Flexible Teaching of Reconfigurable Logic Design
Including a Remote Cloud Lab

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ABSTRACT

Reconfigurable logic systems often consist of a mix of software and hardware requiring design experience from both domains. To reduce the challenge of learning reconfigurable hardware design, we have developed a framework for flexible learning through Internet. Learning takes place using videos, lecture slides, quizzes and lab assignments in addition to regular text books. Lab assignments consist of a physical lab setup accessible through a web browser using the Xilinx Vivado design tool with Xilinx Zynq®-7000. In this paper, we outline the developed material and student feedback after using it.

KEYWORDS
E-Learning Hardware, E-learning in Electrical and Information Engineering, Remote Lab, Reconfigurable Logic, Field Programmable Gate Array technology (FPGA), Web-based Learning, Flexible Learning

1 INTRODUCTION

The introduction of Massively Open Online Courses (MOOCs) on the Internet has in recent years resulted in flexible learning becoming more widespread. Almost any topic can now be learnt from anywhere and at any time. However, receiving knowledge is not sufficient to master a topic. This is particularly true in the field of embedded system development. Thus, it is necessary to work with practical lab assignments to acquire knowledge and skills in hardware design. Thus, we have in recent years undertaken development of teaching resources for hardware design. Our goal is to enable students to both gain knowledge and to do practical work on FPGA development boards through a web browser. The system and our experiences are reported in this paper.

Field Programmable Gate Array technology (FPGA) is the technology used in reconfigurable logic designs. Providing students with such design knowledge and skills are traditionally undertaken through lectures and assignment work at a lab. Much work has been published related to experiences being made on such teaching. Mitsui et al. have presented results from a JPEG application on an Altera NIOS2 development kit [1]. Kumar et al. have developed a platform allowing students to explore both the hardware and software issues associated with real-time and embedded systems [2]. Other alternatives include multi-core systems [3] [4]. However, the concept of remote labs accessible through Internet is a rather new concept [5]. Thus, we are aware of only a few platforms that have been developed for learning digital logic design through a web browser. Drutarovsky et al. provided a measurement equipment framework for testing FPGA designs [6]. This system featured logic analyzer, digital storage oscilloscope and a programmable pattern generator. The students interacted remotely to configure the target FPGA board, and to visualize the measured signals. A remote Altera FPGA lab to introduce digital system design to students is presented in [7]. It is reported as a single user system with latency challenges. Another platform targeted to teaching is the VICILOGIC platform. It provides access to learning resources and a remote FPGA lab [8][9], applying a web-based RemoteFPGA lab concept [10]. Our platform is distinguished from this system by implementing the design using HDL only (rather than also with schematic capture) and by focusing on only
using the FPGA vendors design platform rather than a custom tool. Another platform has been developed in the eDiViDe project [11] where a number of different design labs were made available [12]. eDiViDe presents practical lab setups where one development board is connected to each physical setup, for example controlling the traffic lights in an intersection. These advanced setups are interesting for remote teaching labs, as it is not something a student can easily assemble at home. However, eDiViDe had a narrower scope compared to our work. For example, we have developed teaching material available together with the lab platform.

Further, our assignments build on each other making a natural progression rather than being a number of independent tasks. Lastly, eDiViDe used the older ISE (Integrated Synthesis Environment) design tool, while we are now using Xilinx Vivado with the Xilinx Zynq®-7000 device.

This paper outlines the developed comprehensive teaching resources and our experience in having students using them. The remainder of this paper is organized as follows; the next section introduces the various teaching resources and the infrastructure which we have been implementing. In section 3, the student experiences are presented. Finally, conclusions are included in section 4.

2 TEACHING RESOURCES ACCESSED THROUGH THE WEB

Our work makes it possible for students – in addition to learning in traditional lectures in courses, to have alternative ways of learning the syllabus as well. Further, in addition to being present in the regular lab hours, the students can access a remote lab at any time, see Fig. 1.

