Unified Learning Platform for Embedded Engineering

Ivan Kastelan, Nikola Teslic and Miodrag Temerinac

Abstract This paper presents the hardware and software architecture of a unified embedded engineering learning platform. The platform consists of a base board with FPGA and extension boards with microprocessors. The goal of the platform is to support laboratory exercises in the entire embedded engineering curriculum, reducing the overhead in giving tutorials to students and concentrating on the core material from each course. The platform has been evaluated with students and teachers in courses of the computer engineering curriculum at Faculty of Technical Sciences. The paper gives impressions from the pilot generation of students using the platform.

Keywords Embedded engineering · Learning platform · Education

1 Introduction

The success of the education of future engineers of electrical engineering and computer science largely depends on the quality of laboratory work during their studies. Through laboratory work it is possible to enhance the role of students from passive listeners to active participants, which further encourages them to participate in the process of learning [1]. Knowledge gained through practical experience in the laboratory is shown as deeper and more permanent.

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Industry recognizes the growing need for highly educated personnel in the field of electrical engineering, computer engineering technology and embedded systems [2–5]. In response, many electrical engineering programs increasingly put an emphasis on learning in the field of embedded systems, mainly relying on the increasing number of laboratory-based courses that largely follow the principle of so-called active learning. The dynamics needed to satisfy the needs of the industry places teachers responsible for the design of laboratory environments required to conduct courses under considerable pressure. The situation is further complicated by the fact that, due to the dynamic development of the field, laboratory environment needs to be regularly renewed. Finally, it is desirable that the program of instruction uses different and often inconsistent laboratory environments and learning platforms.

Quality and efficiency of laboratory work in the field suffers due to the additional time and effort required to acquaint students with the hardware platforms and software tools for each course. Because of this, especially at the beginning of the course, it is difficult for students to divert attention from the used tools to the fundamental principles that constitute the main contribution of the course.

Engineering education is one of the most dynamic types of education because of new technologies in the field which occur rapidly. Therefore, it is necessary to constantly be up to date with the development of new technologies and students need to learn using the latest teaching and laboratory resources.

To overcome the above problems, the Faculty of Technical Sciences in cooperation with another 8 institutions from 7 European countries developed a universal platform for laboratory exercises in the field of embedded computer systems—E2LP platform [6]. It is a platform that supports laboratory work in the majority of cases required for the training of engineers in this field and thereby accelerates their knowledge by reducing unnecessary consumption of time to become familiar with a variety of platforms. Wide range of courses that this platform supports is enabled by the development of extension boards that connect to the base board.

Based on previous observations and industrial experience in the field of embedded systems, a unified modular platform for learning was developed. The platform aimed to increase the efficiency of lab-based courses. It is based on the generation of field programmable gate array (FPGA) manufactured by Xilinx—Spartan-6. The platform is designed to cover all aspects of embedded engineering including: (1) the design of digital systems, (2) the design of computer systems, (3) signal processing, (4) computer networks and interfaces, (5) system integration [7]. Maximizing the efficiency of lab-based courses is based on the idea of using the implemented unified platform throughout the entire curriculum. The main contribution is the effective education of future engineers capable to face the current challenges in the field of embedded engineering and their applications in real time. Software for the platform was developed with aims to help students use the platform more easily and inform the students about the platform operation at a given moment (the value of the signals, clock frequency, etc.).

This paper describes the basic elements of the E2LP platform:

- Base board with FPGA,
- Extension boards based on digital signal processor (DSP) and ARM processors and
- Software for the platform.

This paper is organized as follows: Sect. 2 presents the architecture of E2LP base board. Section 3 describes extension boards. Software is presented in Sect. 4, while Sect. 5 gives first impressions from the pilot generation using the platform. Section 6 gives concluding remarks and plans for future improvements.

2 E2LP Base Board

The E2LP Base Board is based on an FPGA in the Xilinx Spartan-6 family. In conjunction with the Xilinx ISE and XPS programming environments, it is a complete solution for the design of digital and computer systems with FPGA components (Fig. 1).

The aforementioned Spartan-6 FPGA integrated circuit is surrounded by a set of peripherals that can be used to generate complex systems. Figure 2 shows a block diagram of the development board with all available peripherals and connections between individual components marked.

