Mechatronics E-course for regular students and adults: realization and comparison of efficiency

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Abstract— **This paper describes execution and gained experience with two practically oriented E-courses from mechatronics. Both courses have in common that they include remote experiments and are executed completely online, which is still rarity in the practically oriented engineering education, especially in non-university education. The execution details and educational approach applied in each course were adjusted to two specific target groups. The target groups of a first course 'Control of nonlinear mechanisms' is a group of regular local and regular international students of mechatronics. The target group of second course 'Basics of mechatronics' are employed and unemployed adult professionals from various engineering fields who have already finished their formal education but want to acquire new knowledge. For both courses interactive E-materials and E-tests in Slovene, English and partially also in German language are available within two learning portals, also adjusted to the needs of each target groups. First course was tested with 40 regular students and the second course with the group of 70 adult professionals mostly from industry. While adult professionals appreciated the fact that the course was executed completely online, the regular students have still preferred conventional lectures and especially conventional laboratory exercises over remote ones. Based on the teaching instructor's observances and on the results of anonymous questionnaires, the advantages and disadvantages of the replacement of traditional laboratories with remote laboratories are discussed from a critical point of view.**

Keywords-education; remote laboratory; mechatronics; adult education; vocational training; distant education

I. INTRODUCTION

Until recently the distance education courses for engineers were quite rare, although the distance education is due to its many advantages already quite widespread in other no-engineering disciplines. The main reason for this is that efficient engineering education should include experimental work on real devices, which usually takes place in laboratories and therefore requires personal presence of the learner. This has recently changed with the introduction of distance laboratories that enable remote execution of experiments from anyplace and at anytime [1],[2],[4]-[6],[10],[14]-[17],[19]. However the establishing and maintenance of the remote laboratories is technically very demanding and mostly also costly. Therefore, the practical use of such laboratories in regular education of higher number of learners is still not very common. One of the possibilities to ease the burden of establishing remote laboratories with high number of experiments and courses is to share it between few partners. An example of such shared laboratory is laboratory established within the Leonardo da Vinci EDIPE (E-learning Distance Interactive Practical Education) project [1], [17]. Here the courses are offered by thirteen universities from eleven European countries within the same portal and with some common functionality like booking system. However, beside technical problems, which can be at least partially reduced by sharing of the remote laboratory, there are also many educational problems. Those problems differ according to the target group of learners. In this paper applied educational approach and results will be presented for two courses, each with its own target group.

Both in the paper presented courses aim toward offering practical experience by incorporation of remote experiments. First course was developed within EDIPE project [1], [17], [19] and is intended for education of regular students of mechatronics from eleven European countries. This course 'Control of nonlinear mechanisms' introduces the students to modelling, simulation and motion control design and implementation for nonlinear mechatronic devices. The course was already successfully implemented in the regular education process of 40 local students. Students' feedback was obtained by anonymous survey and is analysed in the paper.

Second course which will be presented and analysed was developed within Leonardo da Vinci MeRLab (Innovative Remote Laboratory in the E-training of Mechatronics) project [9], [12], [13]. Course 'Basics of mechatronics' is designed for employed and unemployed adult professionals who have already finished their official education. This course was tested by the adult participants with very different background knowledge, various levels of official education and also very different interests. Obtained feedback shows that in contrary to the regular students, the adult professionals highly appreciate the possibility to participate in the completely online course as it can be easier fitted in their busy schedule.

The paper is organised as follows. Second section presents course 'Control of nonlinear mechanisms' developed for regular local and international students. Learning portal, course topics, execution of the course with educational approach and students' feedback are described. In third section the course 'Basics of mechatronics' for adult professionals is described. Details about learning portal, topics, educational approach and participants' feedback are given. Fourth section compares the experience of both courses and gives analysis of usability of completely remote engineering courses based on the participants' feedback obtained at the end of both courses. Last section draws some conclusions and presents plans for future work.