![Figure 1. The remote lab setup including a frame for holding the video camera.](image1.png)

The developed material is included in an elementary course (INF3430, see [13]) and in a more advanced course (INF5430, see [14]), all provided in English language. The elementary course intended for undergraduate studies includes introduction to digital design...
including VHDL, FPGA and system-on-chip design. The advanced course targeting graduate studies covers a range of digital hardware system topics like digital arithmetic design, dynamic partial reconfiguration of FPGA, high level synthesis and functional verification. Our intention is that not only students registered at our own university would be taking the courses but also remotely located students and company employees. That is, study the full course remotely including solving lab assignments. There is a potential for applying the framework for collecting input on performances of each student. Thus, flexible teaching material opens up for the Education Based on Competencies (EBC) methodology [15] where the student contribution and achievements during the semester in lab work are possible to be accounted for in the final grade. However, we have not yet implemented this, and the grade they get is given by a final traditional exam.

Learning of anything, from anywhere and at any time is a recent international trend which also can have a positive impact on traditional lectures. That is, regular lectures are still relevant but can be improved by being complemented with flexible teaching resources both in addition to and by using them as a part of the lectures. This is relevant for the flipped classroom concept which is characterized by increased interaction between students and the lecturer [16]. The aim is to create an environment where the students participate more actively compared to the traditional role as mostly passive receivers in regular lectures. This requires creativity and novelty in how the syllabus is being presented and taught.

Below, we describe the developed resources consisting of videos, quizzes and the remote lab.

2.1 MOOC Platform Selection

We have evaluated multiple available MOOC platforms. The edX platform was selected for the following reasons: It is widely used internationally by leading universities\(^1\), and there is no vendor lock in use. It is an open-source framework, and one may host it oneself. However, a self-hosted installation of edX, naturally does not give the same publicity as making the course available at edx.com. In contrast to using a regular course web page, edX includes functionality for quizzes and follow up of student assignments for the course manager. We have used the platform to give students in the elementary course access to lecture slides, videos, quizzes and lab assignments, see Fig. 2 for the layout and [13] for having access.

2.2 Quizzes

We provide quizzes to most of the syllabus in the elementary course to improve the learning outcome when videos are watched or slides are studied on your own. They provide a helpful supplement to the syllabus in the given text books, since they allow the student to become aware of their level of understanding. We have for a number of years used multiple choice questions for the regular course exam. Now we have assembled these into quizzes provided by the edX platform. For each student registered for the course, the course manager can see what tasks each student has been undertaking. Further, one may see details on which of them that have been answered correctly and wrongly, respectively.

2.3 Videos

We have made videos to some parts of the syllabus and have prioritized parts where we expected oral explanation of the lecture slides would be most needed for an easier understanding. They have both been shown in regular lectures and been made available on the course website or in edX. Further, related multiple choice tests for each video improve the learning outcome when videos are watched on your own. We focused on making the videos according to what we found were the guidelines many applied for making MOOC videos:

- Keep the videos short and normally not longer than 10 minutes.

\(^1\) Created by Massachusetts Institute of Technology and Harvard University in 2012.
• The speaker should keep a proper speed so those somewhat familiar with the topic don’t find the progress too slow. Those finding the progress too fast can easily replay parts of the video.

• Picture of the speaker is not needed in the recording since that can often be distracting and take attention away from what is to be learnt.

The videos were made using the Camtasia Studio tool and a high quality microphone. They consisted of screen capture of lecture slides that earlier had been used in lectures. The tool allows for editing a recording and provides various useful ways of adding annotation after the recording is finished to make it easier for a student to know where to look at the screen. The finished videos were made in mp4 format.

2.4 Remote lab platform

The remote lab setup is implemented as shown in Fig. 3. A student connects through a web interface and is given access through a central server. A framework of design files are first downloaded from edX. The “missing” parts of the design are added to the design locally on the student’s computer where also any simulation takes place.

