Darko HERCOG, Andreja ROJKO, Milan ČURKOVIČ, Bojan GERGIČ, Karel JEZERNIK

University of Maribor

Embedded platform for rapid implementation of local and remote motion control experiments

Abstract*. This paper presents hardware and software solution that enables rapid implementation of motion control algorithms. Presented solution enables control design in MATLAB/Simulink and rapid transition from model-based design to real-time operation on DSP-based target hardware. In addition to rapid control prototyping, presented solution enables data visualization, parameter tuning and remote control by using LabVIEW.*

Streszczenie. *Artykuł przedstawia rozwiązanie hardware'owe i software'owe. Umożliwiające szybką implementację algorytmów sterowania ruchem. Zaprezentowane rozwiązanie wykorzystuje platform MATLAB/Simulink i szybkie przejście z projektu opartego na modelu do celowego urządzenia, bazującego na DSP i działającego w czasie rzeczywistym. Poza tym szybkie sterowanie prototypowe daje możliwość wizualizacji. Dopasowania parametrów oraz zdalnego sterowania przy użyciu Lab-View. (**Aplikacja platformy dla szybkiej implementacji eksperymentów w zakresie lokalnego i zdalnego srerowanie**)*

Keywords: DSP, motion control, rapid control prototyping, remote laboratory.
Słowa kluczowe: DSP, sterowanie ruchu, szybkie sterowanie prototypowe, zdalne laboratorium

Introduction

Nowadays, there are many requests for using advanced control algorithms in motion control applications. Such algorithms are usually very complex, but unfortunately, with the complexity the likelihood of errors in the code drastically increase. There are also numerous requests for shortening development time, increasing quality, reliability and safety of the final product. Successful implementation of control algorithms also requires a very good knowledge of platform on which control algorithm will be deployed. Control developers thus face with a number of requirements therefore the need for new methods and tools that enable faster development and implementation of complex algorithm increase.

Modern methods of designing control algorithms include tools that enable rapid control prototyping (RCP). RCP is technology that enables a rapid transition from block diagram to real-time execution on target hardware. The key element of RCP is an automatic code generation, which eliminates tedious and error-prone hand coding procedures and thus making it possible for engineers to focus on control system design, implementation and evaluation, rather than on time-consuming low level programming.

Several rapid control prototyping solutions that enable design of control algorithms using block oriented programming languages (MATLAB/Simulink, Scilab/Scicos, VisSim, etc.) and rapid implementation of these algorithms on custom or commercially available embedded platforms have been proposed. MATLAB/Simulink has been used for programming of embedded platforms such as microcontrollers (Siemens 80C166 [1], Freescale MPC555 [2], ICP DAS Co. I-8000 embedded controller [3], Renesas M32C87 microcontroller [4]) and digital signal processors (DSP) (Texas Instruments TMS320C30 evaluation module [5], Innovative Integration PC32 DSP card [6]). The MathWorks Company Inc. released a few embedded targets for well known, industry-proven microcontrollers and DSP's (Target for TI C2000 DSP, Target for TI C6000 DSP, Target for Infineon C166, and Target for Freescale MPC5xx). That software support enables control algorithm creation using MATLAB/Simulink and real-time implementation on some commercially available starter kits and evaluation modules. In addition to MATLAB/Simulink, also freely available Scilab/Scicos has been successfully used for programming of on some embedded targets [7-9].

This paper presents a custom made, DSP-based embedded platform that enables rapid implementation of local or remote motion control applications. Presented platform provides an easy transition from the model-based control system design in MATLAB/Simulink to real-time implementation on embedded DSP-based hardware. In addition to rapid control algorithm implementation, platform enables on-the-fly data visualization and parameter tuning using LabVIEW and, by using LabVIEW Remote Panels technology, also remote control. The combination of the commercially available software and the custom-developed control hardware, described in this article, represent powerful and versatile rapid control prototyping solution, suitable for an educational process, as well as motion control research.

The paper is organized as follows: In Section II a brief description of hardware and software components of presented embedded platform is presented. Section III contains the scope of usage of this embedded platform in local and remote motion control experimentation. Finally, conclusions are stated in Section IV.

