just for curiosity". Evaluations confirmed: 95% of the students acclaim the opportunity for self-dependent timing and division of work within their group. 65% favour terns, the others proposed pairs instead. All students agreed that groups of more than 3 members would be "too clumsy". As aforementioned, group memberships are defined in the initial week of the term electronically and independent of the instructors by the students via the course *Learning Management System*: Hereby, students establish new virtual groups and wait for others joining them. Since exclusion lists are possible, approved teams can assure getting into the same group. If no exclusion is set, a student can join a group until it lists 3 members. Our applied method intends to copy real-life, i.e. our method lets groups emerge *naturall*y. As a benefit, the need for regrouping uncooperative teams turned out to be negligible. However, students with weak teamwork skills remain a problem. Thus, it has to be a major concern to encourage joint work.

Communication and Marking
The course's *Learning Management System* provides an essential component for the mobile course and all the students responded positive to it: 95% appraise electronic marking as "reasonable". Moreover, 92% of the students rate the benefit of forum discussions as "good". Nevertheless, however sophisticated virtual scenarios may be, a sacrifice of face-to-face meetings usually implies a decrease of verbal communication between students and instructors. This deficit implies additional problems in the particular context of practical courses: While students can prove their gained knowledge of *theoretical* courses via e.g. virtual exams taking place wherever suitable (provided that authenticity is guaranteed by a supervisor), for *practical* courses the instructor's job is not restricted to check knowledge, but support students in their comprehension of how to *build up* things: thus, he has to supervise their *behaviour and actions* in order to survey manual skills, which seems impossible in a virtual environment. To nevertheless facilitate a comparable level of supervision – in addition to communication standards like emails and forum discussions – the *presentations* were introduced: hereby, some of the groups are chosen at random every week and are forced to present their solutions face-to-face to the instructors. By doing so the instructors largely improve their chances to identify a participant's handicaps or potentials and thus render better assistance.

5. CONCLUSION

With the *Mobile Hardware Lab* we introduced a completely place and time unbounded form of a classical course. The *Learning Management System* makes electronic upload and download of the experimental results and corrections possible while providing all necessary information. Furthermore the contact between organizers and students is maintained by email, a discussion forum, presentations, and a voluntary tutorial hour. The ability for distributed teamwork – which is becoming more and more important in business – is also promoted.

Based on the *PICee++ System*, a fully equipped hardware system is at every participating group's complete disposal transferring a feeling of the laboratory presence to the student.

Evaluations confirmed manifold surplus values by using our concept. However, the outstanding characteristic in comparison with other virtually executed practical courses is the fact that experiments are neither software simulated nor remote controlled via web interfaces, but built and executed on *real hardware at hand* which transfers the idea and ambience of laboratory experiments into a truly mobile environment.

Lastly, the universal configuration of the *Learning Management System* offers the chance to also apply the introduced mobile and web based platform to other courses with far more than 100 students.

6. REFERENCES

[1] The PICee++ System. http://ira.informatik.uni-freiburg.de/~schubert

[2] Hardware Lab 2002. http://ira.informatik.uni-freiburg.de/teaching/hwprak-2002/html/main.de.html

[3] Hardware Lab 2003. http://ira.informatik.uni-freiburg.de/teaching/hwprak-2003/html/main.de.html

[4] Altera Corporation. http://www.altera.com

[5] Elektor. http://www.elektor.de

[6] IC-Programmer. http://www.ic-prog.com

[7] Microchip Technology Inc. http://www.microchip.com

[8] TechSmith Corporation. http://www.techsmith.com

[9] PICee – Single Board µComputer. http://www.lgs-hanau.de/docs/picee/picee.php