The E2LP Base Board performs the following functions:

- based on FPGA, provides the central point of the E2LP platform on which all other parts are connected;
- supplies power for the whole E2LP platform;
- controls programming the FPGA and central processing units (CPUs) on extension boards;
- provides a basic user interface;
- provides storage, multimedia and communication interfaces for the platform;
- provides the platform for digital system design;
- provides test points for debugging.

The key building modules of the E2LP Base Board (Fig. 2) are:

- Xilinx Spartan-6 FPGA,
- ARM-based control processor,
- Mezzanine connector to extension board (Xilinx FMC LPC standard),
- DDR2, flash and multimedia card memory,
- user interface (8 switches, 6 buttons, 8 LEDs, alphanumeric LCD screen),
- snapwire connector,
- CVBS video encoder and decoder,
- video output (VGA, HDMI),
- audio sub-system,
- communication interfaces (USB, Ethernet, RS232 and Infra-red).

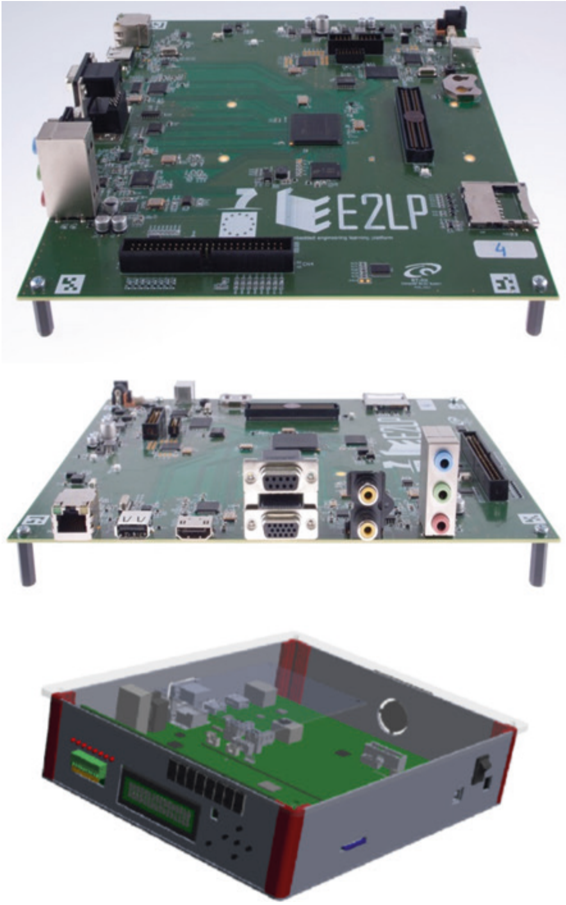

Fig. 1 E2LP Base Board top view (*up*), side view with some of the multimedia and communication interfaces connected to FPGA (*middle*) and 3D view (*bottom*)

The E2LP Base Board, as presented in this paper, together with its extension boards, is working in fully satisfying the main requirement of the E2LP platform—to be used in the complete embedded engineering curriculum and significantly reduce the overhead in engineering education. Implementation of the extension boards whose mechanical requirements are dependent on the Base Board will be explained in the next section.

FPGA component can be configured directly using the Joint Test Action Group (JTAG) coupling system, or indirectly using a dedicated flash memory on board. Flash component that is on the board gives the possibility to use up to four different revisions of the code for FPGA configuration. Personal computer (PC) connects via the appropriate cable (e.g. Xilinx Parallel Cable IV or Xilinx Platform Cable USB) for programming via JTAG coupling system in both cases: for direct FPGA configuration and for programming flash memory.

Due to the high cost of Xilinx's equipment for FPGA configuration via JTAG interface, a custom configuration via USB interface was developed for the E2LP