II. E-COURSE 'CONTROL OF NONLINEAR MECHANISM' FOR LOCAL AND INTERNATIONAL REGULAR STUDENTS

This course was developed within the EDIPE project as one of the 18 available courses developed in thirteen partners from eleven European countries [1], [17], and [19]. All courses contain high quality documentation with theoretical background for learners and teachers, simulations, various exercises, and remote experiments on real electrical or mechatronic devices and are at disposal to teachers and students of participating universities. Therefore they can be applied as regular courses at the universities. Courses include topics from fundamentals of electrical engineering, power electronics, electrical machines, electro-mechanical and motion control systems. Here presented course 'Control of nonlinear mechanism' deals with modelling and motion control of mechatronic devices with nonlinear dynamics.

A. *Learning portal*

Learning portal named PEMC Weblab, Fig.1, is Moodle based and therefore offers all necessary functionalities for distance learning to the instructor and learners. Basic Moodle platform was completed by very efficient booking system [3] which enables the learner to book time slot for execution of remote experiments in advance and prevents multiple simultaneous accesses to the same experiment. The page of the course 'Control of nonlinear mechanism' is shown in Fig.2.

B. *Course 'Control of nonlinear mechanism' topics*

The 'Control of nonlinear mechanism' course covers an extensive topic of modelling, simulation, planning and practical implementation of the motion control of mechatronic device with nonlinear dynamics. All this is important part of the modern education of electrical engineers, machine engineers and mechatronics engineers.

In the course, all basic elements are included which enable the student with adequate pre-knowledge an insight into the problem, an acquisition of some new knowledge, and practical experience in motion control of mechatronic devices. Beside in PEMC Weblab the course is also available within frame of DSP based remote control laboratory, Fig.3. [3], [7], [8], [11].

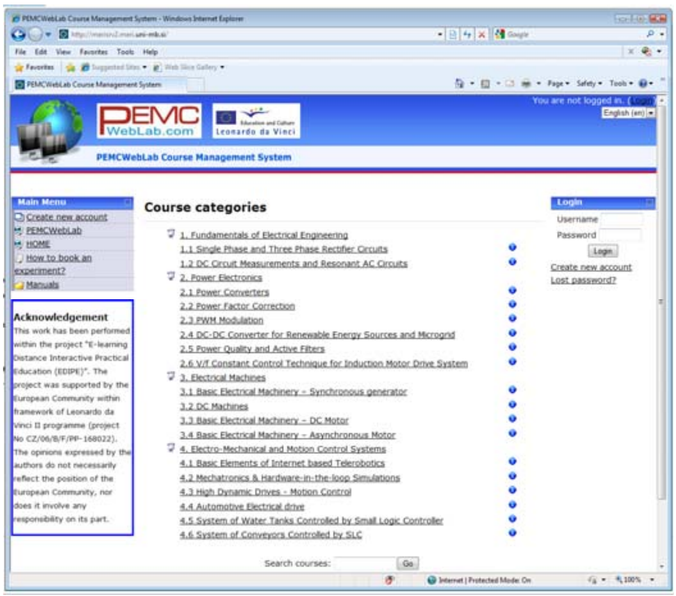

Figure 1. PEMC WebLab learning portal, selection fo courses

Learning objectives of the "Control of nonlinear mechanism" course are:

- Modelling of the mechatronic device with the nonlinear dynamics.
- Planning, implementation and optimization of the linear regulator with the cascade structure (cascade P position, PI speed and PI current controller) for the position control of the mechanism with nonlinear dynamics.
- Planning, implementation and optimization of the nonlinear position controller based on the mechanism dynamic model.
- Understanding the reasons for variations in efficiency of the use of linear and nonlinear control methods in the case of nonlinear mechanism control.

