E-Training in Mechatronics for Professionals

Implementation and Experience

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***Abstract*—Mechatronics is in most of the European countries still the profession in which the need for competent and qualified staff exceeds the number of formally educated professionals. E-training in mechatronics presented in this paper is developed in order to at least partially fill that gap. MeRLab training (Innovative Remote Laboratory in the E-training of Mechatronics) offers innovative way for acquiring knowledge and skills in mechatronics by offering the high-quality educational materials enhanced by the remote exercises executed on various mechatronic devices and constant supervision of the training instructor. As a basic educational approach, the problem based learning was chosen. During the training this approach was stimulated by introducing a number of complex, practically oriented exercises that finish with the remote experiments. Pilot testing of the training was executed with 60 participants, mostly professionals from related fields such as mechanical and electrical engineering. Most of the participants are employed in the industry, while some were the teachers from secondary or high vocational schools. Feedback from the participants shows that overall response to the training is very good, as the majority of participants think that the training fulfils the goals, that the materials are clear and concise, that the exercises and tests are adequate, and, that the whole learning contents is excellent.**

***Index Terms*—Mechatronics, e-training, remote laboratory.**

I. Introduction

In the paper presented professional mechatronics e-training MeRLab is designed for employed and unemployed professionals from engineering and natural sciences who have already completed their formal education and want to acquire some basic mechatronics knowledge. The training was developed from practical experience gained with the high vocational study of regular and part time students at University of Maribor, Slovenia and after doing some market research. Emphasis is put on the practical expertise; therefore, the training includes problem based exercises and remote experiments on real mechatronic devices. The mechatronics remote experiments are, due to the highly demanding design and maintenance, until now used only in the regular education at the universities [1-4] where they are mostly still in the test period. Such experiments are novelty in the practical professional adult education.

The training comprehends four modules; Introduction to Mechatronics, Servomotor in Mechatronics, Electrical Circuits and Mechatronic devices. Each module introduces materials, sets of problem based exercises and remote experiments. For completing the training approximately 50 hours of intensive work during the time period of six weeks is required.

When designing the training environment two learning platforms were combined, a learning portal based on eCampus systems and remote laboratory based on Moodle platform. The result is new, very efficient and user friendly platform that enables both attractive visual design and implementation of different functionalities such as the booking system for remote experiments.

The pilot training was executed with 60 active participants, mostly employed in industry and some secondary and high vocational school teachers. Since in the training a high emphasis was put to the supervision of the learners, the dropout rate was minimal. Evaluation of the training was done according to the anonymous e-survey.

The reminder of the paper is organized as follows. In the second section the learning environment is presented. Third section describes the training organization. Fourth section presents the contents, educational objectives and exercises, as well as the details about implementation and content of one of the remote experiments. In fifth section the evaluation of the training based on the learners' feedback is presented. In the last sections summary is given.

II. Learning Environment

A. Learning portal

The e-learning platform implemented in the training is built by using eCampus system [5] developed by a Slovene company B2, [6]. The system is being used in the field of computer education, IT services and formal education in high schools, college as well as for the adult distance education. The eCampus is according to the usability testing [7] in some aspects better as frequently used open source Moodle system [8]. This is especially true when it comes to the visual design of e-learning content. 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. 1 shows the MeRLab Learning web portal [9]. When entering the portal, the users see the modules to which they are enrolled. For an each module, the basic information such as short summary, educational objectives, target group, required preliminary knowledge and the time requirements, are given. The modules are composed from learning units trough which the users can navigate by using the tree structure showing the modules' contents. Each module in the training also has a working map, where additional files are stored, like for example

more detailed materials which are not part of obligatory materials, different data sheets and similar. The user can see his study progress by inspecting the icon, which shows the percentage of the material that he has already read through. User can also add his own comments to the each unit, which are visible only to him every time he enters the unit. There is also an option to directly contact the instructor by sending a personal message which automatically includes the title of the learning unit from which it was sent. This option is used in the cases when the learners have some specific questions concerning the learning unit. Search function is also provided.

The typical learning unit is shown in Fig. 2. The unit comprehends the explanation and equations, usually also a photo or a scheme and a motivational question. The motivational question should be answered immediately after studying the learning unit and it provides the user with instantaneous information about gained knowledge and understanding.

Each module includes practically oriented exercises and also final assessment test. The results of the final test are shown immediately after the user executes the test. The user is also provided with the information which questions were answered correctly and which not; however for the wrong answers the right answer is not provided. The results of all tests can be any time seen in the menu under 'My statistic'. At the end of each module there is also the anonymous survey questionnaire which provides the learners' feedback to the author and instructor of the training.

