MODESTUM
OPEN ACCESS

Development of a Remote Laboratory Infrastructure and LMS for Mechatronics Distance Education

Ayça Ak [1*], Vedat Topuz [1], Aysun Altıkardeş [1], Bekir Oral [1]
[1] Marmara University, Vocational School of Technical Sciences, Istanbul, TURKEY

ABSTRACT
The problem in schools with mechatronics programs is not only their low student capacity but also their theoretical-content-dominated curricula. However, the manufacturing industry needs highly-talented technical personnel with a lot of practice in this field. E-Learning Education for Mechatronics Remote Laboratory, EDUMEC, offers practical-content-dominated courses over the Internet. The situations and expectations of the target groups were designated using surveys to constitute the educational concepts for the e-mechatronics program and experiments. The target groups are students in vocational schools or engineering classes; engineers or technicians who have completed formal education in mechanical engineering, electrical/electronic engineering, or other technical fields; employers; and teachers. For training, a special multi-lingual e-learning platform has been built in a user-friendly environment with a Learning Management System (LMS). This paper presents the design and implementation of the remote laboratory and LMS. In addition, evaluations by the students who participated in the training are presented.

Keywords: e-learning, mechatronics, online education, remote laboratory

INTRODUCTION

The term "mechatronics" was popularized as technical terminology by a Japanese company, Yaskawa Electric Corporation, and since 1971, it has been protected as a trade name. In the early period of its use, mechatronics was understood as the design and construction activities concerning the inclusion of electronics and systems to the functional structure of various precision mechanisms. Mechatronics is an approach to engineering design that integrates mechanical, electrical and electronic, and computer engineering for a wide range of products and processes.

High-quality mechatronics education is important because there is a clear correlation between a company's economic power and the promotion and development of its junior staff. To be able to persist in global competition, a company requires a well-educated workforce. Engineers must be able to work in interdisciplinary teams, which generally have a multi-cultural composition, and may even be located in distributed places. Specifically, workers must know integrated methodology and design of not only products but also projects and processes. This shift away from traditional work and organizational models toward teamwork and inter-disciplinary projects requires an opposite consideration and response in the form of education (Welp, Labenda, & Jansen, 2006).

A major goal of mechatronics education is to instill students with theoretical operational knowledge as well as practical competencies in the core technical skills. There is a growing need for qualified service personnel in mechatronics, rather than in pure mechanics or pure electronic control technologies (Shetty, Kondo, Campana, & Kolk, 2002).

A well-educated high-performance workforce that possesses practical skills is difficult to assemble in today's world of rapidly changing technology, especially in the electro-mechanical and mechatronics fields. The traditional practice in enterprises globally is to provide training/retraining to their employees via conventional in-company

✉ aycaak@marmara.edu.tr **(*Correspondence)** ✉ vtopuz@marmara.edu.tr ✉ aaltikardes@marmara.edu.tr
✉ bekiroral@marmara.edu.tr

Contribution of this paper to the literature

- A model for practical training of advanced and industrial areas that requires expensive equipment using innovative remote laboratory.
- The development of educational model by content analysis for the online Mechatronics education.
- Multi-lingual special E-learning platform in the user friendly environment with Learning Management System.

training, which can be organized by themselves internally, by hired educators or, quite often, by the producers of the industrial equipment. In the European Union (EU), 38% of the companies rely on such internal training. However, a closer look shows that not all employees participate in such training owing to family responsibilities (40%) or a conflict with their work schedule (39%) (Ferreira & Müller, 2004). It is clear that this training approach usually does not accommodate the individual needs of practicing engineers and technicians. Further, this approach usually does not leverage communications technology and distance learning to accommodate different learning styles.

Aside from in-company training, many other sources of continuing education are used today. Statistically, 32% of the total population in the EU consults the Internet for self-directed learning. However, the use of the Internet to attend online courses is relatively low, reaching only 5% in this group in 2010. Additionally, this rate is growing slower than expected, increasing by only 2 percentage points from 2007 to 2010 (Eurostat, 2013).

E-learning methods are similarly used infrequently for in-company training in the electro-mechanical-mechatronics industry. Experiments that can be conducted remotely are essential for training technicians and practicing engineers in technical professions.

