

Original article

Artificial and real laboratory environment in an e-learning competition

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Abstract

In this paper an approach to a study of multivariable system control is presented, where special attention is devoted to the implemented remote experiment. It has been realized through an e-learning environment, based on the E-CHO, Matlab, PHP software and a MySQL database. The e-management system E-CHO has been developed at the Faculty of Electrical Engineering, Ljubljana, Slovenia and is already widely used in different educational, business and academic applications, however, this is its first use in control design. The system is used for the communication with the users and the performance of the remote virtual (simulated) and/or real-time experiments using a laboratory pilot plant. The environment allows testing, design and evaluation of various modelling and control techniques. The system has now been used three times as an e-learning and e-competition game in 2007/2008, 2008/2009 and 2009/2010 and has been accepted very well among the students. In students' opinion the idea of e-learning competition introduces a novel, alternative approach to the study, enables more freedom in work organization, increases learning efficiency and stimulates students' interest. Since the presented system is very adaptable, direct extensions are possible in the sense of virtual and remote experiments with different models and real pilot plants.

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1. Introduction

This paper presents an approach to an e-learning system, used for studying multivariable control design using a virtual experiment and a remote real-time laboratory pilot plant. The remote experiment was realized through an e-learning environment E-CHO, which served as an user interface and e-management system; Matlab 7.04, which was used for the execution of the experiments; and supplementary programs PHP and MySQL database, used for handling the requests and serving the waiting queue.

In the past few years, the Faculty of Electrical Engineering in Ljubljana, Slovenia, invested intensive efforts into the introduction of the Bologna study, which is a common study structure in most of the European faculties. The introduction of the new study also involves a renovation of the existent lecture programs. Since the new study allows more freedom for students to select their lectures, a large portion of the program renewal is focused on the attractiveness and new technologies presented in the scope of the individual lectures. Therefore, in the past 3 semesters (2007–2008,

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2008–2009 and 2009–2010), at the Department of Automatic Control, in the frame of Multivariable systems lectures, we decided to introduce an alternative instead of classic approach to laboratory exercises – an e-learning system, including virtual experiment and a real laboratory pilot plant.

In previous years the laboratory practices comprised of classic multivariable control design using different laboratory pilot plants. The work in this manner required the students to be present at each practice, where students in groups of two solved different problems regarding multivariable control. The newly introduced laboratory practices, using the developed e-learning system are very similar to the past ones from the design point of view, however, students' work is no longer obliged to the actual laboratory and can be performed at any time and on any computer with access to the internet, running Matlab software [5]. The Matlab software is in fact not needed for the actual performance of the experiment or the communication with the system, but to find a solution to the given problem. The implementation of the system included everything else necessary for the successful execution of the experiments (pilot plant, visualization, data acquisition, signal measurements, etc.); therefore, no additional programs (except the internet browser and Matlab software) were needed.

The e-learning system was built in a manner that allowed students to examine open- and closed-loop characteristics of the virtual model and the pilot plant, using appropriate control structures. In this way different model characteristics, needed for the control design, could be obtained. The complexity of the controller could then be defined by users themselves and could range from the simplest proportional controllers to a complex combination of observers, feed-forward, output and state controllers.

To gain more students' interest, to stimulate them to put more effort into the exercises and to make them more interesting the e-learning experiment was designed as an e-competition. The control design results of each group were recorded and later compared to the solutions of other groups to obtain the best control structure and therefore the winning, second and third group. The final classification of the groups was then used as a basis for the experiment evaluation and final grade of each individual.

Since the e-learning approach presented, introduces a subject specific e-learning implementation, extensive interdisciplinary cooperation was required during application development, as no existing commercial or open source e-learning software could be used without adaptations and further development. Thus, the technical basis of the idea was realized using the E-CHO software, which is already extensively used for a variety of e-learning solutions in different target academic and business environments (more than 10,000 users in corporate and academic institutions), but has yet never been used in a configuration with a virtual or real pilot plant. The E-CHO environment was developed exclusively at the Faculty of Electrical Engineering, in the Laboratory for Telecommunications (LTFE), while the whole e-learning environment was built in cooperation of the LTFE and the laboratory for modelling, simulation and control (LMSV and LAMS) [1].

The ideas presented in this paper are alike to the work done by Yang and Alty [12], Grimaldi and Rapuano [2], and Hoffman et. al. [3], however, beside the similar approach, the architecture of the presented system and its software and hardware equipment are completely different.