The communications options available to the user include forums, new messages and messages archive. After signing to the portal the user sees new messages and last three forum posts directly. Also the latest information provided by the training instructor is shown on the first page.

B. Learning management system

Monitoring and evaluating the learners' activity during the training is of major importance for successful distance education. Especially helpful to the instructor are systems that gather and analyze the information concerning the learner's study behavior [10]. eCampus system provides a number of the tools for course management, user administration, analysis and progress tracking. Following tools are available:

- Searching for the user. The search can be conducted by using the learners first or second name as well as the learner's user name. After conducting the search, the page with learner's data is displayed. It is possibly to change the data, to send a personal message, to change the learners working group or enroll him in the courses/modules.
- Signing in the new user. This option allows easy creation of new user account.
- Overview of the assessments results. The results of the assessments test are showed for selected learners groups, time period and modules. Also data which questions were answered correctly and which wrong are available for an each learner.
- Overview of the survey questionnaire results. The

Figure 1. Front page of the learning portal

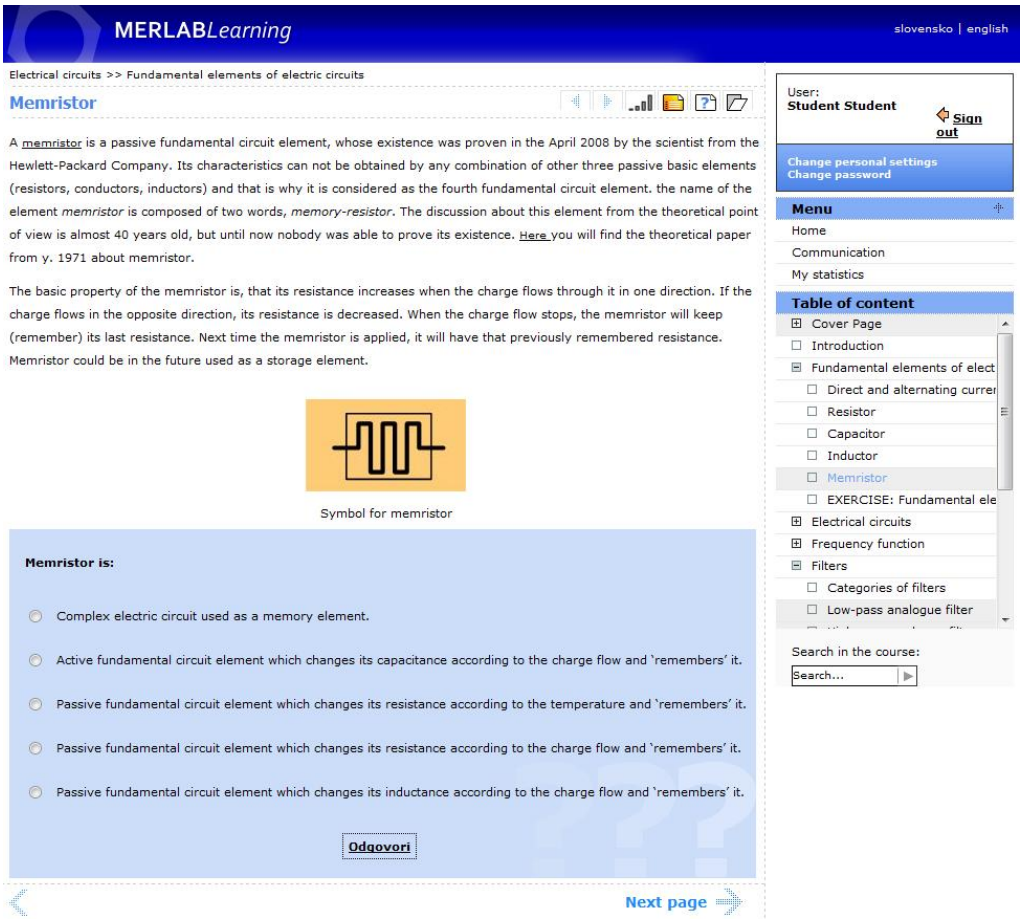

Figure 2. Learning unit

results of the survey questionnaire are shown for separate modules and groups of learners. The results can be exported to the formatted table in Excel.

- Overview of the user's activity. The users activity data such as the date of first and last visit, study progress in percents and study time spend for each chapter and all together, are shown.
- Daily users' activity. This tool gives the information on which days the learner has visited the portal and his activity in that day.
- Presence of the user. The list of users present at the portal is shown.