After the implementation is finished locally, the design files are uploaded to the remote lab through the central server. The design is assigned to one of the three local servers where it immediately is being compiled. The user can follow this process through the Xilinx Vivado console window in the web interface, see Fig. 4. If the compilation ends without any errors, it is uploaded to the assigned FPGA board, and the student can observe the behaviour through the video camera, see Fig. 5. The web interface is implemented using Django which is a high-level Python Web framework. Three local servers (Dell OptiPlex 7020 MT desktop mini-towers with i7-4790 core) allow for up to three students observing their system running at the same time. However, up to 10 users are allowed concurrently to be interacting with and compiling on each local server. Thus, the capacity would be 30 students in total working on the system. The coordination of the users and their tasks are undertaken with Celery which allows for distributed task queues. When granted access to run a design on a board, the behaviour is observed through a MicroSoft LifeCam Studio camera (model 1425), see Fig. 1.

The interaction between the student and the remote lab is as follows:

1. The student selects a lab assignment and gets files downloaded to own computer.
2. The student implements the solution of the assignment locally using the Xilinx WebPack and verifies the design with simulation using the Modelsim PE Student Edition (or the Xilinx WebPack internal simulator).
3. The student logs in to the remote lab and files including the student solution are uploaded to the local server (tar.gz format).
4. The compilation is undertaken on the local server, and an FPGA configuration file is generated.
5. If the design compiles without errors, a time slot is allocated for testing the design on the FPGA-board together with observing the performance through the camera.

As seen in the lower part of Fig. 4, the user has access to hardware switches and

Figure 3. Remote lab architecture overview.
Figure 4. Remote lab board (ZedBoard) with accessory boards for 7-segment display and remote switch controls connected as seen through the remote lab web interface.

Pushbuttons through the web interface. These are used in various ways in the lab exercises to control the realized systems. The live video stream of the camera is shown to the student at 30 frames per second using HTML5 video. Low latency is important as the user interacts with the FPGA board through virtual switches and pushbuttons while watching the board at the same time through the video camera.

Our implementation has a latency of less than 250ms from the time when the student changes an input to the student can see the change in the live video stream. This means that the delay is noticeable, but it is not an obstacle for the student. For example, it takes the student more time to move the mouse and to click a button than it takes to display the change. The low latency is achieved through the following optimizations:

- In the video compression settings, we make every video frame a keyframe rather than the default of only every 15 frame. Since decoding is only undertaken for every key frame, we obtain less delay due to more frequent decoding.
- Rather than buffering video (which is normally beneficial when watching multimedia content), we drop delayed frames.

The development board used is an AVNET/DIGILENT ZedBoard (Zynq™ Evaluation and Development, see www.zedboard.org). The board and accessories are mounted on a plate contained in a frame also holding the video camera and possible light, as seen in Fig. 1. Currently only assignments for the elementary course have been provided in the remote lab. Thus, future work includes also providing assignments for the advanced course in the remote lab.

### 2.4.1 Switch Controlling Card

One challenge with controlling equipment in a lab is that there are no physical hands available to turn possible switches on the design board. Therefore, we have designed a switch emulating board that makes a user remotely able to turn switches on and off, see Fig. 4 (plug-in board on the left) and Fig. 5.

It interfaces to a PC via USB and uses the FTDI Chip USB to UART interface FT230XS. This enables the PC to communicate with the USB using a standard asynchronous serial protocol using Python scripts.

The PC communicates with an onboard ARM Microcontroller, STM32L152 from STMicroelectronics. A program inside the microcontroller converts the received serial data into parallel format and sends it to the three double PMOD connectors on the ZedBoard. The status of each bit is also shown on the 24 LEDs on the board. In this way we can watch the input pattern from a remote
location through the video camera. This complements with the switch settings also being shown graphically in the web interface where switches can be in on or off position, see Fig. 4.

2.4.2 Seven Segment Board

The Zedboard has an advanced OLED display module available. However, we have earlier had good experience in using the traditional and much simpler 7-segment display in design assignments. Since this is not available on the ZedBoard, we made a plug-in board with four 7-segments, see Fig. 4 and Fig. 6.