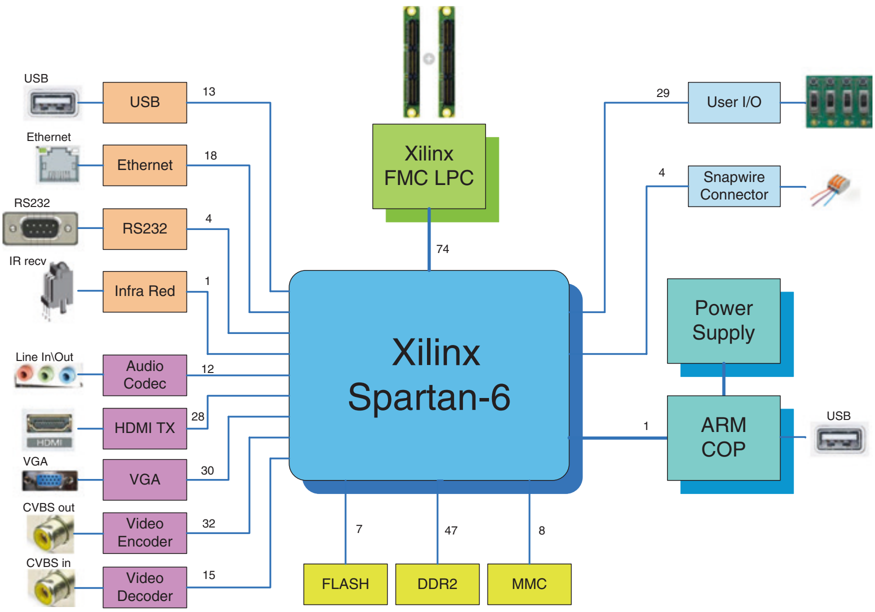

Fig. 2 Architecture of E2LP Base Board

platform. This innovative way of configuration is using a standard USB cable and is supported by specially developed software for E2LP platform. The custom method of FPGA configuration can bring significant savings to potential users, keeping in mind the price of standard solutions for programming (aforementioned configuration cables).

Complex programmable logic device (CPLD) is used for the selection of one of the three options of FPGA configuration. The presence of extension boards, as well as the desire of the ARM on Base Board to program the FPGA, is managed by the CPLD integrated circuit which can be configured in one of three configurations shown in Fig. 3:

1. Chain of FPGA, CPLD and Flash—configuration is performed via the JTAG Platform Cable.
2. Chain of FPGA, CPLD, Flash and ARM—ARM CPU is used to configure FPGA.
3. Chain of FPGA, CPLD, Flash, ARM and extension board—extension board is attached and JTAG-configurable parts can be configured on it.

Bearing in mind the need for constant improvement of the laboratory environment, providing an elegant way to extend the functionality of the platform was taken into consideration. In order to achieve that, connection with extension boards is implemented using the connector with small capacitance and high speed to ensure signal integrity even at high speeds of data transfer.