In the field of mechatronics, various remote experiments and remote laboratories have been developed (Basso & Bagni, 2004; Casini, Prattichizzo, & Vicino, 2004; Castellanos, Hernandez, Santana, & Rubio, 2005; Corradini, Ippoliti, Leo, & Longhi, 2001; Gadzhanov, Nafalski, & Nedic, 2014; Hercog, Gergic, Uran, & Jezernik, 2007; Ko et al., 2005; Salzmann, Gillet, & Huguenin, 2000; Sanchez, Dormido, Pastor, & Morilla, 2004; Tan, Lee, & Leu, 2000; Valera, Diez, Valles, & Albertos, 2005). Most of these studies provided training in only a limited number of experiment facilities through a single set. In addition, most of these studies utilized the LabVIEW or MATLAB platform. The number of studies offering both training opportunities and experiments is very low. The study by Xu et al. (2013) is unique in that the authors introduced an Internet-based remote-controlled robot crossover project through an international cooperative program based in Japan, China, Thailand, and Taiwan.

Rojko et al. (2011) had represented the Merlab project in their study. In Merlab project the training, special E-learning platform has been built in the user-friendly environment, which is based on a combination of commercial eCampus platform and open-source Moodle platform. The sets in the Merlab project are two degrees of freedom SCARA robot and a servo motor. Rodrigiuez et al. (2015) presented hardware and software architecture for developing educational laboratories by connecting real programmable logic controllers (PLCs) to virtual industrial plants. Fernandez et al. (2015) demonstrated how using mechatronics and robotics in distance education can be a motivational tool to promote retraining for people of all ages who received minimal training during engineering.

The "E-Learning Education and Innovative Remote Laboratory for Mechatronics" project, which we call EDUMEC, was co-funded by the European Union Lifelong Learning Program called Leonardo da Vinci Transfer of Innovation Action. This project was conducted by eight project partners under the leadership of Marmara University Vocational School of Technical Sciences. The other project partners are Festo, Çizgi-Elektronik, and TEGEV from Turkey; the University of Versailles Saint-Quentin-en-Yvelines and the Universite de Technologie de Belfort-Montbeliard from France; Zavod Prava Poteza from Slovenia; and the Czech Republic VSB - the Technical University of Ostrava from the Czech Republic.

The main aim of the EDUMEC project is to introduce good practices into vocational training in mechatronics related to national and international qualifications. To realize this goal, we leveraged information and communication technologies (ICT) and established methodological as well as didactic approaches. All training materials were prepared according to levels 3, 4, 5, and 6 of the European Qualifications Framework (EQF).

The EDUMEC project is unique compared with similar studies owing to the following novel aspects:

- Multilingual Web portal (English, Turkish, Czech, Slovenian, and French),
- Innovative real-time control platform (RTCP),
- Up-to-date remotely controlled laboratory (RCL),
- Multilingual pedagogical course books for self-learning,
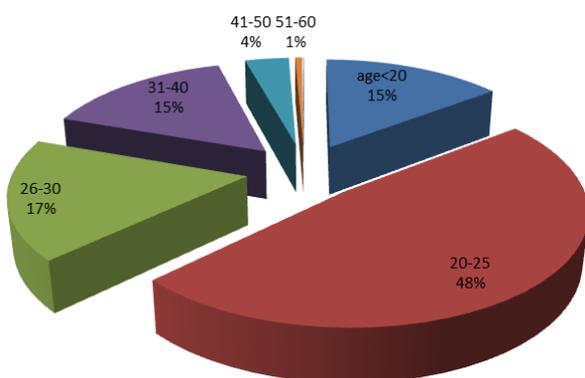- The opportunity for advanced and industrial learning with three experimental sets.

Figure 1. Age distribution of student participants

Anyone who wants to improve their technical knowledge/skills can benefit from the educational opportunities offered by this project free of cost. Membership is compulsory to participate in this project and get an appointment to perform experiments using the appointment system.

Analyses of the knowledge and skills requested by students and trainers are presented in Section II. The infrastructure of e-learning mechatronics education in the remote laboratory is shown in Section III. Section IV presents the evaluations by the students who participated in the EDUMEC program. Finally, the conclusions are given in Section V.

ANALYSIS OF THE SITUATION AND CONCEPTUAL DEVELOPMENT

The first important part of the EDUMEC project is analyzing the situation and conceptualizing the educational approach. The analysis included situation analysis and evaluation of the pre-requirements for implementing development education in vocational education and relevance of the European labor markets, identification of stakeholders, exchange of good practices and concepts for module development and development of an e-mechatronics program.