The paper is structured as follows. In Section 2, both hardware and software realizations of the project are discussed. Section 3 explains the idea of the e-competition project through which the transition to distance learning approach is enabled. In Section 4 some future plans are presented. The paper ends with some concluding remarks.

2. Materials and methods

As mentioned before, because of the specific problem, no commercial or open source e-learning software was appropriate for the implementation of the project. Instead, we modified the E-CHO software with newly designed interface for the communication between the main server (running E-CHO) and the slave computer, running Matlab and a pilot plant.

2.1. Hardware implementation

The pilot plant that was used for the real-time remote experiment is a Coupled Drive Apparatus TQ-CE108 [11], which is a multivariable MIMO system (multiple inputs and multiple outputs).

As shown in Fig. 1 the inputs to the plant are two voltage signals, each controlling the angular speed of one DC motor (ω_1 and ω_2), while the outputs are voltage signals, on representing the angular velocity of the working station

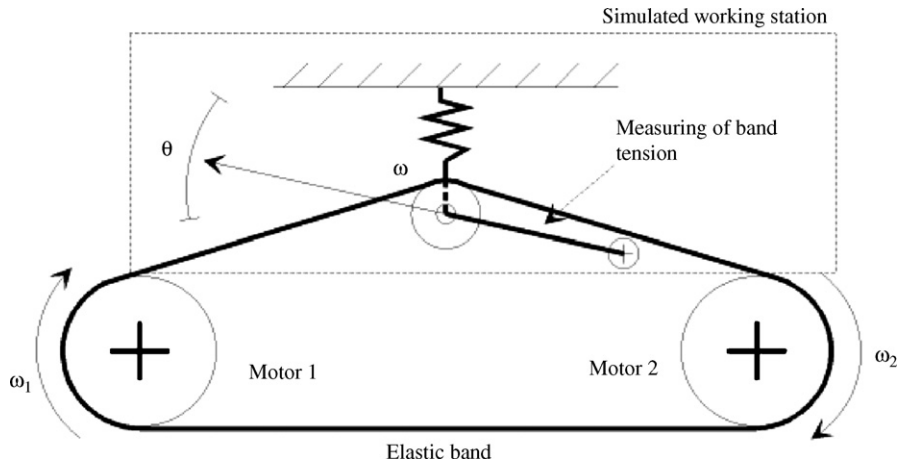


Fig. 1. Schematic representation of the Coupled Drive Apparatus (TQ-CE108) pilot plant.

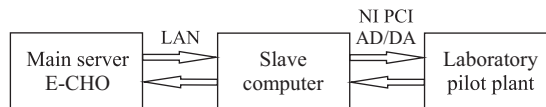


Fig. 2. Schematic representation of the hardware setup.

(ω) and the other the tension of the elastic band through the angle sensor (θ). Schematic representation of the pilot plant is shown in Fig. 1.

The selection of the appropriate pilot plant for the experiment is crucial, since it needs to be complex enough for the development of various control structures, but also fast enough to suit the requirements of the proposed system and to reduce the time of each experiment.

The pilot plant was connected to the slave computer through the National Instruments PCI AD/DA card, which converts the control and measurement signals to analog or digital form. The slave computer was linked to the main server, which was running E-CHO software, through the World Wide Web network. Schematic representation of the hardware setup is shown in Fig. 2.

The slave computer, which performed the experiments was also used for handling the video stream from the USB web camera to the main server running E-CHO.

2.2. Software

In the introduction it has been mentioned that the whole e-learning project is based on the E-CHO software, running on the main server using Apache Server 2.0, PHP 5 and a MySQL database. E-CHO e-learning platform (Fig. 4) is the result of experiences with e-learning implementation, extensive analysis and usage of related products in Laboratory for Telecommunications at the Faculty of Electrical Engineering [9].

The E-CHO system comprehends e-learning functionalities and can also be integrated to the other web-based applications. The system platform provides:

- e-learning management (LMS – Learning Management System),
- e-learning content managing (LCMS – Learning Content Management System),
- tracking of teacher's activity and student's progress,
- knowledge assessment and testing,
- e-learning standard support (SCORM and QTI) and multilingualism.

System functionality allow different user roles. The roles define the level of rights to system access. Users can access their personalized functionalities through a specific interface, similar to the one presented in Fig. 3.