Hardware and software components of embedded platform

The core component of presented embedded platforms is DSP-2 controller (Fig. 1). This controller is based on Texas Instruments TMS320C32 floating point processor, which is used for control algorithm execution, and the Xilinx FPGA of the Spartan family, which mainly implements the peripheral interfaces. DSP-2 controller (Fig. 1) contains all the necessary peripheral for torque, speed and position control of the AC and DC motors. It contains multiple A/D and D/A converters, 3-phase pulse width modulator (PWM), an optically isolated digital I/O, interface for incremental encoder, random access memory, Flash read-only memory, and Controller Area Network (CAN) chip. Based on DSP-2 controller, two different types of embedded control platforms have been develop. The first one (DSP-2 Learning Module – Fig.1) is intended for AC and DC motor control as well as general purpose control applications. This module is composed of the DSP-2 controller and an additional board, where the power supply and expansion connector take place, for important DSP-2 I/O signals. Learning module is plant flexible because a variety of in-house developed plants or plants from different manufactures can be connected to the module through an expansion connector (Fig. 1). The second platform (DSP-2 Robotic Controller) is intended for robotic applications. Using this platform, motion control of up to 4 axes mechanisms can be achieved.

Code generation and data visualization solution for DSP- 2 platforms is based on two well-known commercially available software packages i.e. MATLAB/Simulink and LabVIEW (Fig. 2). MATLAB, Simulink and Real-Time Workshop (RTW) are used for control algorithm development, simulation, offline analysis and rapid executable code generation. After deploying process, generated code is executing on embedded DSP-2 platform and through the analogue and digital I/O lines drives the real process. Meanwhile, LabVIEW virtual instrument (VI), running on the PC, is used as a user front end. LabVIEW VI provides the ability for online parameter tuning, data visualization, online analysis and, using LabVIEW Remote Panels technology also for remote control via the internet. Programming of DSP-2 platforms using MATLAB/Simulink has been achieved by additional DSP- 2 toolbox (DSP-2 Library for Simulink) [10], which contains a set of Simulink blocks for all available DSP-2 I/O ports (Fig. 2); including blocks for analog and digital I/O, 3-phase pulse width modulation (PWM), incremental encoder, memory read/write, serial and CAN communication. When the Simulink model, containing DSP-2 blocks, is deployed on the DSP-2 controller, the DSP processor placed on the DSP-2 controller performs reading from and writing to the DSP-2 controller peripherals, depending on the DSP-2 blocks (Fig. 2) used in the Simulink model.

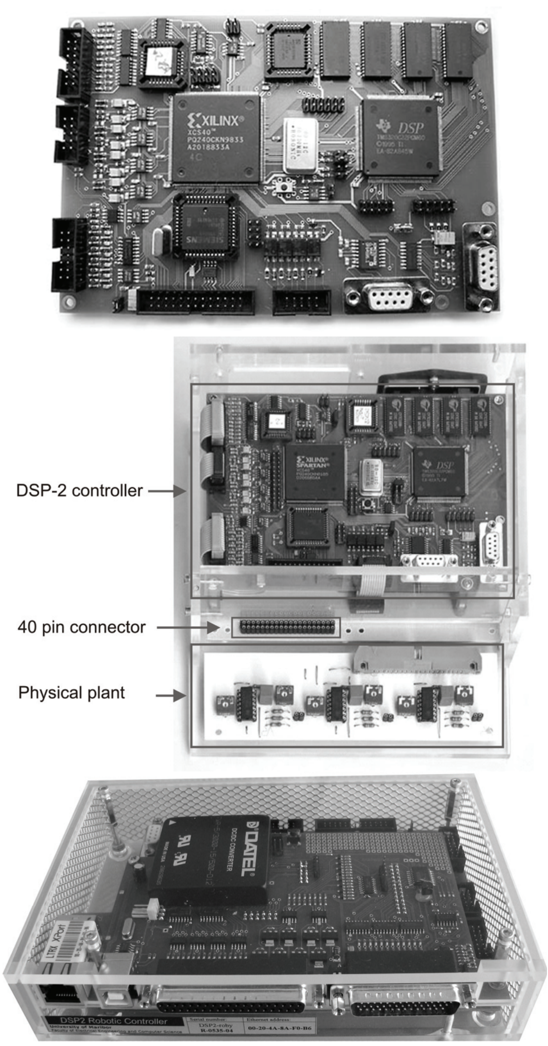

Fig. 1. DSP-2 embedded platforms: DSP-2 controller, DSP-2 Learning Module, and DSP-2 Robotic Controller.

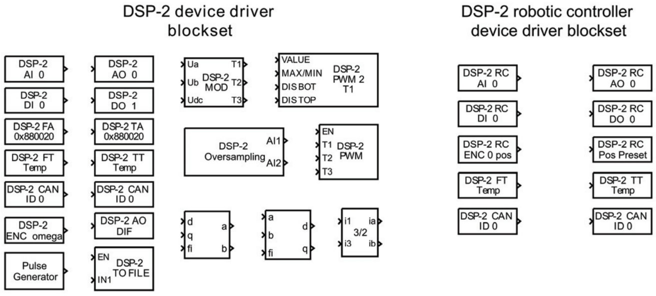

Fig. 2. Simulink device driver blocks for DSP-2 control systems.