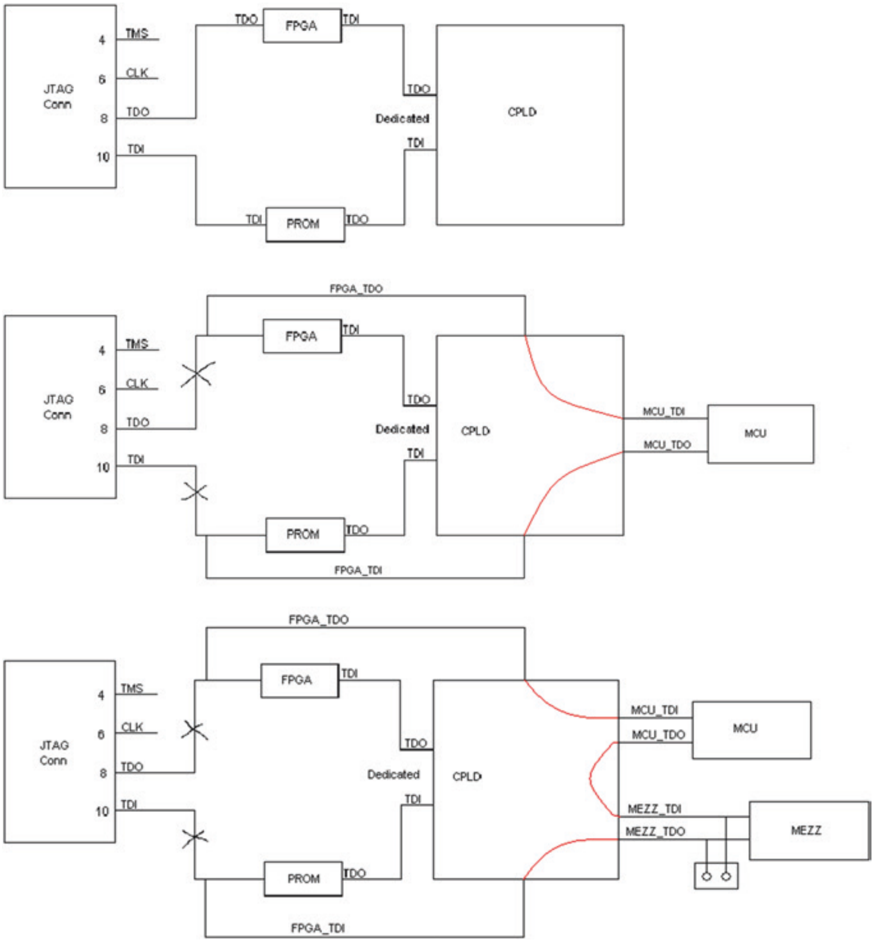

Fig. 3 Three versions of JTAG chain for FPGA configuration: using the Platform Cable (*upper*), using the USB connection to PC application (*middle*) and using USB with extension board support (*lower*)

In order to make the solution as general as possible, Xilinx FMC LPC connector standard was used. This connector provides 80 lines connected to the FPGA pins, of which 68 are general purpose input/outputs through which the indirect access to all peripherals on the board is enabled. In addition, the connector has access to the JTAG chain, I2C bus and user-programmable generators that allow the synthesis of clock signals in a wide frequency range.

The next section describes the implemented extension boards which connect to the E2LP Base Board via the FMC LPC interface.

3 Extension Boards

Three extension boards were implemented for the E2LP Base Board:

- Extension board based on ARMADA processor
- Extension board based on ARM LPC processor
- Proto-board extension

3.1 ARMADA Extension Board

One of the extension boards of the E2LP platform was designed to support laboratory exercises in the field of embedded computer systems based on the Marvell processor 88DE3108, known as ARMADA 1500. This processor is connected to the RAM memory in the form of two DDR3 modules with a capacity of 4 Gb (256 M $\times$ 16), i.e. 8 Gb in total. The modules are connected to the so-called “fly by” topology.

The extension board based on Marvell ARMADA 1500 has the following functions:

- based on ARM processor, provides the extension to the E2LP platform suitable for highly sophisticated signal processing and execution of real-time software;
- connects to the E2LP base board via Mezzanine connection;
- connects to the exterior with USB, LAN and HDMI interfaces;
- provides the extension to the E2LP platform suitable for implementing laboratory exercises in the field of digital signal processing, real-time system software, computer networks and system integration.
- provides test points for debugging.

Two HDMI interfaces allow connecting devices and displaying images on monitors and/or TV. To achieve an elegant way of extending the functionality of the platform, expansion ports are implemented using Xilinx FMC connector with small capacitance and large speed, in order to ensure signal integrity even at high speeds of data transfer.

The block diagram (Fig. 4) gives a high level overview of the E2LP extension board based on Marvell ARMADA 1500 processor.

ARMADA extension board is managed by Android operating system. It is chosen due to its popularity as it is recording a growing presence in the market of mobile devices. It is estimated that Android OS is currently used by hundreds of millions of mobile devices around the world. This board uses version 4.2.2 (Jelly Bean) with built-in support for Google TV (ver. 82210). Source code for Android is available under the “free and open” license for use. Android SDK allows students to make application through its applicative interface (API) as well as the necessary tools for developing Android applications in the Java programming language.