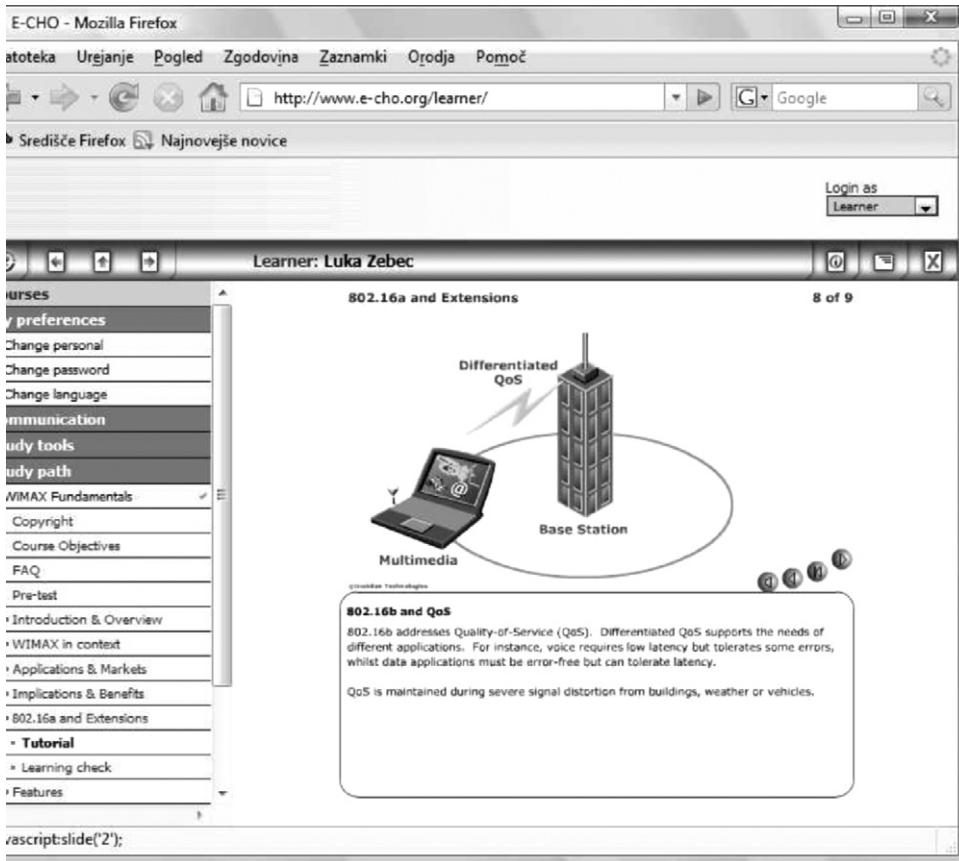


Fig. 3. E-CHO system teacher's interface.

When developing the e-learning idea, core functionalities of the E-CHO were of significant importance. Besides the mentioned properties, the E-CHO system enables importing and downloading of different sorts of electronic material, communication between students and the mentor, forum and questionnaire. Therefore, the process of content development was simplified.

The software used to carry out virtual and real-time experiments on the pilot plant was Matlab 7.0 with Simulink add-on. The interface connecting the E-CHO software and Matlab was built using a PHP program and a MySQL database. The PHP script was used for handling the execution requests incoming from the E-CHO interface and sorting them to the waiting queue. The waiting queue implemented using a MySQL database is important, because the experiment can be accessed by one user at the time only and multiple requests cannot be served at once. The database also contained various data about the users and the performed experiments (uploaded files, number of trials, experiment efficiency, etc.). The waiting queue which was served by a PHP script was executed using a PyCron task scheduler. Before executing each experiment, program checked for the consistency of the user-uploaded data (controller parameters), which was needed for successful execution of the trial. If the structure of the data file was error-free, the request was passed to Matlab for the actual performance of the experiment. On the other hand, if the errors were present, the data file had to be corrected and re-uploaded.

The PHP script executed a Matlab m-file code, which contained the algorithm for successful trial on the pilot plant (input/output data handling, creating result files, controller structure, etc.), through the shell-execute command. The input data to the experiment was a file containing the controller structure, i.e. parameters. After each experiment, m-file script generated the data files containing the results of the trial. If any problems occurred during the experiment an error file was generated. Afterwards, the PHP script returned the result or the error files to the main server, which displayed them in the E-CHO environment to the user over the internet browser, at the next scheduled run.

Parallel to the real-time experiment on a pilot plant, a real-time video stream of the plant performance was available.