By using this tools, actions such as sending a messages to the learners every time they have finish one of the assessment test, are possible. Additional analysis also enables improvement of the materials. For example, if it was found out that many learners have answered the same questions wrong, additional explanations were added to the materials. Further, analyzing the access of the learners to the portal and time spent for study enabled the instructor to find the learners who were behind with study and send them messages in order to motivate them for more regular study. Also in the cases, when the analyses has shown that the learners needed unusually long time for completing single exercise, the messages with additional help and examples were sent to the learners.

C. Remote laboratory

The significant parts of the training are remote experiments performed within DSP-based Remote Control Laboratory [11]. Therefore an efficient connection between the eCampus based learning portal and remote laboratory had to be established.

Remote laboratory is independent web portal which is due to the specific needs built on the Moodle platform. It includes few additional features such as downloads and the booking system. User account is required. Before engaging in the remote experiment, the participants must book the time slot in the booking table, Fig. 3. When the booking is valid, the users can proceed to the experiment. For each booking, a new web page with user front end is created and is valid only for the booked time slot and the user who booked the time slot.

In order to spare the user the burden of double signing in the automatic connection between eCampus system and Moodle was established. When a new user is added to the data base in the eCampus system also a new user in the remote laboratory is created with the same user name and the same password.

In the learning units where remote experiments should be executed, there is a direct link to the booking table in remote laboratory which, when the booking is valid, opens the user front end and enables control over remote experiment. Since this transition from the eCampus learning portal to the booking table and further to experiment is direct, the users do not notice that the platform has changed.