As a practical example in the course, the mechatronic device called mechanism with a spring with a DSP-2 control system is used, Fig.4, [3]. The direct current motor shaft is covered with a silicon material and drives the Plexiglas disc. The disc is fastened to the bearing, while on the other side of the bearing the spring is attached. The whole mechanism is fastened on Plexiglas housing. This mechanism is very suited for remote experiments due to its smaller size, no limit and end switches and minimal wear and tear at the long time operation.

C. *Execution of the course*

The first part of the course is intended for familiarization with the theory. Each chapter is also supplemented with an example that represents the use of theory on a practical example. For example, in the chapter dealing with a basic dynamic mechanism model, the dynamic model of the mechanism with a spring is derived and explained. Corresponding MATLAB/Simulink simulation model is also

built and tested afterwards. Then, the theory concerning the motion control problem follows, together with the design of suitable controllers and their implementation for the motion control of the mechanism with a spring. After the theoretical part with the simulations, the experiments in the remote laboratory follow.
When ones obtain unsatisfying results, the additional correspondence with tutor or literature study follows. The course flow is schematically shown in Fig. 5.

Figure 2. PEMC WebLab course documentation

Figure 3. Remote laboratory web page

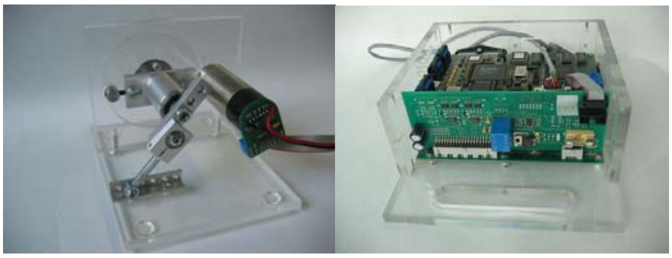

Figure 4. Mechanism and DSP-2 controller

D. *Students' feedback*

In the course altogether 40 students of mechatronics in two consecutively years were involved. 18 of them have filled anonymous questionnaire which they were handed after conclusion of the course. The feedback was as follows:

- 94% of students think that remote laboratories are a useful addition to ordinary laboratory exercises, while only 22% are of the opinion that remote experiments could entirely replace conventional laboratory exercises supervised by assistant.
- 94% of students are of the opinion that remote experiments are suitable for the strengthening and repetition of knowledge which they have already gained. Further, 72% have the opinion that remote laboratories are suitable also for acquiring completely new knowledge.
- 39% of students performed remote experiments for the first time.
- Despite the fact that remote experiments can be performed independently of the place and time, 61% of the students still prefer executing the experiments in the laboratory to remote experiments, 33% of students could not decide for one option and 6% prefer remote experiments.
- As much as 78% of students have the opinion that they learn more when executing the same experiments in laboratory as when they execute equivalent remote experiments. The rest 22% of students could not decide for one option.

III. E-COURSE 'BASICS OF MECHATRONICS' FOR ADULT PROFESSIONALS

Second E-course which is going to be described in this section is professional mechatronics E-training for employed and unemployed adult professionals from engineering and natural sciences. The emphasis is again put on the practical expertise, since this is the basic need of the participants from this target group. Therefore, the training includes many problem based exercises and high share of the work effort has to be put into execution of remote experiments.

The pilot training was executed with 70 participants from Slovenia in March-April 2009. Additionally the training was executed for small group of 4 participants from Austria. The majority of the participants were workers from the industry.

Also 20 primary and secondary school teachers were participating the training. Around 40% of the participants have finished vocational secondary school, around 25% vocational high school, 20% university study, while the rest provided no data concerning their educational background. Average age of participants was around 45 years. 90% (63) of the participants have successfully finished the training since intensive tutoring has minimized the drop-out rate.