For parameter tuning and data visualization using LabVIEW, additional LabVIEW toolkit (ComVIEW) [11] has been developed, which enables automatic LabVIEW VI creation during code generation process from Simulink model (Fig. 3). The appearance of the automatically created LabVIEW VI front panel depends on the DSP-2 global signals defined in the Simulink model. Those global signals are exchangeable between the DSP-2 controller and LabVIEW VI and have to be defined using special blocks provided in the DSP-2 Simulink blocks. For each of the DSP-2 global signals, a numerical control or numerical indicator is automatically created on LabVIEW VI front panel. When this LabVIEW VI is running, the communication link between front panel controls and the DSP-2 global input signals are automatically established, as well as the connection between the terminal front-end indicators and the DSP-2 output global signals.

Additional documentation regarding DSP-2 hardware and software components is available online at [12].

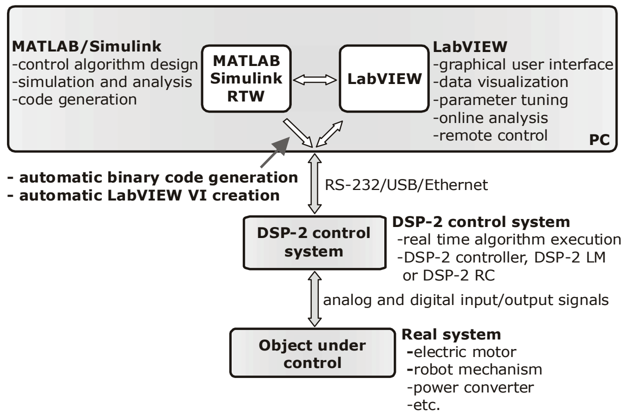

Fig. 3. DSP-2 code generation and data visualization solution.

The scope of usage

Presented embedded platforms are powerful, flexible, easy to use and, thus, suitable for an educational process. Efficient learning in the field of engineering requires a mixture of theoretical and practical exercises. Therefore, laboratory experiments play, and will certainly play, an important role in control-engineering education [13]. During experimental work, students become acquainted with real-world features and gain experience and knowledge, which can not be obtained by just using simulations. In the following subsections, the usage of this platform as a learning supplement within educational process is briefly described.

Local experimentation

Presented platform has been successfully used in different control courses at our faculty. In all these courses students usually start experimental work by building mathematical models of the real plant. After mathematical model derivation, they work on theoretical control algorithm design and perform closed loop simulation in MATLAB/Simulink. When the simulation results satisfy the given criteria, students must also verify the designed controller, on the real system. Experience has revealed that students quickly become familiar with DSP-2 platforms and Simulink intuitive model-based programming. Using this platform student can concentrate on control system design, simulation and experimental control verification, rather than on low level programming. By comparing simulation and experimental results they also gain experience with non-ideal and nonlinear features present in a real world systems. Using DSP-2 embedded platforms, motion control of relatively rapid dynamic systems can be achieved. For example, typical execution time of relatively complex algorithm on this platform is between 100 and 150 micro seconds.

Remote experimentation

Although, classical hands-on exercises are very useful and educational, they have many limitations regarding space, time, and staff costs. Laboratories are usually fully occupied, and students have to conclude their research within the time allotted for experimental work. The problems with traditional classical labs can be avoided by using remote experiments and remote laboratories. In remote experimentation, users operate with the real system, although they are not physically present in the lab. The remote users can conduct their experiments by accessing the lab when they most need it and from a remote's location which is more comfortable to them. Remote laboratories are mainly used within the academic field to enhance classroom lectures, share research equipment, and supplement the learning process.

In the field of mechatronics and automatic control, a variety of different remote experiments and remote laboratories has been developed [14-30]. These remote experiments include different objects under control, like DC motor [14-22], inverted pendulum [14, 15, 25-28], magnetic levitation [14, 15], coupled tanks [14, 15, 24, 28, 29], helicopter [14, 15, 23, 24, 29], ball and beam [15] and others. In the majority of existing solutions, remote users can execute experiments, change predefined controller parameters, observe results in text or graphical view and download the experimental results.