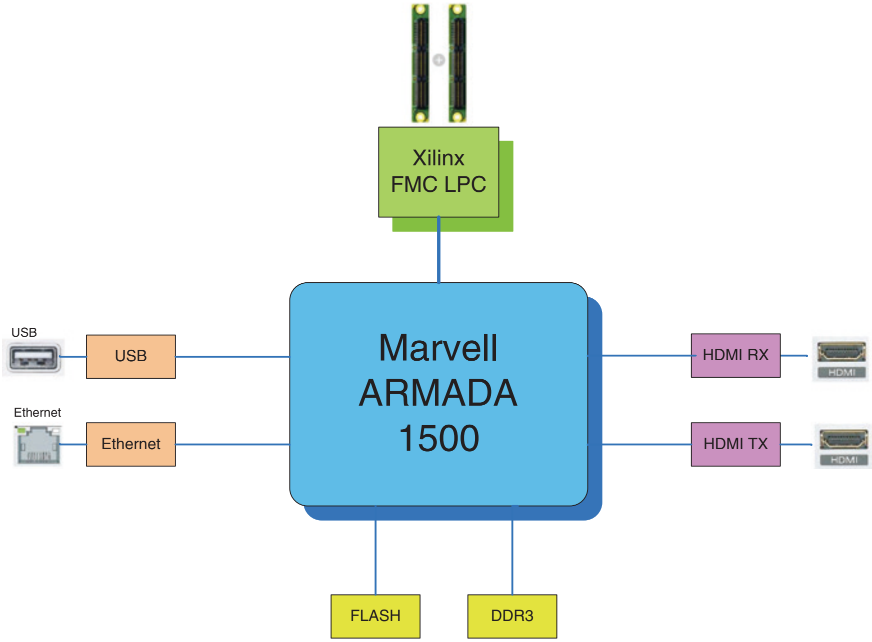

Fig. 4 E2LP extension board with ARMADA 1500 processor

This extension board allows implementation of the laboratory exercises in the following subject categories:

- 1-D digital signal processing
- 2-D digital signal processing
- computer networks and communications
- system integration
- system software
- Android development

The extension board can use all the resources from the E2LP Base Board and in addition to that, it can use its own USB, HDMI, LAN, Flash and DDR3. ARMADA can be programmed via JTAG interface through the Base Board and connected to PC for debugging and execution.

Also, E2LP extension board based on Marvell ARMADA 1500 can be used independent. It has possibility to be powered externally through JST's header 1×4 2 mm vertical connector (12 and 3.3 V voltage level is needed).

3.2 NXP LPC ARM Extension Board

In order to support laboratory exercises in courses for which a complex processor and operating system are not required, and to support low-level programming, the second extension board was developed with the basic ARM microcontroller. It contains:

- LPC2364 microcontroller
- DS18S20 High-Precision 1-Wire Digital Thermometer
- LM386 Low Voltage Audio Power Amplifier
- BMA250 digital accelerometer and I2C
- Snapwire connector with 8-pins
- Push-button switches, rotary encoder and LEDs
- TJA1040 High speed CAN transceiver.

The block diagram (Fig. 5) gives a high level overview of this extension board. The following are specifications of this extension board:

- 10-bit ADC with input multiplexing among 6 pins.
- 10-bit DAC.
- Four general purpose timers/counters with a total of 8 capture inputs and 10 compare outputs. Each timer block has an external count input.
- One PWM/timer block with support for three-phase motor control. The PWM has two external count inputs.
- Real-Time Clock (RTC) with separate power pin, clock source can be the RTC oscillator or the APB clock.