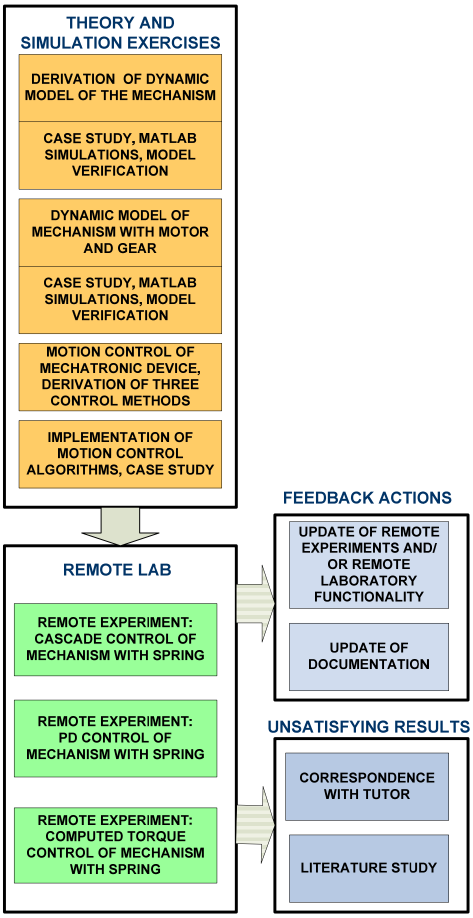

Figure 5. Course flow

A. *Course topics*

The training is composed from four modules; Introduction to mechatronics, Servomotor in mechatronics, Electrical circuits and Mechatronic devices. The whole training requires around 50 hours of intensive work. Each module is given with complete e-materials (in English, Slovene and partially also in German language). Exercises are given for each chapter and there is also an extensive e-test for each module, which is scored. Questions for self-evaluation are given for each unit. Each module also includes remote experiments. The experiments are performed on three devices: two degree SCARA robot, servomotor and circuit with different type of filters including switched capacitor filters, Fig. 6. All experiments are implemented within DSP-2 based remote laboratory [3], [11]. The content of each of the four modules is as follows:

- In the first module 'Introduction to mechatronics', the meaning of the term mechatronics and its short description is given. Then, the historical development from the pure mechanical systems to the state-of-the-art mechatronic devices is described. The structure of mechatronic systems and the role of each element of such a system are also discussed. Required time for the module is about 2 hours.
- In the module 'Servomotor in mechatronics' the role and application of the actuators with motion control in mechatronics is described. Description of the motion control problem and of few frequently used controllers is discussed first. Then, the basic operation principles of direct current motor are presented. Short description of its construction, static characteristics and equations is also given. Finally, the case study of the servomotor is performed trough the remote experiments. Required time for the course modules highly depends on the participant's initial knowledge. However, it is 15 hours on average.
- In the module 'Electrical circuits' first the fundamental elements of electrical circuits, including new fundamental element memristor, are presented. Then AC and DC electrical circuits are briefly described. The frequency characteristics and its graphical presentation in the form of the Bode plot are discussed next. Further filters are presented in the details as one of frequently used electrical circuits in the mechatronics. Emphasis is put on the passive and active low-pass, high-pass and band pass filters. Switched capacitor filters and digital filters are also described. Basic operating principles and frequency characteristics of the filters are studied trough the remote experiments executed on the passive and switched capacitor filters. Required time for the module is 15 hours on average.
- In the last module 'Mechatronic devices', the structure and operation principles of complex mechatronic devices are described. First, mechanical elements, such as the gears, the belts and the joints, are considered. As a simple mechatronic device and building block for more complex devices, a joint drive system is presented. Next, it is shown how joint drives are used to build a robot. The operation principles of the robots are explained in the case study. Finally, the real world problems in the control of complex mechatronic devices are demonstrated by executing the remote experiments with the SCARA robot. Required time is 15 hours on average.
User front end for the executing the remote experiment with SCARA robot is shown in Fig. 7 (similar are also user front-ends for other experiments). Front end is available in English and Slovene language. The user can choose between three

motion controllers and tune the controllers' parameters. Most important signals are shown in the user front end in graphical form. The live picture of the experiment is also transmitted by using Webcam client.