In addition to the local use, the presented embedded platform has been successfully utilized in developed remote control laboratory [21] (available online: www.weblab.si). Remote laboratory, which is intended for the students in the field of automation and mechatronics, offer the possibility of the implementation of real experiments on a distance. The access to the contents of the remote laboratory is enabled only for registered users. The registration is free of charge and it is possible to register right on the web portal of the remote laboratory. Remote laboratory includes a set of real objects under control (DC motor, nonlinear mechanism, SCARA robot, etc.), which are controlled by DSP-2 control systems. The remote user is able to run an experiment, adjust the process or controller parameters from a set of predefined parameters and observe system response in graphical view (an example of graphical user interface is shown in Fig. 4).

Unlike other remote laboratories, accessible on the Internet, presented laboratory actually contains online e-courses, which are upgraded with remote experiments. At the beginning of each course, basic information about the course is stated: a brief description, target group, suggested background, learning objectives and intended learning time. Furthermore, the entire teaching contents, questions for examination, computational tasks and experimental tasks to be carried out in remote experiments, are given. All the data and necessary documentation are at disposal in Slovenian, as well as in the English language.
More information regarding implementation, effectiveness and experience with this remote laboratory in education process can be found in [31].

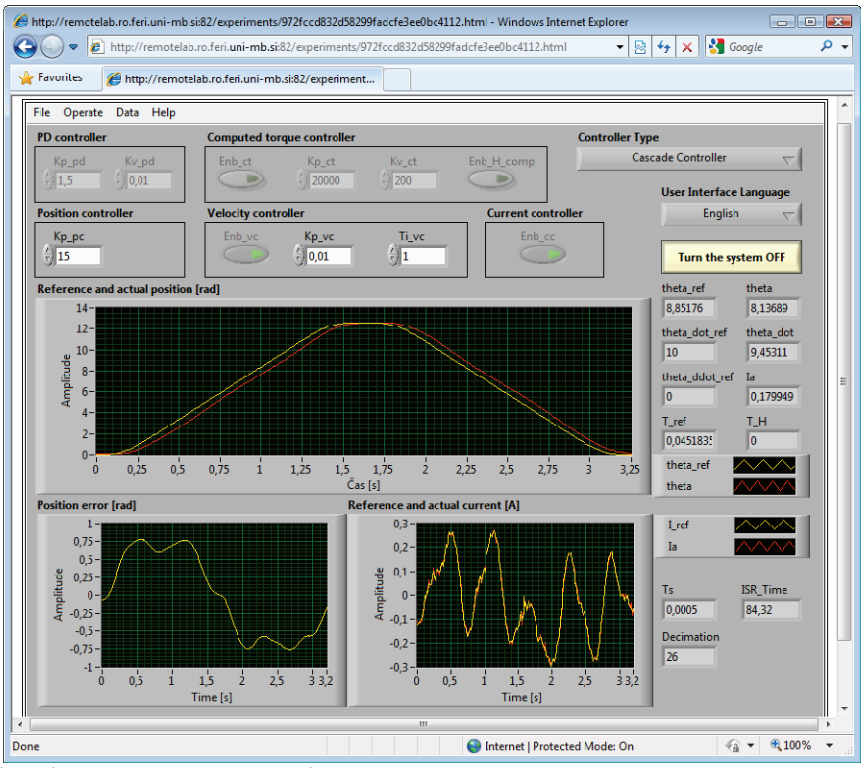

Fig. 4. The user interface for the implementation of remote experiments.

Conclusion

In this article, embedded platform that enables rapid implementation of local and remote motion control experiments has been presented. Presented platform is powerful, flexible, easy to use and, thus, suitable for an educational process, as well as motion control research. Presented platform has been successfully used in the educational process. Control courses are now integrated with demonstrations and hands-on experiments, with the purpose of minimizing the traditional gap between theory and practice. In addition, the same platform has been used in developed remote laboratory. Remotely available experiments enable the students and the teachers a greater flexibility as far as the time and place of the implementation are concerned, as well as solves the problem of lack of experimental devices and/or larger classes of students.

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Authors:
dr. Darko Hercog, E-mail: darko.hercog@uni-mb.si; dr. Andreja ROJKO, E-mail: andreja.rojko@uni-mb.si; mag. Milan Čurkovič E-mail: milan.curkovic@uni-mb.si; dr. Bojan Gergič E-mail: bojan.gergic@uni-mb.si; dr. Karel Jezernik University of Maribor, Faculty of Electrical Engineering and Computer Science, Smetanova 17, SI-2000 Maribor, Slovenia, E-mail: karel.jezernik@uni-mb.si;