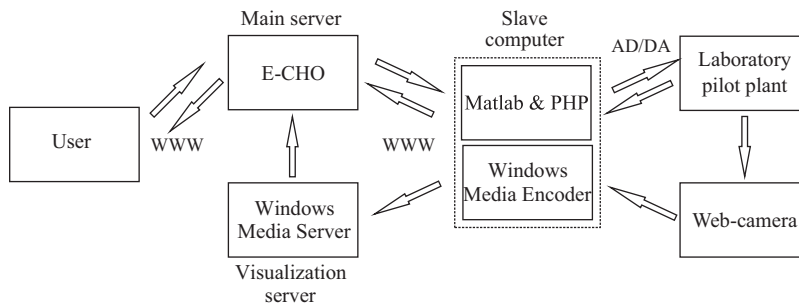


Fig. 4. Schematic representation of the software realization.

Video was captured through a web-camera, encoded and streamed using Windows Media Encoder. The stream was sent to the streaming server, running Windows Media Server software, which handled the stream and redirected it to the E-CHO interface. During the experiment the video was displayed in the internet browser on user's computer.

The schematic representation of the complete software and hardware realization is presented in Fig. 4.

3. E-competition

To make the e-learning experiment more interesting and to stimulate students to put more effort into the control algorithms design the experiment was designed as an e-competition. However, each student has been given a choice whether to pass the laboratory practice by participating in the e-learning competition or in a classical way. In all three semesters all the students decided to try the e-learning project. A virtual competition between the students has proven to be very popular among the students, since it stimulates their effort and creativity as reported by Matko et. al. [6].

The e-competition consisted of three phases which needed to be accomplished one after another if the student wanted to achieve the practice goal. The main goal of the practice was to design an efficient controller(s) for tracking the reference signals, while taking into account the limitations of the control signals. Beside that, an extent of students' knowledge in multivariable control was one of the main interests.

The e-competition phases were designed as follows. The first phase was a theoretical part of the experiment. Students needed to correctly answer to 3 randomly chosen groups of 5 questions (15 questions all together) regarding the multivariable systems theory.

Each question offered several possible answers where at least one is correct, however, there was a possibility that all of the answers were correct. Students were given a one wrong answer pass, meaning that only one of the fifteen answers could be answered wrong. Two false answers returned the user to the beginning of the level, which could be restarted after 1 h break designated for additional study. As the questions were randomly chosen for each trial the sets of questions were usually different. If at least 14 out of 15 questions were correctly answered the first phase was marked as passed and the student was allowed to continue to the second phase.

The second phase involved planning and design of the multivariable controller, which could be tested online using a Matlab-Simulink model. The second phase was thus only a virtual experiment using a Matlab simulation, intended to build a control structure, which gives stable results and can be later used on a real plant. In this step the students were able to measure the open- and closed-loop responses of the system, which were needed for successful tuning of the controller parameters. Setting the state-space control parameters to appropriate values students also had a chance to measure different data about the system, such as: output values, state estimation, and open- and closed-loop response. The control scheme used for running the experiments is shown in Fig. 5. After the students uploaded their own data files containing the controller parameters, the environment performed the experiment, returning the measured results. If the closed-loop properties were acceptable (i.e. the closed-loop system was stable) the second phase was marked as passed and the student was allowed to continue to the third and final phase. If the system response was unstable, the controller parameters had to be re-tuned to meet at least the stability criteria.

Similar to the second, the third phase also involved planning and design of the controller, but this time the students were allowed to test the control structure on the real pilot plant. From the system point of view, this means that the Simulink simulation block, representing the model, was replaced with the input/output block, which ensured