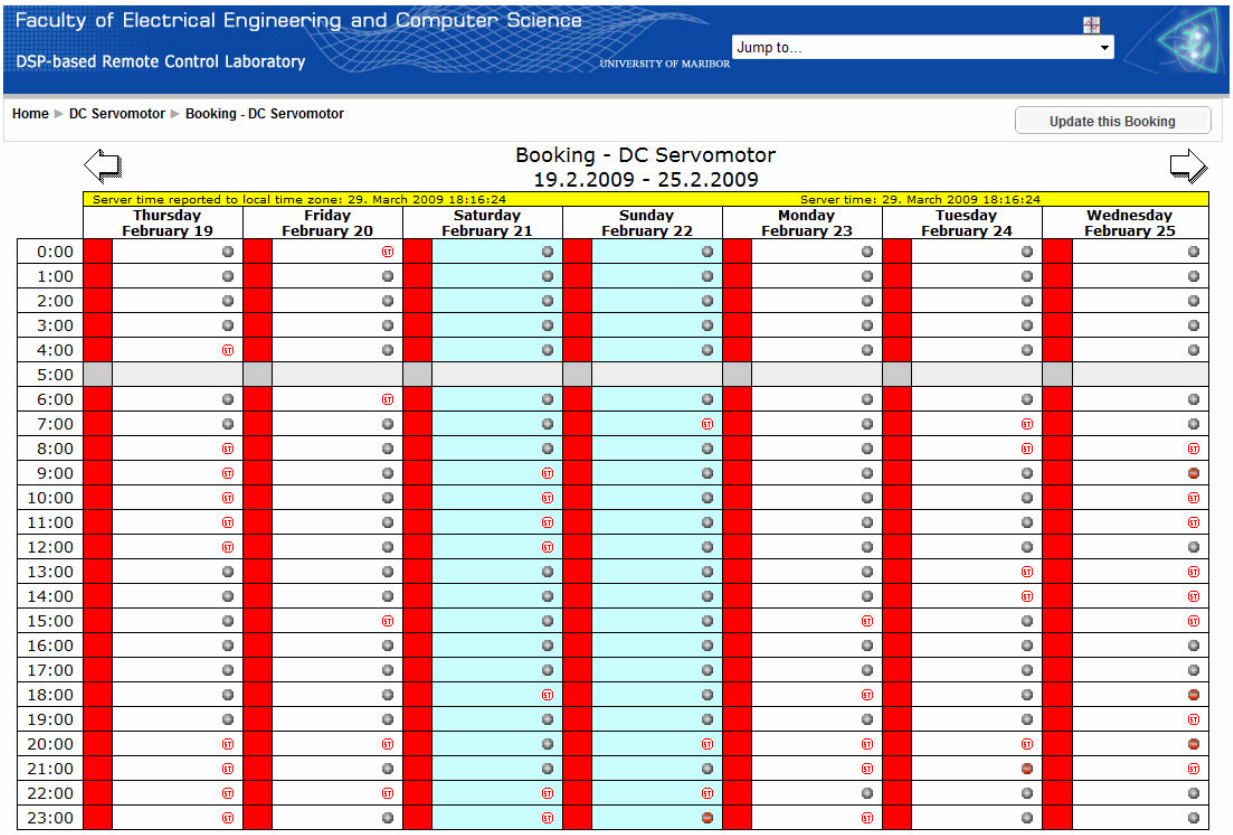

Figure 3. Booking table

III. Organization of the Training

E-training was supervised by the instructor who was also the author of the materials and designer of the remote experiments. The training flow is shown in Fig. 4. Before the training one live meeting, about three hours long, was organized with all the participants. Due to the large number of participants this was done in few smaller groups. The purpose of the meeting was:

- to establish the contact between the instructor and the learners,
- to teach the learners how to use web portal,
- to present the learners the training concept and how the training will be executed,
- to present the learners the modules and remote experiments.

Directly after the first meeting the training has begun. The training was divided into logical modules: Introduction to mechatronics, Servomotor in mechatronics, Electrical circuits and mechatronic devices. The learners were aimed to self-study the materials and answer motivational questions. After each chapter there was at least one practical exercise which the users had to solve and send the results to the instructor, who 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. The last exercise in each module was remote experiment. 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 were provided within few hours, while the maximal waiting time was always less than 12 hours. The learners were also whole time encouraged to send the question about the materials and exercises. 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.

IV. Training Contents

In the continuation of this chapter each of the four training modules, educational objectives and practical exercises will be described. Also the remote experiment included in the last module will be presented in more details.

A. *Module: Introduction to Mechatronics*

In the module, the meaning of the term Mechatronics and a short description of this new technical field 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.

Educational objectives:

- Acquaintance with the field of Mechatronics.
- Acquaintance with the historical development from mechanical to mechatronic systems.
- Acquaintance with the structure of mechatronic systems and the role of its elements.

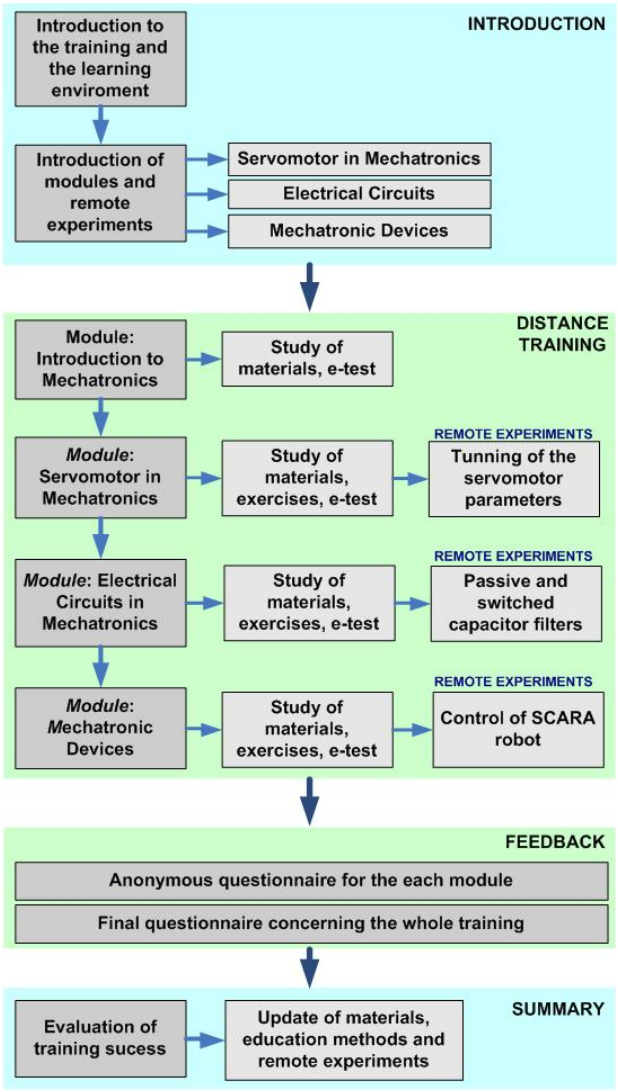

Figure 4. Training flow

B. *Module: Servomotor in mechatronics*

In this module the role of the controlled actuators in mechatronics is described. Description of the motion control problem and of few frequently used controllers is given first. Then, the basic operation principles of direct current motor are presented, together with a short description of its construction, static characteristics and equations. 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.