In this part of the project, an analysis of needs concerning knowledge and skills as requested from industrial partners was conducted. The goal was to analyze the cognitive and formative knowledge of the target groups, analyze learning levels and explore advantages and disadvantages of the methods and content applied to the in-house training of partners. Finally, an analysis of the needs related to education methods in in-house training was performed.

For the situation analysis and the evaluation of requirements, questionnaires were distributed to students and teachers in three countries: Turkey, France, and Slovenia. More than 1,000 students participated in the survey. Female participants constituted only 10% of the survey participants. The age distribution of the participating students is shown in **Figure 1**.

Almost 450 of the surveyed students had earned a Bachelor's degree. The second-most frequent educational level was vocational and high school. Nearly 70% of the survey participants had consistent employment and just over 200 participants had part-time employment or were freelancers. Most of the students who participated in the survey expressed an interest in mechatronics, IT, software engineering, electronics and robotics (**Figure 2**).
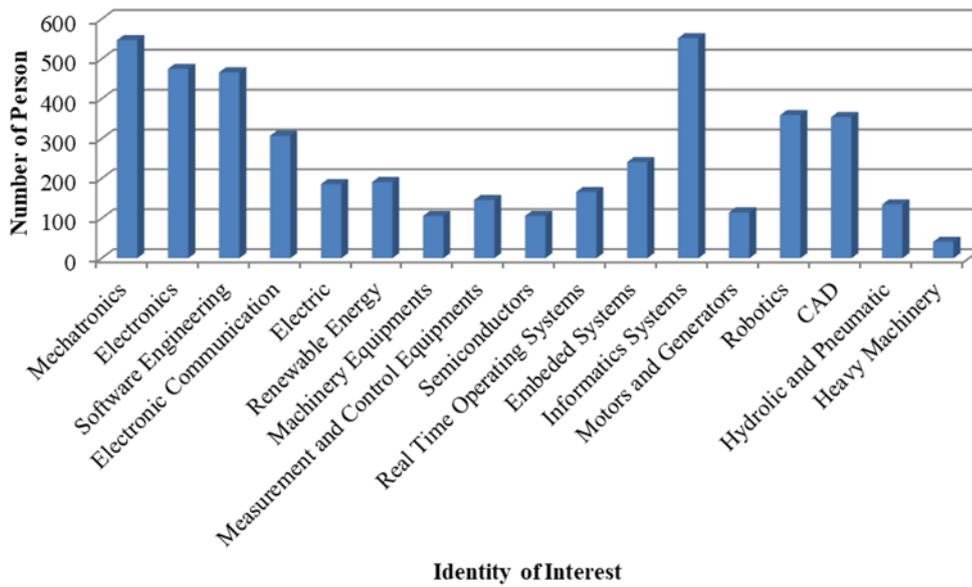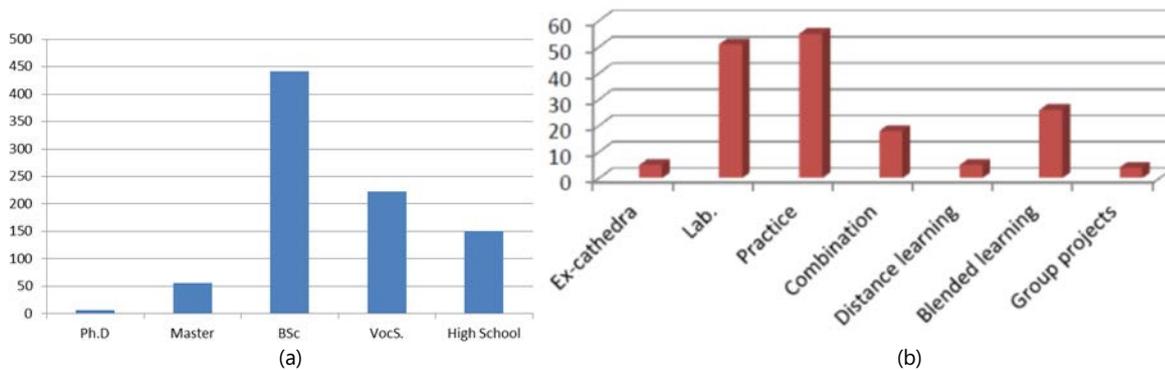
Figure 2. Interest in various fields

Figure 3. (a) Educational level and (b) Most commonly used learning styles in the participating organizations

More than 600 of the student participants believed that they were able to find and select information from various sources such as the Internet. Nearly 60% of the students stated that they could quickly adapt to new working methods and technologies: around 20% reported that they are good at adapting and only a minority thought their adaptation abilities were unsatisfactory. Just above 50% of the participants agreed that they are very good at multi-tasking and another 20% reported that they are good at this skill.