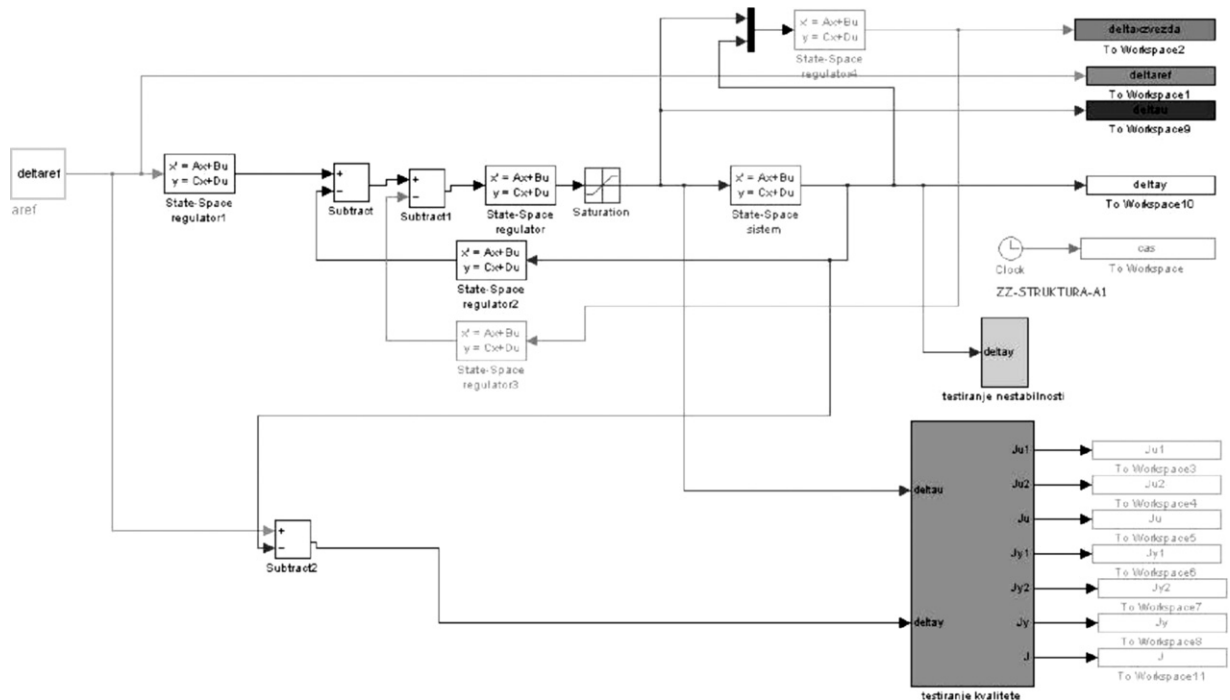


Fig. 5. Control scheme used for running virtual and remote laboratory experiments.

communication with A/D–D/A converters and therefore with the real pilot plant. The control scheme is similar to the one in Fig. 5, where the state-space model is replaced with Simulink's AD/DA block. Similar to phase two, students were able to measure open- and closed-loop characteristics of the pilot plant, which are of special importance, since the built-in model used in phase two was fairly different from the real pilot plant used in the third phase. In order to achieve optimal control of the plant, students had to adjust the control parameters in the designed control structures. When students achieved stable and acceptable control of the plant the experiment was finished. However, the system allowed the students to upload as many sets of controller parameters as they wanted to achieve better response and more accurate reference tracking.

The best result of each student group was stored in the system and used for the final evaluation of the competition procedure.

Beside the three main steps described above, in the frame of E-CHO system, users had the access to a variety of literature linked to the multivariable control, such as Maciejowski – Multivariable Feedback Design [4], Morari and Zafiriou – Robust Process Control [7], Patel and Munro – Multivariable Systems Theory and Design [8], Skogestad and Postlethwaite – Multivariable Feedback Control, Analysis and Design [10].

The last step in e-learning experiment was a non-obligatory questionnaire, which the students were asked to answer. After examining the responses, the following can be concluded:

- new possibilities of laboratory exercises were interesting for all the students and very well accepted,
- students agree that such work organization stimulates cooperation between the partners of the team,
- stimulates on-line study,
- e-learning enables freedom in study organization,
- students prefer to preserve a part or even all auditory exercises and lectures in a classical way.

4. Future plans

After three successful semesters in e-competition project and its well acceptance among the students, further effort is invested into the development of similar setups with other laboratory pilot plants. Our near-future plan is to modify