Educational objectives:

- Acquaintance with the role of actuators in the mechatronic devices.
- Understanding the basic operation principles of direct current motor.
- Understanding of the steady-state motor characteristics and motor data as are usually provided by the manufacturers of motors.
- Understanding the principle of open loop control and feedback control.
- Ability to tune control parameters of servomotor and implement servomotor as a drive in mechatronic devices.

The module includes few problem based exercises which direct the learners to study important topics in more details. The exercises include:

- Open loop and feedback control. The learners should list and explain few cases of open-loop and feedback loop control systems. Also some concrete problems of tuning PID controller's parameters have to be solved.
- Operation principle of the direct current motor. The learners should explain how direct current motor works by describing a provided animation.
- Direct current motor characteristics. Based on the producer data sheet the learners should calculate some data such as maximum torque and angular velocity, required voltage input to reach desired velocity, viscous friction parameter and motor power.
- Servomotor. The learners should list and explain the usage of servomotors in modern cars.
- Remote experiment. The users perform open loop control of the motor and analyze the results. Afterward, the tuning of the servomotor parameters (feedback control) should be executed.

C. *Module: Electrical circuits*

In this module 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 is 15 hours on average.

Educational objectives:

- Understanding the operating principles of the fundamental elements of the electrical circuits.
- Ability to calculate frequency response of the electrical circuit.
- Understanding operating principle of the passive and the active filters.
- Ability to design passive and active low-pass, high-pass and band-pass filters.
- Acquaintance with the operating principle of digital and switched capacitor filters.
- Knowledge of how to measure the frequency characteristics of the filters.

Problem based exercises in the module include:

- Description of the possible usages of memristor in modern mechatronic devices.
- Calculation of the impedance, usage of operational amplifier 741.

- Analysis of the electric circuits by using Bode plot. The exercise includes calculation of the magnitude and the phase of the output signal, if the input signal and Bode plot are given.
- Design of the passive filters. The learner should design various types of the filters (low-pass, high-pass, band-pass) and sketch Bode plots.
- Remote experiments. The learner should measure the magnitude function of the passive analogue filter and draw the magnitude plot. Also the magnitude function of the band-pass filter with switched capacitors should be measured and sketched.

D. Module: Mechatronic devices

In the last module, 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.

Educational objectives:

- Acquaintance with the structure of complex mechatronics devices.
- Acquaintance with the mechanical elements of mechatronic devices.
- Ability to design a joint drive system.
- Acquaintance with the basics of robotics, robot kinematics, dynamics and motion control.
- Understanding of the real word problems in the control of the complex mechatronic devices.
- Ability to tune the parameters of the position controller of the mechatronic device.

Problem based exercises in the module include:

- Analysis of joint drive system. The learners had to write the dynamic equations of motion for system with actuator, gear and a specific load. Then they calculated what load can be implemented when gears with different gear ratios are used.
- Biomimetics and modular robots. The task is to choose and study one biomimetic or modular robot. Following had to be described: construction of the robot, for which working tasks the robot is suitable, which are the most challenging problems at the design and implementation of such robot, number of drives, sensor and implemented controller.
- SCARA robots. Learners are aimed to search for data and describe commercially available SCARA robots. They should also list the working tasks for which are such robots are appropriate and reason the answer.
- Remote experiment. In the remote experiment the learner tune parameters of few different position controllers and investigate dynamic influences between the robot joints.

E. Example of remote experiment: SCARA robot

Remote experiments on three different devices are offered in the training. One of the experiments is performed on two degree of freedom SCARA robot.

SCARA robot was designed specially in order to be implemented in education and for remote experiments. The joints of robot are driven by two direct current motors which are mounted on the robot base. The advantages of such solution are the lower moving masses and therefore also lower inertias of the robot's joints. Each of the motors is equipped with the incremental encoder. Arm joints are connected to DC motors through the driving belts and the gears. As a controller for SCARA robot a special extended robotic version of DSP-2 control system is applied. The control system was developed at the Institute of Robotics, Faculty of Electrical Engineering and Computer Science, Maribor and is described in [12].

User front end for the executing the remote experiment with SCARA robot is shown in Fig. 5. Front end is available in English and Slovene language. The user can choose between three motion controllers (cascade, PD with position and velocity loop, computed torque) and tune the controllers' parameters. Most important signals are shown in the user front end in graphical form. This includes the reference and actual position of both joint, position errors of both joints and the reference and actual current of both joints. Some other signals are shown in numerical form. As it can be also seen in the Fig. 5, the live picture of the experiment is also transmitted by using Webcam client.