Nearly 65% of the student participants reported that they are very good at using hardware equipment and another 30% responded that they were good at it. More than 800 students reported that they are very good or good at using selected word-processing programs. Nearly all the participating students responded that they are good or very good at using e-mail. Only a minority of students said that they do not have skills in searching the Internet. 85% of the students said that they are active in at least one Internet forum/chat room. 96% of the students had personal computers with an Internet connection at home. Nearly half of the students had already participated in an e-learning course and most of these found it useful. 71% of the participants had already participated in informal training programs that were not part of their formal education.

More than 75% of the participants had never operated a mechatronic device through the Internet. There are various reasons for not participating in e-learning courses, including more than 520 students reporting that no such course had been organized until then; 11% said the reason was lack of time, about 5% said the training schedule did not fit their working obligations, and another 5% was not interested in such education.

In the questionnaire for educators/teachers, 183 people responded. Most of the participating organizations had over 700 students. The educational levels of these organizations are shown in **Figure 3a**. The most commonly used learning styles in these institutions are shown in **Figure 3b**; the most frequent responses were practice, laboratory work, and blended learning.

Table 1. Preferred Lessons

| Name of the Course	Definitely Should (5)	(4)	(3)	(2)	(1)	Definitely Should Not(0)
Fundamentals of Electrical Engineering	18%	8%	13%	10%	8%	43%
Fundamentals of Mechanical Engineering	13%	6%	12%	10%	5%	50%
Mechatronic Systems and Devices	30%	15%	11%	6%	8%	33%
Introduction to Automation	24%	14%	12%	8%	8%	37%
Introduction to Robotics	31%	14%	12%	5%	4%	34%
Applied Sensor Systems	20%	11%	13%	6%	4%	46%
Applied Control Systems Theory	14%	9%	13%	6%	5%	53%
Servo Drives	12%	7%	12%	7%	6%	57%
Power Electronics	12%	19%	11%	6%	6%	57%
Electrical Circuits	16%	12%	11%	8%	4%	49%
Digital Systems	22%	13%	11%	5%	3%	46%
Industrial Robots	17%	9%	10%	6%	4%	54%
Robot Programming	32%	11%	10%	5%	3%	38%
Micro Controller and Embedded Systems	24%	8%	10%	6%	4%	48%
Signal and Image Processing	16%	10%	11%	7%	4%	52%
Building Management Systems	9%	7%	11%	7%	5%	61%
Computer Aided Measurement and Control	21%	8%	11%	8%	4%	43%
Manufacturing Technology	11%	6%	12%	13%	8%	58%
Materials Science	8%	8%	9%	8%	6%	61%
Engineering Software	31%	13%	10%	7%	3%	37%
PLC Controllers and Industrial Networks	15%	9%	11%	7%	4%	54%
Artificial intelligence	30%	12%	11%	6%	4%	36%
Emerging / Alternative Technologies	33%	12%	10%	4%	2%	39%
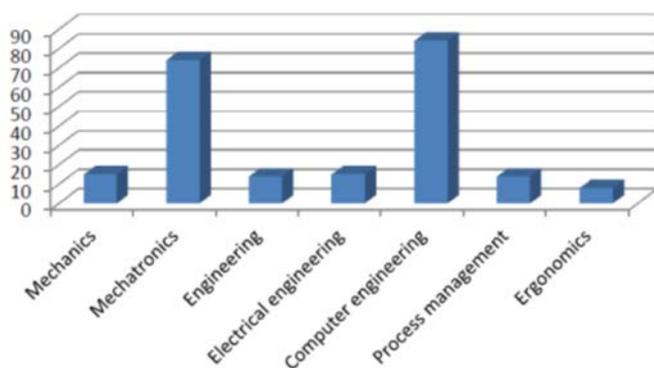
Figure 4. Areas for the planned remote laboratories

Participants were asked which course they would prefer to take for 23 lessons. They were asked to rate each option from 0 to 5 based on their preference. The students were mostly interested in the following courses: Mechatronics Systems and Devices, Introduction to Robotics, Robot Programming, Engineering Software, and Artificial Intelligence and Emerging/Alternative Technologies (**Table 1**).