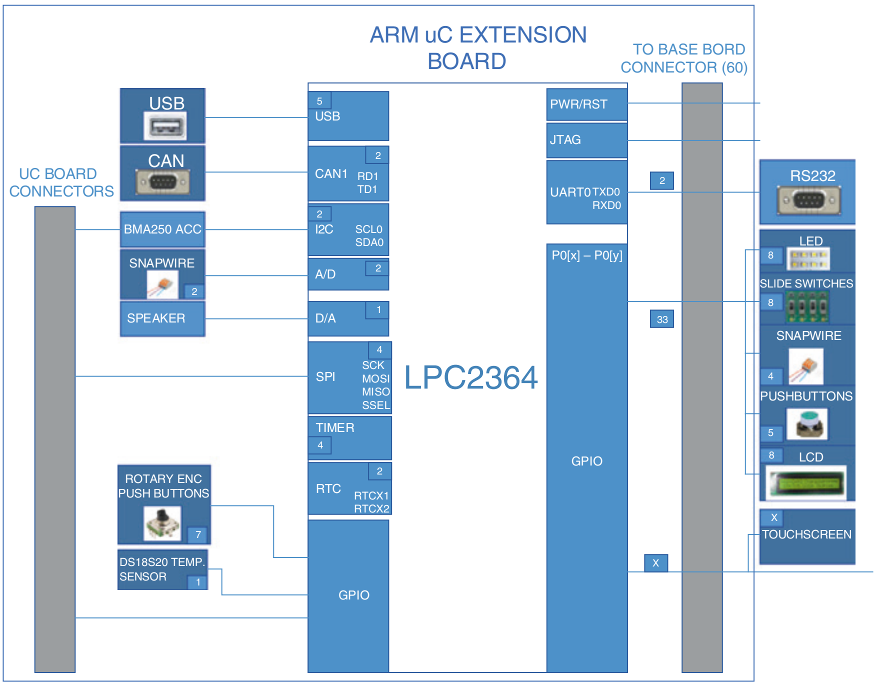

Fig. 5 E2LP extension board with NXP LPC ARM processor

- 2 kB SRAM powered from the RTC power pin, allowing data to be stored when the rest of the chip is powered off.
- WatchDog Timer (WDT). The WDT can be clocked from the internal RC oscillator, the RTC oscillator, or the APB clock.
- Standard ARM test/debug interface for compatibility with existing tools.
- Emulation trace module supports real-time trace.
- Single 3.3 V power supply (3.0–3.6 V).
- Four reduced power modes: idle, sleep, power-down, and deep power-down.
- On-chip crystal oscillator with an operating range of 1–24 MHz.
- 4 MHz internal RC oscillator trimmed to 1 % accuracy that can optionally be used as the system clock. When used as the CPU clock, does not allow CAN and USB to run.

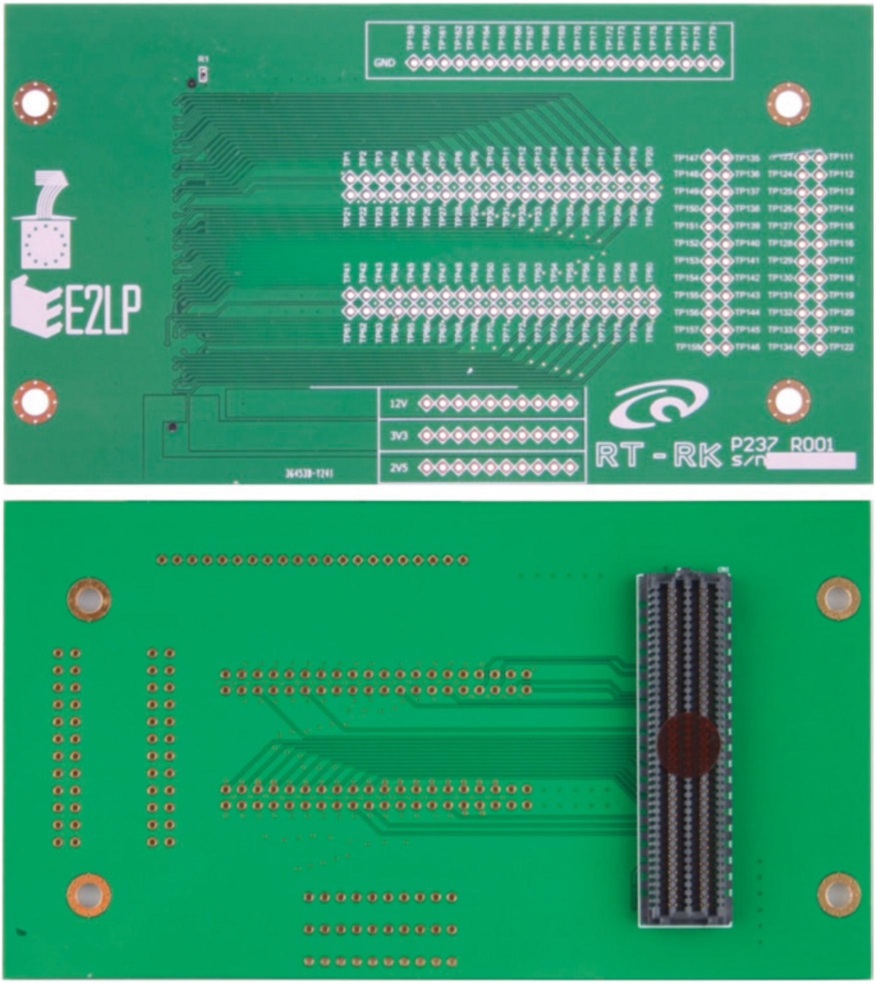

Fig. 6 E2LP proto-board extension—*top* and *bottom* view

This extension board allows implementation of the laboratory exercises in the following subject categories:

- Basic low-level programming
- Computer architecture
- Simple high-level programming (C language)
- Control engineering
- Industrial software

3.3 *Proto-Board Extension*

The third extension board is a simple proto-board (Fig. 6) which provides open access to every general-purpose pin on the FMC mezzanine connection to FPGA on Base Board. This board is useful for practicing basic electronics and building devices which connect directly to FPGA. Since the pins connect directly to FPGA, it is user's responsibility to adhere to the FPGA's electrical standards.