The user can choose the simultaneous movement of both joints, or movement of just one joint. In the case when motion of only one joint is chosen, the second joint is held in the zero position by the controller. When executing the tasks trough remote experiments, the user should first measure the response (errors and currents) of the robot with different controllers and different parameters. Next, the movement of only first joint should be chosen. The user must observe the influences of motion of moving joint to the non-active joint and comment the results. The results of all controllers must be compared and commented. It is also expected that the participant give some prepositions how the efficiency of the controller could be improved.

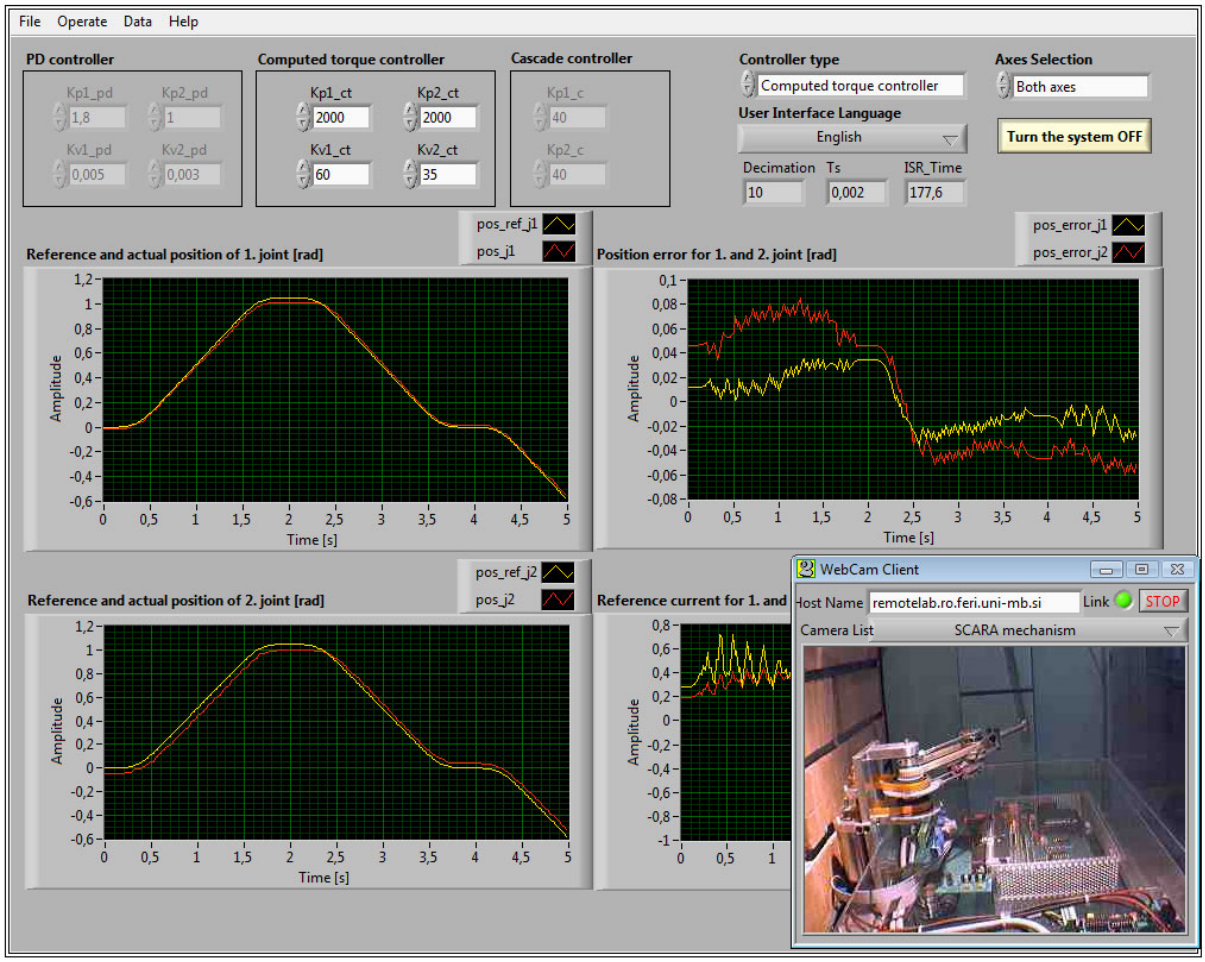

Figure 5. User front end for remote experiment with SCARA robot

V. Evaluation

At the end of each module an evaluation was conducted based on the results of the anonymous survey questionnaire. Overall the learners have responded very positively about all aspects of the training. Following results were obtained from 55 learners:

- To the statement 'The contents of the training correspond to the training goals' 5 participants (9%) choose answer 4 –somehow agree, 18 (33%) answer 5-mostly agree, while 32 (58%) choose the highest possible answer 6 - completely agree, Fig. 6.
- For the statement 'The learning time flied quickly' two participant have chosen answer 2, 2 participants answer 3, 5 participants answer 4- somehow agree, 14 (27%) answer 5-mostly agree and 32 (58%) answer 6-completely agree, Fig. 7.
- For the statement 'I like the visual design of learning portal', one participant has chosen answer 3, two participants answer 4-somehow agree, 14 (25%) answered 5-mostly agree and 38 participants (69%) answered 6 completely agree, Fig. 8.
- For the statement 'Motivational questions are well chosen' 2 participants have chosen answer 4-somehow agree, 19 (34%) have chosen answer 5-mostly agree and 34 (62%) the answer 6-completely agree, Fig. 9.
- For the statement 'Assessment test are adequate' 2 (4%) participants have chosen answer 3, 4 (7%) have chosen answer 4-somehow agree, 9 (16%) have chosen answer 5-mostly agree and 40 (73%) the answer 6-completely agree, Fig. 10.
- For the statement 'The content is clear and concise' 1 (2%) participant has chosen answer 3, 7 (13%) have chosen answer 4-somehow agree, 21 (38%) have chosen answer 5-mostly agree and 26 (47%) the answer 6-completely agree, Fig. 11.
- For the last statement 'I estimate the whole e-learning content as excellent' one participants choose option 3, two participants option 4-somehow agree, 17 (31%) option 5-mostly agree and 35 participants (63%) the option 6- completely agree, Fig. 12.

In the questionnaire the learners were also encouraged to give additional remarks. First they were asked what they specially liked in the module and then, what they were missing or disliked. Under things that they liked mostly following was stated:

- remote exercises,
- clear and concise materials,
- animations,
- web links,
- fast response of the instructor,
- practical examples,

- motivational questions,
- everything.

Under things that they disliked following was stated:

- nothing, I liked everything (most of replies),
- I prefer conventional in-the classroom lectures,
- more animations,
- not seeing how perfectly solved exercise looks like.

In accordance with this analysis few minor improvements concerning the contents and the training should be considered in the future.

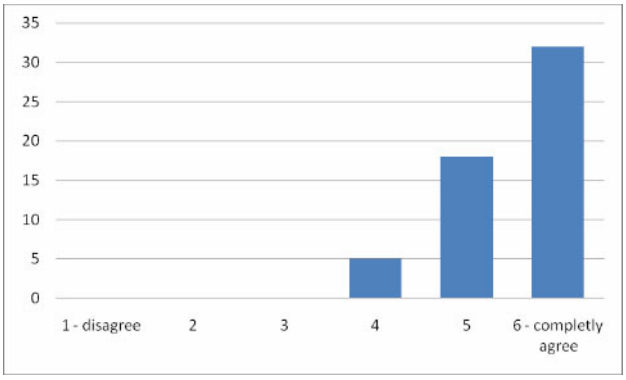

Figure 6. Feedback for the statement 'The contents of the training correspond to the training goals'.

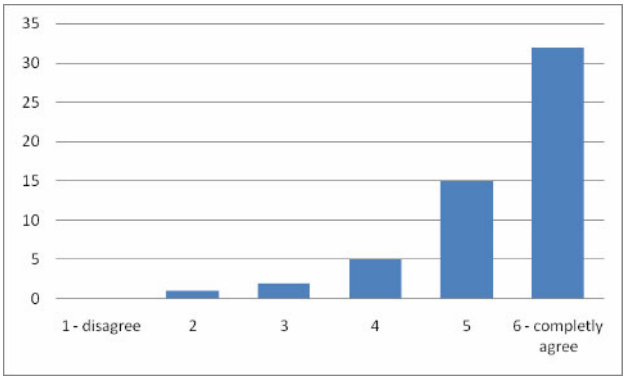

Figure 7. Feedback for the statement 'Learning time flied over quickly'.

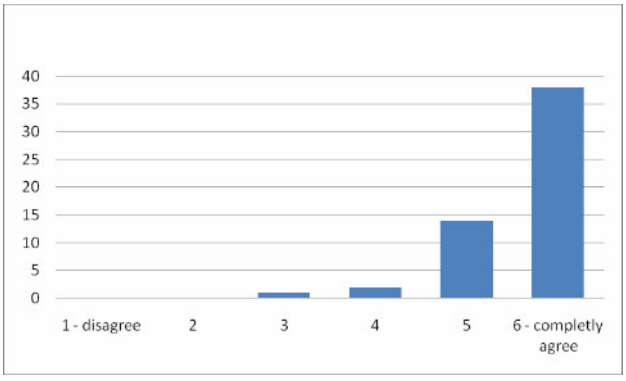

Figure 8. Feedback for the statement 'I like the visual design of the portal'.