Nearly half of the participating organizations had no plans of adopting distance learning, and nearly 40% of them had not considered distance learning as an option. The major concerns regarding the introduction of distance learning were costs, technical possibilities, and lack of interest from students. Almost 74% of the participating organizations had planned to introduce remote laboratories into their educational process, largely in the areas of mechatronics and computer engineering (**Figure 4**).

Planning for remote laboratories was most common in technical vocational schools, vocational higher-education institutions, and universities (bachelor's degree level) (**Figure 5**).
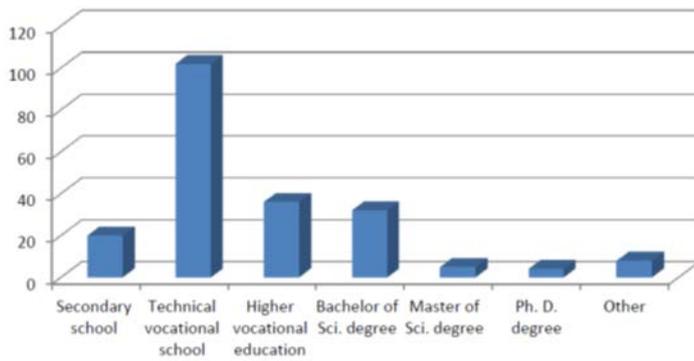
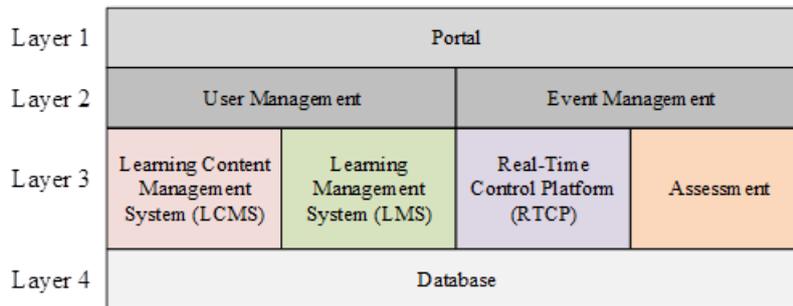**Figure 5.** Educational levels for the planned remote laboratories

Figure 6. Training model

INFRASTRUCTURE OF PROJECT

The realized project-training model is based on the UKeU e-Learning framework (Habraken, 2008). As shown in the **Figure 6** the framework is built using four layers. Each layer describes the services that perform specific tasks in a certain area of the e-Learning solution.

Layer 1: Portal **-** The portal provides a single port of entry for the users to the different services in the e-Learning framework and is responsible for the authentication of the users. The user can access more than fifty books, job advertisements, and announcements using this portal. List of courses is given in the **Appendix**. The course books were selected based on the responses to the questionnaire shown in **Table 1**. All the books were pedagogical self-learning-directed texts written at EQF levels 4, 5, and 6 in five different languages (English, Turkish, French, Czech, and Slovene). The homepage of the Web portal is shown in **Figure 7**.
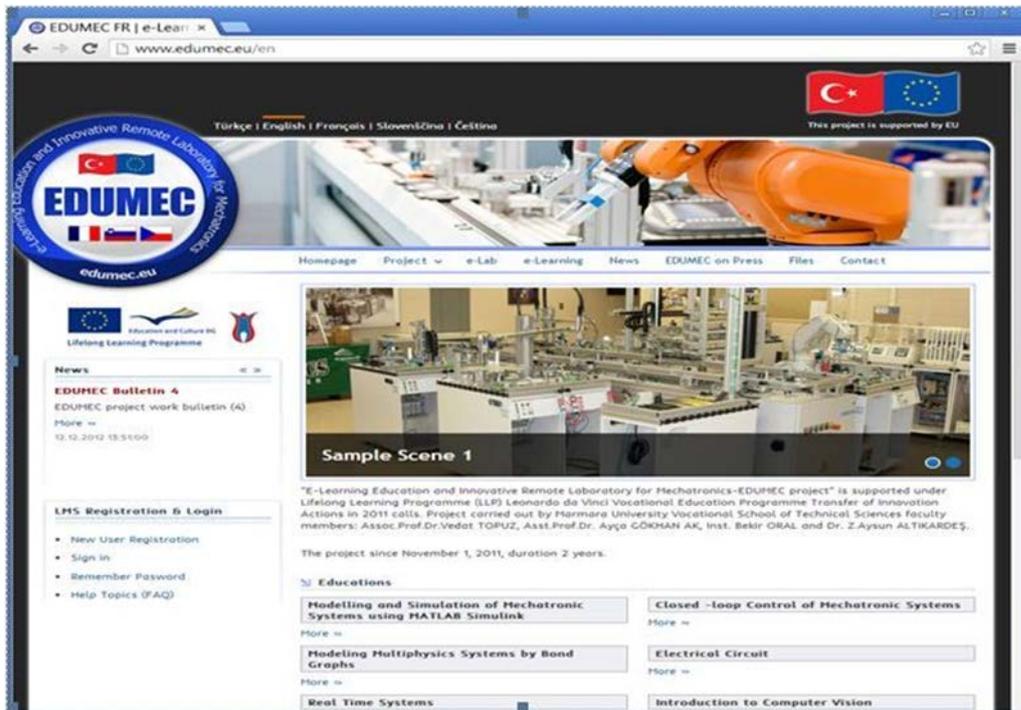
Figure 7. The homepage of the EDUMEC Web portal

