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 characterized 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 realize 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.
The Mobile Hardware Lab was already taught in the summer term of 2002 and is now offered for the first time in a completely web based form for the next term.

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

1 INTRODUCTION

The Hardware Lab offered by the Institute of Computer Science at Albert-Ludwigs-University of Freiburg is a manditory 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* [8, 18] 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 student 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 programms like a running LED light.

Designing Combinatorial 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 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

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cuircuits are built using discrete logic gates the students learn how to simulate and implement them completely in software just like modern computer aided design. After the software stage is complete, the circuits will be realized 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 - for example, a resistor and capacitor measurement device - 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 addtional 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 complications arising, and 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:

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 item 2 are submitted and then corrected by the organizers.

Originally, 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. Consequencely, 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 learned 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 additionally been created with a *Presentation Recording Tool* [13] 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 relavant 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 solution to the instructors every week in-

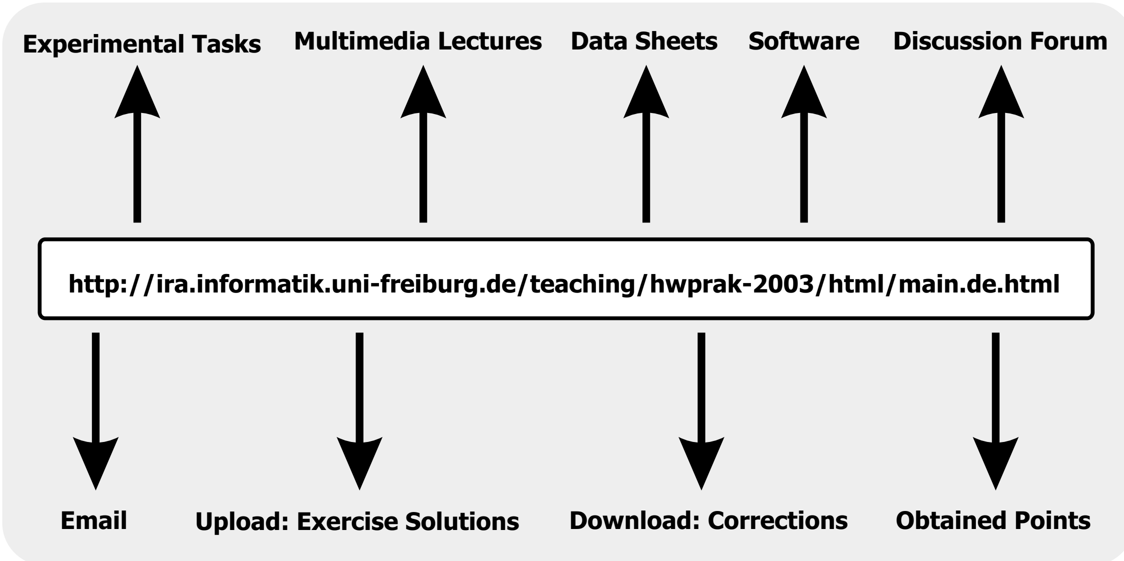

Figure 1. The Learning Management System

stead 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 [2, 8, 18]. 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.

This processor has many nice features and a simple straightforward architecture [12] that makes it very well suited for a basic course. Some of the features the PIC16F84 Microchip offers are:

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

The development of the programs, compiling, and then the simulation is all carried out with the freely available software tool *Microchip MPLAB* [12]. The real programming process of the PIC16F84 processor is done with the software tool *IC Programmer* [11] using the integrated serial port of the *PICee System*.

With directly connected input and output devices (e.g. keyboard, switches, display) complex experiments are possible and can be realized 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* [2, 4]. These two boards were designed by the Chair of Computer Architecture Group and can be attached to the connector strip in the main *PICee* board as shown in Figure 2. All the important signals of the PIC16F84 processor like Reset, VCC or CLK are also available on the two extension modules (the corresponding pins can be

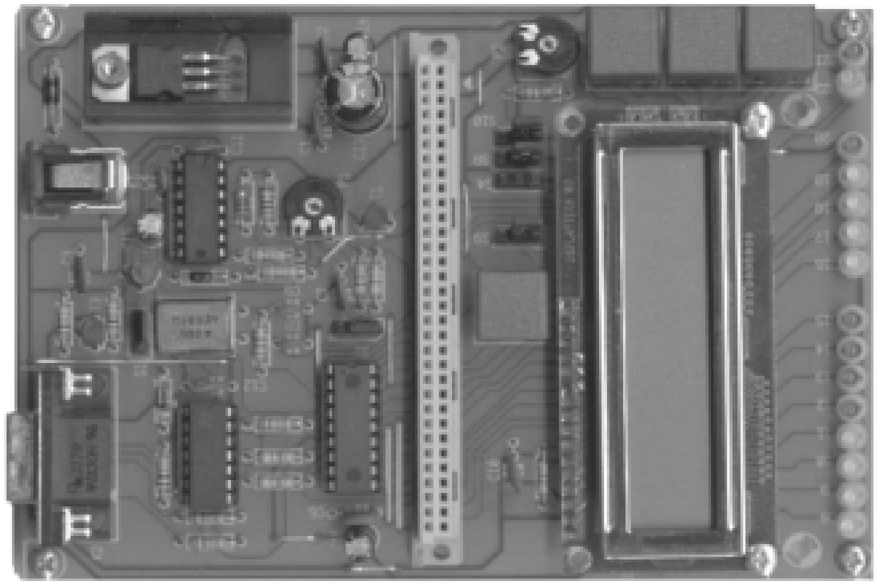

Figure 2. The PICee System

seen in the lower part of Figure 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 freely available software *Altera MAX+PLUS II Baseline* [7]. 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 Combinatorial and Sequential Circuits* can be embedded in a 'real' development environment.