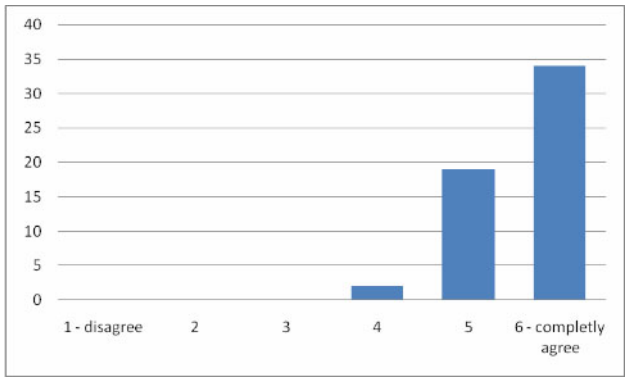

Figure 9. Feedback for the statement 'Motivational questions are well chosen'.

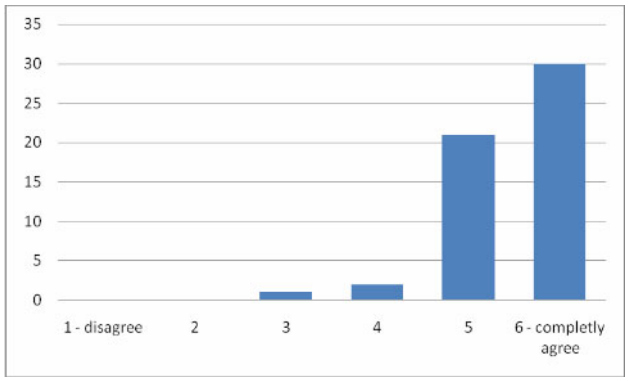

Figure 10. Feedback for the statement 'Assessment test are adequate'.

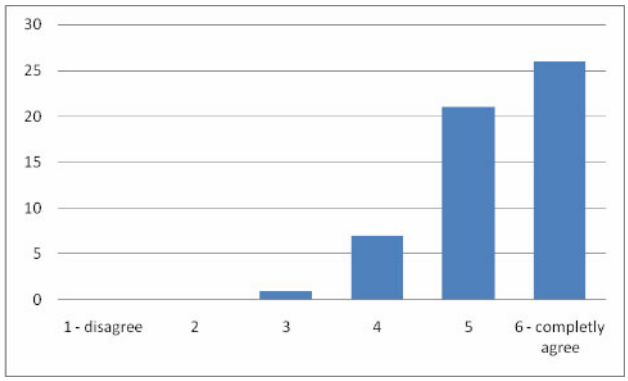

Figure 11. Feedback for the statement 'The content is clear and concise'.

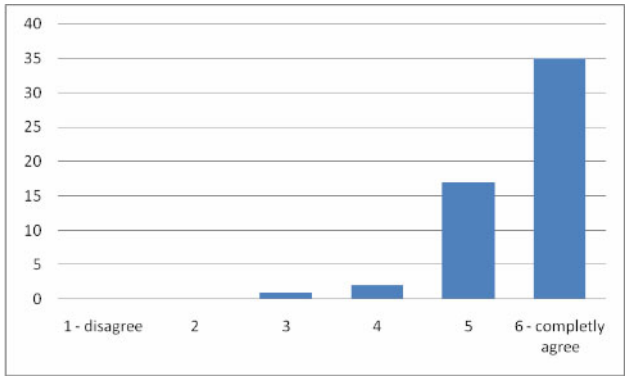

Figure 12. Feedback for the statement 'I estimate the whole e-learning content as excellent'.

VI. CONCLUSION

It is obvious that e-learning method of knowledge transfer makes a significant way into all education levels including vocational education and training. Key to the successful project outcome, that is satisfied learners enriched with useful knowledge and great experience are (i) reliable, adjustable and user-friendly learning management system such as eCampus, (ii) multimedia and interacition based e-learning material with practical experience, such as remote experiments and (iii) competent experts who can and want to motivate trainees to reach the learning goals.

Based on the feedback obtained from the participants of in the paper presented mechatronic training, we strongly believe the described approach of e-training is the modern, innovative and inspiring way how to proper satisfy the growing needs of our time.

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