Layer 2: Common Services - They do not perform any pedagogical function. While User Management service authorizes users and assigns privileges to every user, Event Management services provide scheduling and reminder functions for users.

Layer 3: Learning Services - These services provide the core functionality for e-Learning solutions. This layer determines four different services. In Learning Content Management System (LCMS) module, lectures prepared by instructors in PDF, PowerPoint or Flash format are uploaded to the system. It is also possible uploading the videos in AVI or MPEG format via this module. Learning Management System (LMS) is a service which registers users, tracks courses in the catalog, records data from learners and provides searching and reporting capabilities to users of the service. A multilingual real-time LMS has been designed and implemented to manage the Web-based asynchronous training offered. This system is based on a robust architecture that connectivity with the RTCP. The LMS logs and reports detailed data (such as date and place of attendance, courses and exams taken, scores on exams, and performed experiments) for each registered user. These reports were used to generate an "EDUMEC Certificate of Achievement" for the user.

Three different users are defined in the LMS system. These are:

a. *Trainee:* The trainees only attend classes, exams and practices, and make appointments for experiments.

b. *Instructor:* They can add lessons to the system in the course module or questions and answers to the exam pool in the exam module. In the experiment module, they can follow the experiment live and interfere with the experiment if desired.

c. *Administrator:* Admin can give the instructors relevant authorities; query the progress of the course attendees and observe the progress of the trainee according to the exam result. He/ she also prepare the certificate of achievement.

Assessment. Assessment System is a service which measures students' performance against specific goals. Through this module, trainees are examining over the internet. Examination dates and times can be determined by the country/teaching staff of the course. The questions of the exams are determined randomly for each trainee according to the difficulty of the questions entered into the system by instructor. When a trainee enters more than one test, he or she is faced with different questions. It is also allowed to enter an exam for one course only once in a day. The courses and durations attended by trainees are controlled via the LMS system. Trainees who do not have the minimum attendance period to the course are not allowed to enter the exam at the end of the course. The success criterion is to have participated in the courses in the specified time period and to obtain a success rate of 60% from the online examination.