2.5 Lab Assignments

The assignments start at a very basic level and progress through more complex designs:

1. Learn the Xilinx Vivado design flow through some simple design examples. A 2-4 decoder is designed, difference between signals and variables in VHDL is exemplified, and the creation of shift registers by the means of component instantiation is to be undertaken.

2. The second assignment consists of the following:
   a. Learning about subprograms and libraries in VHDL
   b. Learning how to create hardware descriptions in VHDL, and to create test benches to simulate them.

3. This assignment is targeted at teaching state machine design including with ASM flow diagram before VHDL code is written. The task is to control a pointer on an actuator output with the help of a shaft encoder for position measurement, as seen in the lower part of the video image in Fig. 4. This is relevant since the course is a part of a robotics study program at the university.

4. The final assignment consists of the implementation of a system-on-chip system using the Zynq processor on the board.
3 EXPERIENCES FROM USING THE TEACHING FRAMEWORK

Developing a flexible teaching framework including a remote lab is an extensive task where priorities have to be made. We have had regular meetings in the project with relevant people where all aspects of the flexible teaching material have been discussed, including academic content, teaching platform, technical solution and remote lab tasks, etc.

The developed teaching resources have been gradually introduced into the regular courses as they have become ready to be applied. This has allowed us to assess them before they are being used at a larger scale including for remote students not present at the university. This section summarizes experiences we have made including feedback from students.

The conducted surveys have been important to get feedback on how helpful and user friendly the developed teaching material is and how it can be improved. It was undertaken in 2016 in the last lecture of the elementary course (INF3430) and the advanced course (INF5430), respectively. We have collected feedbacks on their experience in using the different teaching resources (only videos for INF5430).

As seen in Fig. 7, the students find the edX platform easy to use, confirming the user friendliness of the platform.

The platform is accessed slightly more often at the university compared to at home, see Fig. 8.

The main feedback on the use of videos was that the learning outcome has been at or above average, see Fig. 9. The advantage of them is that one can go back and see them again to better understand what is being presented. Another positive thing being mentioned is that they can be seen anywhere and at any time. Moreover, their format of being more focused and concentrated than lectures are appreciated. A large majority of the respondents appreciate their relatively short length, see Fig. 10.
This confirms others experience which we took into account when making the videos (as mentioned in section 2.3). That is, try avoiding videos longer than 10 minutes. However, the compactness of the videos was by a few mentioned as a challenge, who indicated that a slower progress would have been desirable. Other challenges were the lack of opportunity to ask questions.

Course lecturers have appreciated the use of videos in regular lectures in combination with the ordinary instruction. Thus, the need then for teaching preparation becomes reduced, but they are still able to comment on the content of the videos and answer questions students may have. Many of the students have watched the videos both in lectures and on the web page, see Fig. 11.

Multiple choice questions are available both after videos and related to available lecture slides. Students appreciate the questions, since they mention that they are helpful for learning and to determine which parts of the curriculum they may have misunderstood. However, evaluations show that quizzes are mostly used for preparation right before the exam (rather than during the semester).

The implemented remote lab was available in INF3430 autumn 2016, however, we saw a limited interest in starting to use it. Students express the following reasons for why not using the remote lab:

- Good access to the physical lab.
- Lab assistants supervising in the physical lab (an active discussion forum or a chat function related to the remote lab could compensate some for that).

We have provided information about the lab to other relevant teaching institutions in Norway through e-mail and presentation at a national FPGA conference. Thus, we expect the platform would get more in use in the future both at our own institution and other universities. The platform has shown to have a stable performance providing uninterrupted service.

4 CONCLUSION

The paper has been concerned with outlining the design of new flexible teaching resources for learning reconfigurable logical design from anywhere and at anytime. It consists of videos, lecture slides, quizzes and lab assignments with the latter undertaken through a physical lab setup accessible through a web browser. The collected experience from students applying the teaching resources indicates that they are appreciated and lead to increased and more effective learning. Future work includes having more students enrolled in the courses and continue collecting feedback regarding user experience. Further, extending the teaching resources are also relevant.

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REFERENCES