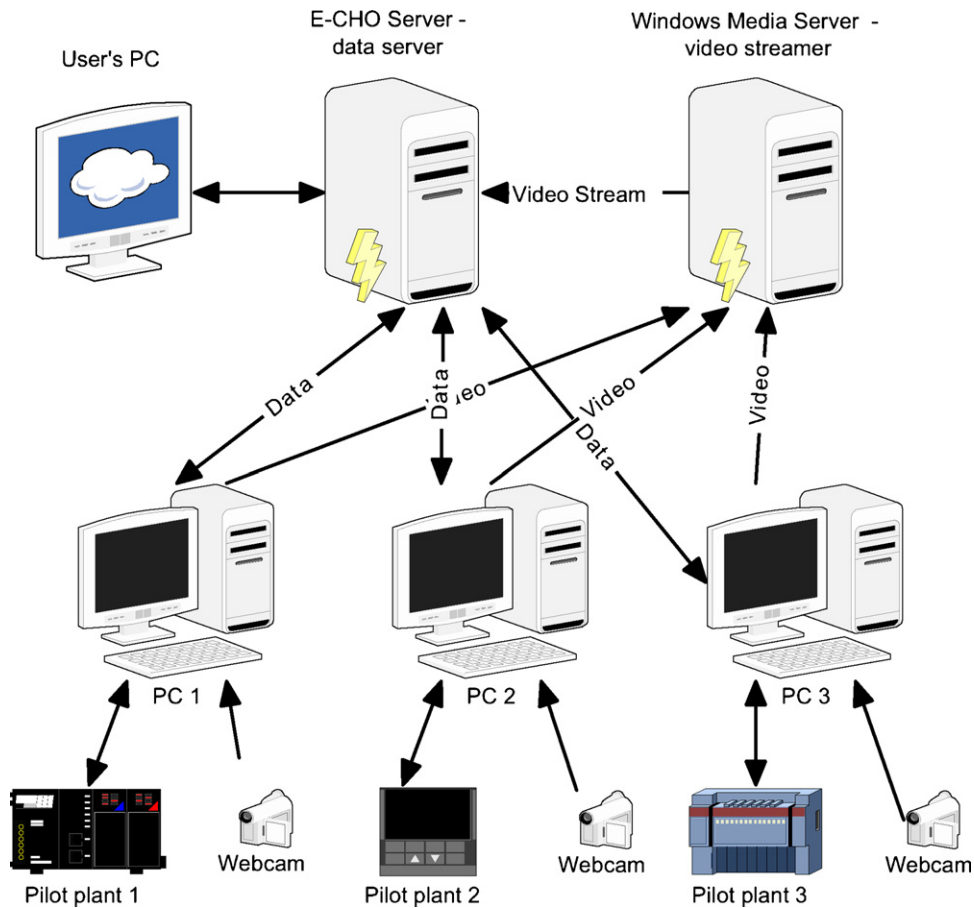


Fig. 6. A possible structure of the virtual laboratory.

the existent system in order to be applicable also with other multivariable or univariable pilot plants. Since the system presented in this paper is very adaptable, it could easily be used as a platform for other virtual or real-time experiments. The plan is to use several computers and pilot plants to build a virtual laboratory. The advantage of using the presented system is in its modularity, since it works as a whole, but is consisted of a several independent units (main server, streaming server, executive computer, and pilot plant), which can easily be exchanged with a similar one to suit the needs of another experiment.

Mainly, this means that the Matlab routine, on the slave computer needs to be replaced or modified to meet the requirements of another plant. Thus, everything else, regarding the E-CHO system, visualization and communication between the computers can stay intact.

A possible structure of the virtual laboratory with multiple computers and pilot plants is shown in Fig. 6. The setup of the main servers, running E-CHO and Windows Media Server will remain the same as in the presented system. However, very likely more powerful servers will be needed to cope with multiple data and video transfers from several computers and devices.

Beside the introduction of new technologies in the study program, the implementation of the virtual laboratory would reduce the load in the actual laboratory, since it would allow higher student traffic and 24/7 access to each pilot plant. Therefore, a more pleasant approach to the laboratory practice is possible, as the students are no longer obliged to attend the exercises on a certain day in a week, but have a possibility to access the system 24 h a day, 7 days a week and thus organize their study time themselves.

5. Summary

The paper presents some ideas and a possible approach regarding the sequential transition from classical to e-education in the field of multivariable control. The idea was realized and tested on the basis of the prepared project. In the past three semesters the experiment based on the Coupled Drives Apparatus, however, in the future additional experiments, using other pilot plants, are planned. The performed experiment was accepted very well among the students, since the received feedback was very positive. The students agreed that such work stimulates on-line study and the cooperation between the partners of the team and allows more freedom in study organization, compared to the conventional methods. Also, the performed e-competition increased student's creativity and represented a stimulus for them to put more effort into the study. The introduction of the virtual laboratory would, therefore, be a reasonable step in the future. Such a laboratory could be applicable to practices at other lectures, auditory exercises and also exams, but it can be expected that a certain amount of personal contact is still important as well for the students as for the teaching staff. We believe, that together with the additional materials and enabled self-testing possibilities the system can be effectively extended for a long-distance learning courses.

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