B. Learning portal

The e-learning platform implemented in the training is built by using eCampus system developed by a Slovene company B2, [18]. The eCampus is simpler to use then Moodle; therefore it was better choice, since some training participants were not very skilled in working within learning portals. Also visual design of eCampus system is superior to the in Moodle. For MeRLab training the original platform was partially customized to fit the requirements of the training and to enable direct connection to the remote laboratory. Fig. 8 shows the MeRLab Learning web portal [12]. Example of typical learning unit with text, scheme and question for self-assessment can be seen in Fig. 9.

Figure 6. Mechatronic devices for remote experiments

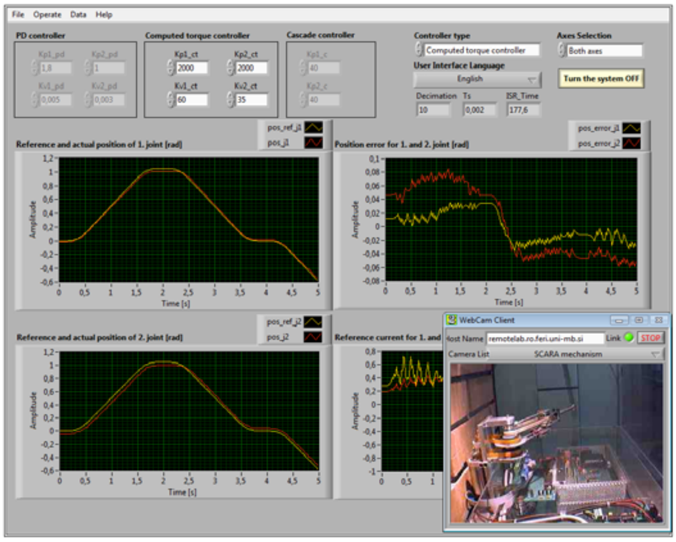

Figure 7. User interface for remote experiment with SCARA robot

C. Execution of the course

The training flow is shown in Fig. 10. Before the training one live meeting, about three hours long, was organized with all the participants. During the meeting the participants meet the instructor, have learned how to use learning portal, what will be the training flow and what exact contents of the training are.

Directly after the first meeting the online part of the training has begun. The learners were aimed to self-study the materials and answer questions for self-assessment. After each chapter there was at least one practical exercise which the participants had to solve and send the results to the instructor. The instructor then gave them the feedback about their success, additional aims and instructions for further work. The participants also had to finish assessment test for each module with number of questions from the materials and exercises. The last exercise in each module was remote experiment. The report concerning experiment also had to be send to the instructor. To pass the training, the participants had to complete all the tasks and tests in all modules with at least 50% of success.

During the training, a lot of attention was put to the communication between instructors and participates. Typically the answers to the participants' questions and feedback concerning the solved tasks and remote experiments reports were provided within few hours, while the maximal waiting time was always less than 12 hours. This was most likely also the main reason while the motivation of participants remained high during whole training. Most of the communication was done by sending the personal messages. Also phone communication was encouraged, although the learners didn't use it very much and preferred the communication through the messages. For some participants with weaker knowledge additional live meeting was organized in order to help them at understanding of specially demanding concepts.

The participants were already between the training and especially after the training asked to provide feedback and comments to the materials and training itself. Based on those some additions and improvements of the materials were made already during the training. Formal evaluation was executed at the end of training and lead to the additional changes.