4 E2LP Software

Software for E2LP base board system is divided in two parts. The first part is software developed for housekeeping microcontroller (PHILLIPS LPC214x). The second part is software developed for PC working station. Communication between those two parts is established via USB connection.

The software for housekeeping microcontroller (Fig. 7) is in charge of the following tasks:

- Monitoring of board's power supply levels via AD converters which are part of microcontroller unit (MCU)
- Checking if FPGA is configured
- USB HID interface bring-up
- Sending monitored data to working station side through USB connection.

Program is stored in the flash ROM of the LPC214x and is started upon board's power-up or after resetting MCU.

The core of the MCU's application is USB HID kernel. All monitoring data are read periodically form the USB interrupt service routine which is invoked every millisecond.

Application for the PC working station is designed to enable users to monitor base board parameters:

- power supply levels
- configuration state of FPGA on Base Board.

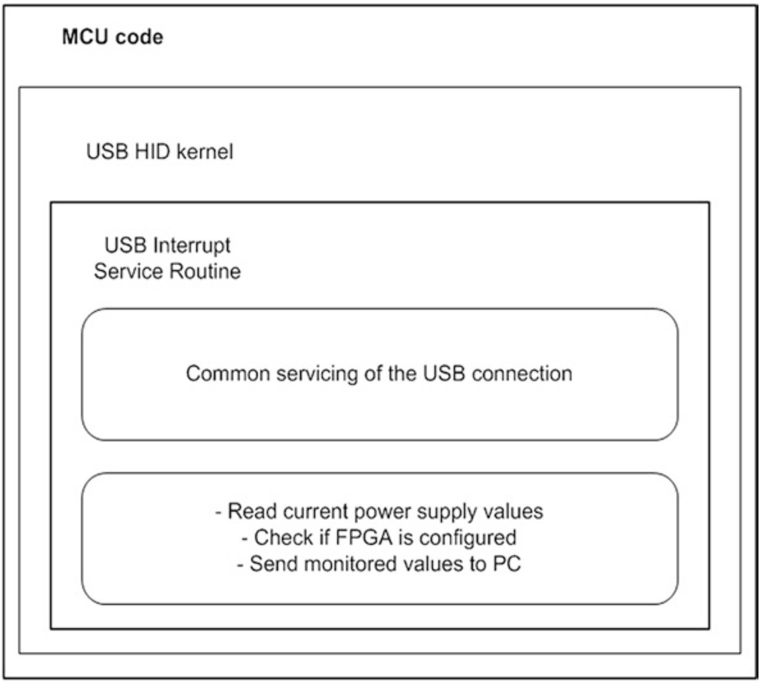

Fig. 7 Architecture of MCU software

It collects information from the board's housekeeping MCU via USB connection and displays them to the user.

Using the developed E2LP configuration utility, the user can:

- connect its PC via USB to the Base Board and control it,
- check the state of voltages on Base Board,
- control whether the application is connected to the JTAG chain,
- select .bit file for configuration and configure FPGA on Base Board.

Figure 8 shows the main windows of E2LP configuration utility, where the user configures the FPGA. Messages about configuration success are shown in the application window.