The second extension module (Figure 4) corresponds to a freely configurable experiment 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*.

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* components.

4 CONSEQUENCES OF A WEB BASED LAB

We shortly discuss the consequences of the mobile course structure arising for both, the organizers and the students. One of the advantages is that the groups now have possibility to get familiar with the tools and components without any pressure with respect to time. Self-initiative is also favoured through this style of lab course by allowing the students to run secondary experiments which is usually handled very restrictive in a classical lab because of the narrow time frame in which the main solutions must be achieved.

Another great milestone is the rise of potential participants. The maximum number is only restricted now by the sets of available hardware components. In contrast to classic hardware labs the hardware used is very cheap with about 200 Euro per *PICee++ System*. Laboratory space moreover is no longer a mandatory requirement.

However, one disadvantage is that the students no longer have experience with the *classic* instruments like oscilloscope or frequency generator. Some of this is compensated for with appropriate experiments in combination with the introduced extension modules (capacitor measurement device for example).

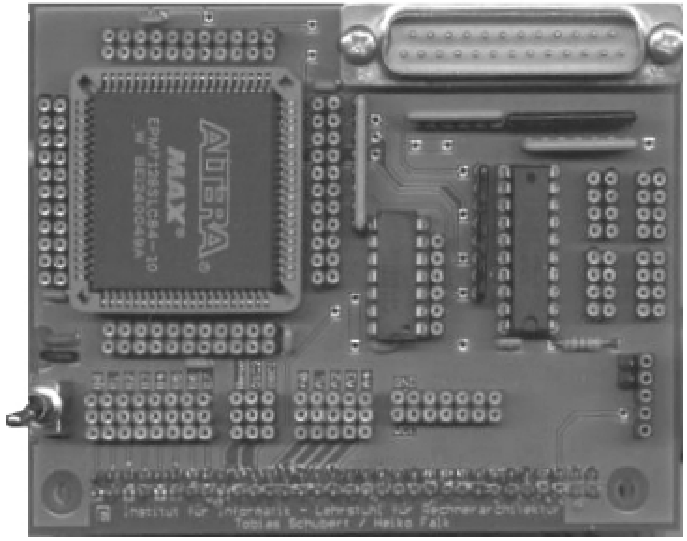

Figure 3. The first extension board

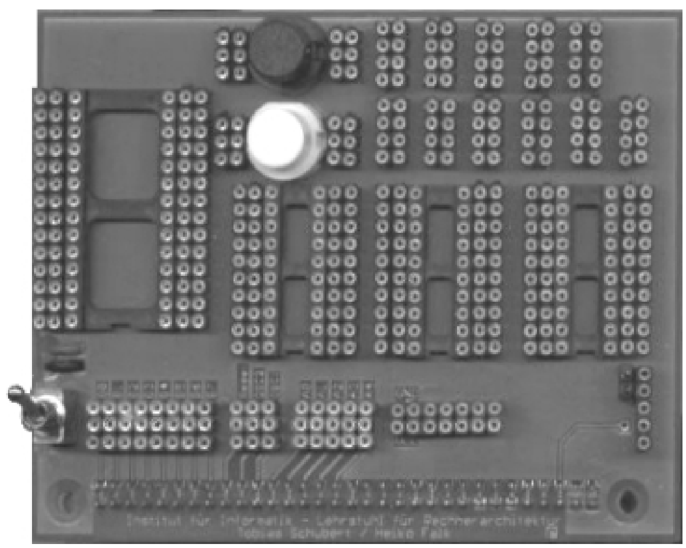

Figure 4. The second extension board

A certain loss in contact between students and organizers which is caused by the electronic upload and download of the experimental results and the online discussion forum has to be accepted. For this reason it seems to be difficult for the organizers to distuingish between *good* and *bad* participants or groups. To avoid this, the *presentations* indicated in Section 2 and the voluntary tutorial hour were created.

The introduced mobile and web based hardware lab is integrated into a whole number of related projects at the University of Freiburg and other universities as well [1, 5, 6, 9, 10, 14, 15, 16, 17]. The outstanding characteristic of this lab in comparison with other virtually executed labs is the fact that the experiments are not only simulated using software or special web interfaces, but actually being executed on *real* hardware which transfers the idea of *classic* laboratory experiments into a mobile web-based environment.

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 mail, a discussion forum, presentations, and a voluntary tutorial hour. The ability for distributed teamwork is also promoted which is becoming more and more important in business.

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.

An evaluation of the hardware lab executed in the summer term of 2002 has confirmed our procedure. Particularly the multimedia lectures on the different topic blocks as well as the lack of time constraints has discovered a great resonance with the students.

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 students.

Acknowledgement

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