Figure 8. Portal for adult learners

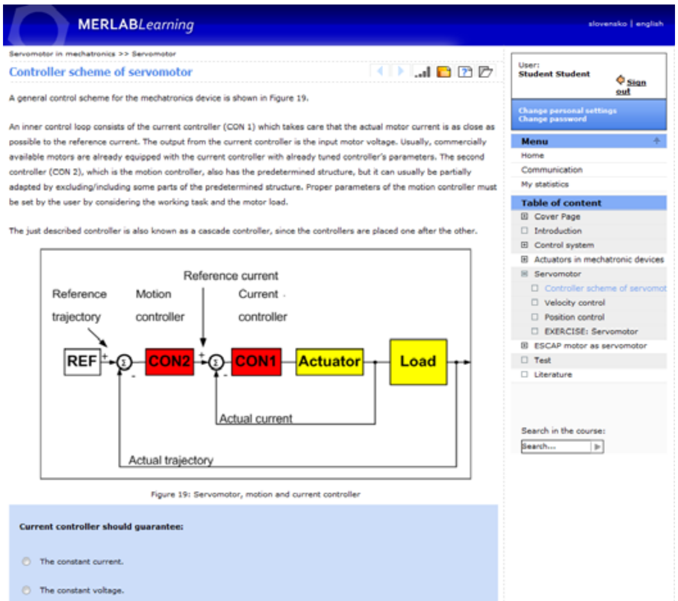

Figure 9. Learning unit

D. *Participants' feedback*

At the end of each module an evaluation was conducted based on the results of the anonymous survey questionnaire. Since the target group was different as in first course, also questionnaire was adapted. Overall the learners have responded very positively about all aspects of the training. The questionnaire was composed of statements that could be ranked from 1-Strongly disagree to 6-Completely agree. 55 participants took a part in the survey.

Following was found out:

- Almost all participants (92%) have executed remote experiments for the first time. Further, almost everybody have completely agreed (64%) or agreed (23%) with the statement 'I appreciate the possibility to execute remote experiment from anywhere and at anytime.' This really highlights the importance of introduction of the remote labs instead of local labs in the adults' education.
- Then 68% have completely agreed and 23% have agreed with the statements that installation of required software is easy and that the booking systems, as well as user front-ends for remote experiments, are easy to use. From this, it can be concluded that the whole system for execution of remote experiments is user friendly and that learning of how to operate it do not present additional burden for the participants.
- There have been some mixed answers concerning the statement 'Remote experiments were operating without any problems', where only 79% have chosen completely agree, agree and mostly agree, while 21% have disagreed. However this was caused by the antivirus programs and firewalls, which, if present, can block the access to remote experiments. However after those two obstacles were removed, everybody has been able to work with the experiments. The questionnaire's results also show that most of the participants have used the possibility to execute remote experiments for more than once.
- Almost everybody have completely agreed (76%) or agreed (17%) with the statements that the learning portal is clear and well organised and that the contents are clear and concise. Also, over 80% have completely agreed (49%) or agreed (32%) that the gained knowledge will be useful in their further career and that the contents of training correspond to the training goals. Those results are a good indicator that given content is up-to-date and also enough practically oriented.
- The participants have been very positive when valuing the E-training in general. 73% have completely agreed, 20% agreed, 7% mostly agreed with the statement 'I think the whole E-training is excellent'. No one has disagreed. Similar results have also been for the statement 'I will recommend the training to the colleagues and friends.' where 81% have completely agreed, 17% have agreed and 2% have mostly agreed. Again, there has been nobody who has disagreed.

In the free-worded feedback also collected in the survey, the participants have expressed the wish to include even more links and animations into materials. Some commented that they have lacked the time to participate in forum discussion, but overall no greater problems at the training were mentioned.