5 Impressions from the Pilot Usage of the Platform

Pilot usage of E2LP platform happened in academic year 2013/14 when students of the 2nd year used it in laboratory exercises of the course Logic design of computer systems 1—Digital systems design. Total of 218 students attended the course and used the platform. The platform received mixed feedback, with negative

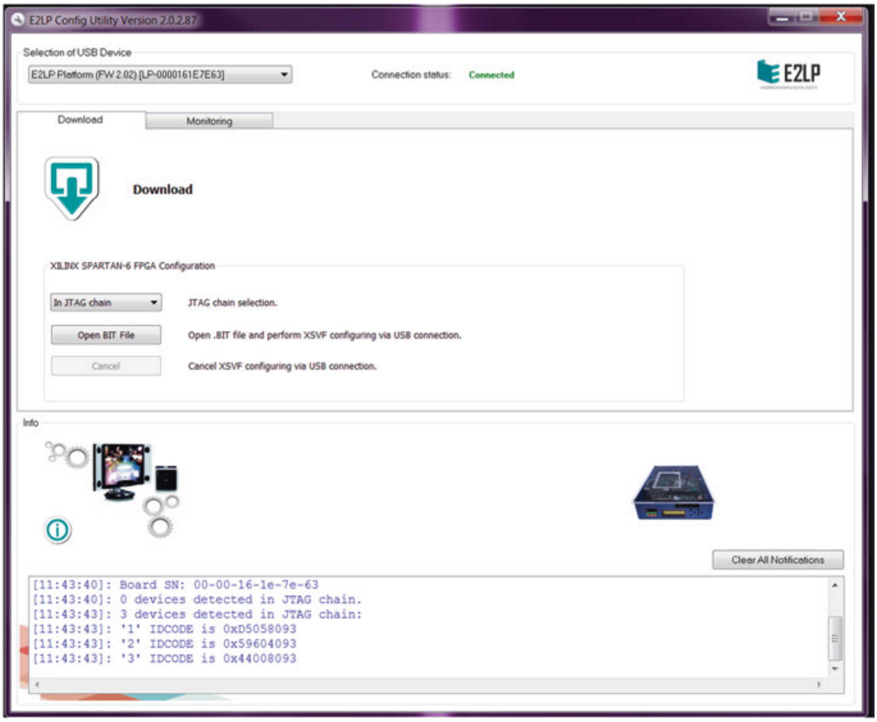

Fig. 8 E2LP configuration utility

comments reflecting the fact that pilot usage of the prototype inevitably contains a lot of bug solving. Nevertheless, overall impression was positive and students benefitted from the ability to work on a real platform and make digital design which was immediately verified as a real system, not just as a simulation.

Evaluation of the platform [8] was performed in the following ways:

- At the end of each graded laboratory exercises, students filled in the Lab Feedback Questionnaire (LFQ),
- At the end of the course, students filled in the Motivated Strategies for Learning Questionnaire (MSLQ).

Figure 9 shows responses from students related to the usage of the platform. From the histogram, it can be seen that the overall response was positive and that the platform is promising to improve education efficiency in embedded engineering curriculum.

In the following academic year, 2014/15, the same students used the platform in courses in the 3rd year, while the new generation of students used it in the Digital system design course. More detailed evaluation results are available in the paper about E2LP evaluation, later in this book.

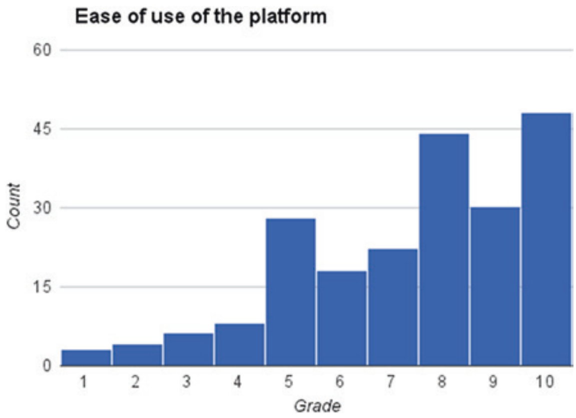

Fig. 9 Impression about the ease of use of the platform

6 Conclusions

This paper presented E2LP platform which aims to be used in the complete curriculum and reduce the overhead in engineering learning. It will ensure a sufficient number of educated future engineers in Europe, capable of designing complex systems and maintaining a leadership in the area of embedded systems, thereby ensuring that our strongholds in automotive, avionics, industrial automation, mobile communications, telecoms and medical systems are able to develop. In such a manner, the E2LP intends to increase European competitiveness in the learning process of embedded computer engineering, ensuring further technological and methodological development of the educational approach in this field.

Platform is extended with the augmented reality interface [9] and remote lab [10], to make it a complete system for education of embedded computer engineers. More about this can be read in the respective papers later in the book.

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