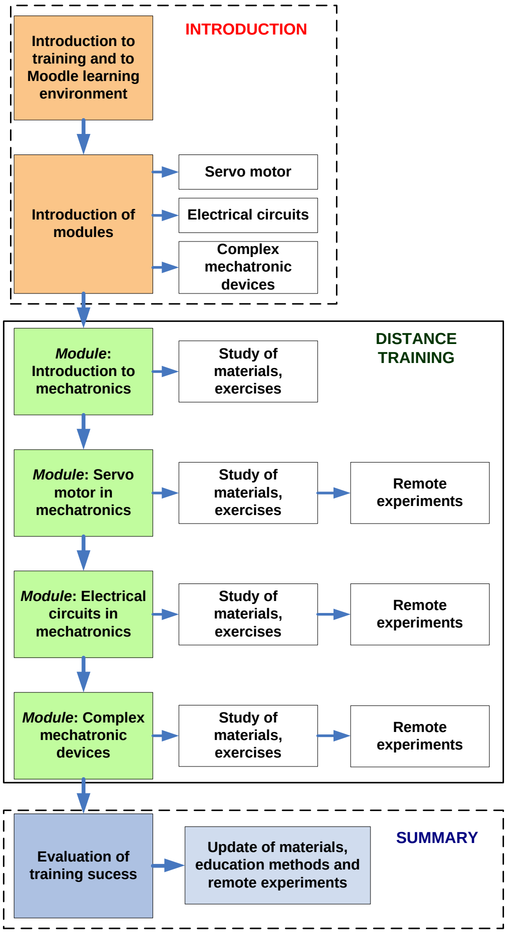

Figure 10. Training flow

IV. COMPARISON OF PARTICIPANTS' FEEDBACK FOR BOTH COURSES

Although the E-learning in both in the paper presented courses was very well accepted by participants, there are still significant differences between two learning groups. In this section we will try to discuss the reasons for difference in obtained feedback.

First, somehow surprising finding was that the majority of regular students (61%) still prefer conventional laboratory exercises over remote one, although they are very accustomed to the use of web. The situation was completely different in the group of adult participants, who have very much appreciated (what is believed to be the main advantage of remote laboratories) the time and place independency that such approach offers. Based on the experience from in-the-lab exercises with local students, the main reason for this might be that most of the students still do not come well prepared to the laboratory. Assistant, who is present in the laboratory, usually helps them with additional explanation. On the other side, at the remote exercises the students have to do everything by themselves and there is no one to provide the immediate feedback concerning the correctness of results. Then, the second reason is still the fact that remote experiments do not cover all aspects of local laboratory work since there is no direct physical contact with the experiment. For example the students do not have to deal with setting up equipment like connecting the cables or performing the measurements by analogue measuring instruments.

Also from instructor's point of view it must be said that the current technology of remote laboratories still do not enable the remote experiments to be equivalently good as the local ones. Therefore it should still be used only as supplement to laboratory exercises (also 94% of students have agreed with that) and in order to strengthen already gained knowledge (again also as 94% of students). However remote exercises are better choice then only simulation at the cases where there is not enough of available laboratory equipment or in other circumstances that make impossible to execute laboratory exercises. Such circumstances were however present in the second target group of employed professionals and in this case remote experiments were really high appreciated.

Concerning the operating specifics of remote laboratory which was used in both courses, both groups had no significant problems. This is a good indicator that booking system, software installation and operation of remote experiments are user friendly and suitable also for unskilled user.

V. CONCLUSION

Remote laboratories are believed to be a good solution in education in the cases when there is not enough available experimental equipment, when the participants have limited time, are distant from laboratory, or they have some kind of physical disability. Also introduction of remote experiments is considered as an optimal exploitation of the available technical resources.

While all this is true to great extent, in the paper described experience shows, that it is still essential to realize what limitations of such an approach has. Working with remote experiments still do not completely equals the laboratory experience, as no direct contact with instrumentation is included. Moreover, the students' answers which were gained via the questionnaire show that although the students find the remote experiments useful and an interesting supplementation of regular laboratory work, there is just a few of those who are of the opinion that such an approach could entirely replace conventional laboratory exercises. Likewise, a great majority of students are of the opinion that they learn more in laboratory than when executing remote experiments.

On the other side, the remote experiments show their usefulness when applied in the education of adults. In this case the time and place independence were much appreciated.

In the paper presented two courses are going to be implemented and regularly updated also in future. The training from basics of mechatronic which was developed for adult professionals is also going to be commercially offered to the companies for the supplementary education of their employees. Therefore, it can be expected that the training will, in the future, at least partially fill the gap between low number of available formally educated mechatronics and high market requirements in Slovenia.

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