Real-Time Control Platform (RTCP). In the EDUMEC project, according to the training model, experiments are conducted in real time. For this purpose, an infrastructure was constructed to enable real-time and remote
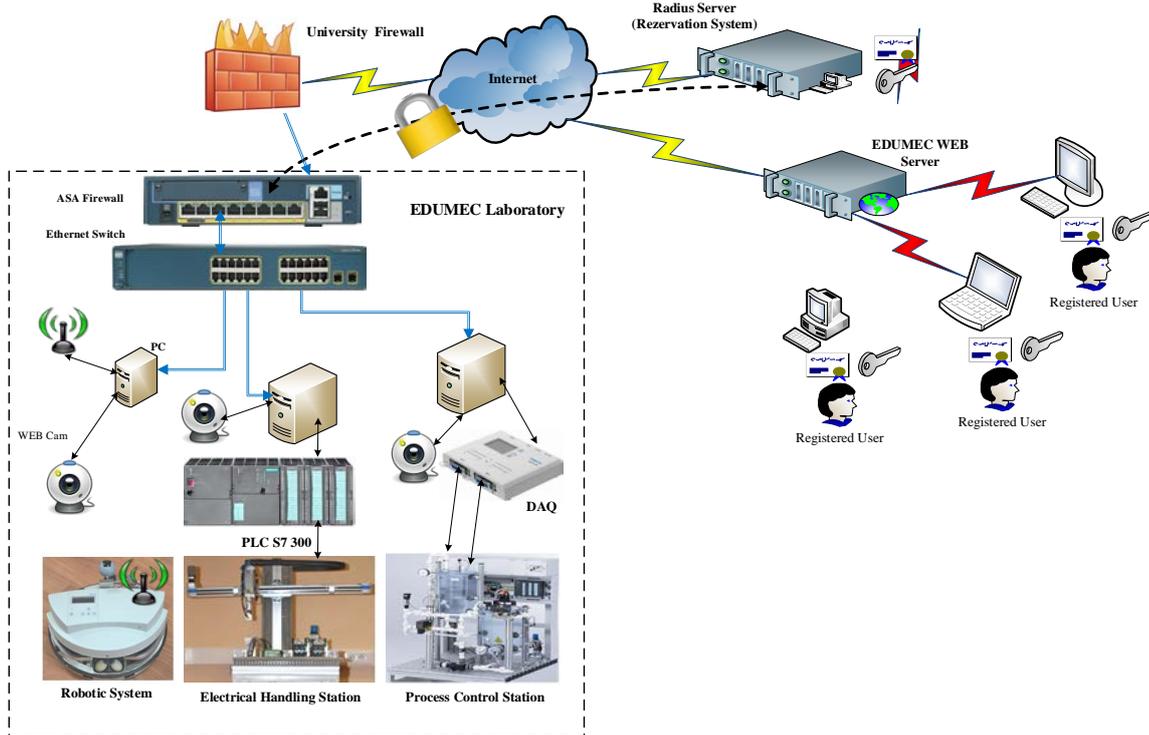
Figure 8. Remote laboratory network infrastructure

Figure 9. Reservation interface

experiments. The EDUMEC remote laboratory network infrastructure was based on client-server architecture; the structure is illustrated in **Figure 8**. In this connection, the users provide the virtual private network (VPN) connection to the system via a remote procedure call (RPC) protocol. The system provides a reservation, based on available days and time slots, to the user to enable the performance of experiments. The system security is provided by the VPN connection created by a Cisco ASA Firewall.

Three mechatronic sets have already been established in the RTCP. However, the physical infrastructure is designed to support many more experimental platforms. To use the experiment sets, users follow these steps:

1. Download and install the e-Lab VPN-Client application.
2. Make a reservation using the Web portal e-LAB reservation system. Then, the Radius server generates a unique number to maintain a VPN connection. This unique number used for remote desktop (RDP) connections using the VPN-Client application (**Figure 9**).
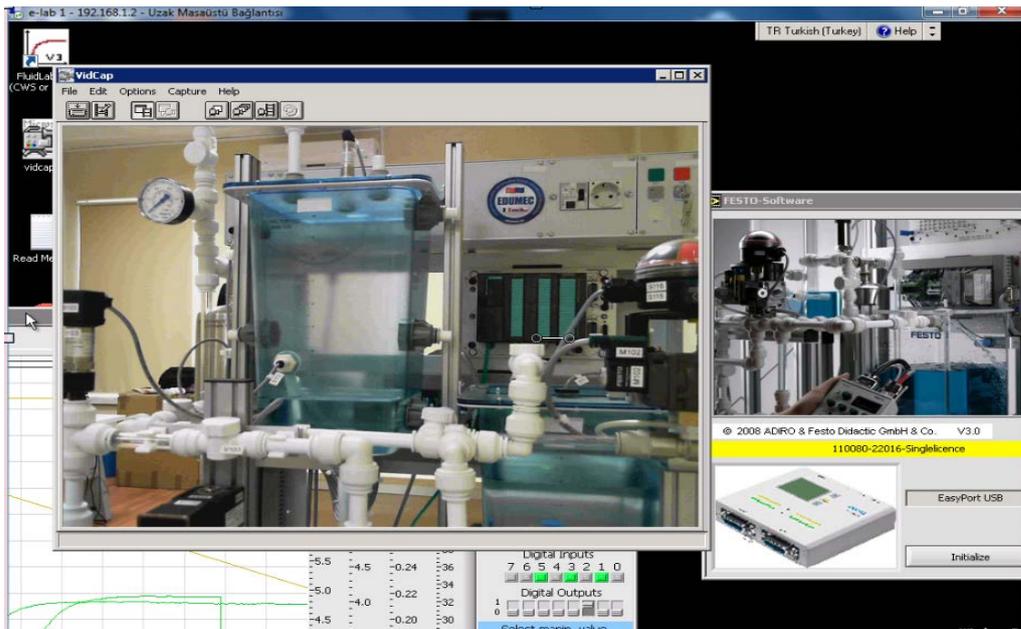
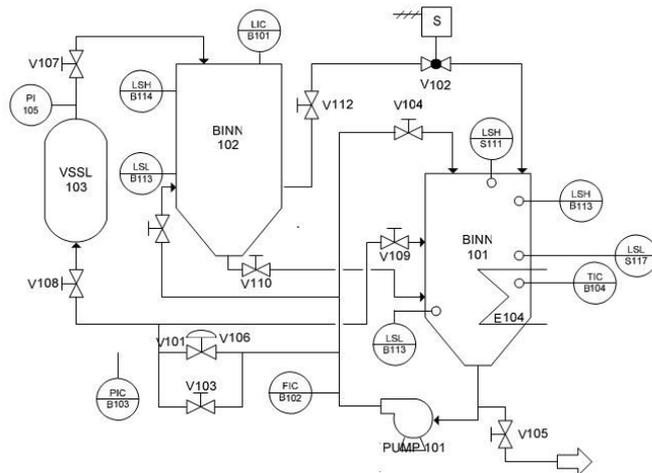**Figure 10.** Remote access to the process control unit

Figure 11. P&ID diagram of the process control unit

3. At the reserved time, a VPN connection is established via the VPN-Client application, which uses an RDP in the background.

Remotely Controlled Laboratory

In this project, three experiment sets were used to form a remotely controlled mechatronic laboratory, selected based on the users' preferences given **Table 1**: a process control set, mobile robot, and electric and pneumatic handling system. Users can remotely conduct experiments related to different aspects of mechatronics and control areas using these training sets.

Process control set. In this set, four types of process control experiments (liquid level control, flow control, pressure control, and temperature control) can be performed via remote connections to a PLC or a computer and a data acquisition (DAQ) board. The remote system during real-time Web-based control is shown in **Figure 10**.

A detailed picture and PI diagram of the process control system are respectively shown in **Figure 11**.

The process control system consists of the following components: BINN 102 and BINN 101: Upper and lower tanks; PIC/B103: Controller: (PLC or DQA board and PC); Pump 101: Centrifugal pump; V106: Proportional valve; V 102: Two-way ball valve with pneumatic rotary drive; LIC/B101: Ultrasonic level transmitter; LSH/B114, LSL/

Table 2. Experiments for process control

Experiment	Objectives
Project planning	• Draw up a PI diagrams for a controlled system. • Draw an Instrument loop diagram of a controlled system.
Analysis of the tank	• Calculation of container volume.
Analysis of a pump	• Determining the delivery rate of a pump.
Analysis of a proportional valve	• Determining the flow rate of a proportional valve.
Analysis of a heating element	• Operation of a heating element.
Analysis of an ultrasound sensor	• Recording the characteristic of an ultrasound sensor.
Analysis of a flow meter	• Recording the characteristic of a flow meter.
Analysis of a pressure sensor	• Recording the characteristic of a pressure sensor.
Analysis of a temperature sensor	• Recording the characteristic of a temperature sensor.
Commissioning a level-controlled system	• Determining the operating range and operating point of a controlled system.
Commissioning a flow controlled-system	• Determining the operating range and operating point of a controlled system.
Commissioning a pressure-controlled system	• Determining the operating range and operating point of a controlled system.
Commissioning a temperature-controlled system	• Determining the operating range and operating point of a controlled system.
Identification of a controlled system.	• Determining the time response of a controlled system. • Determining operation of a controlled system with P controller. • Determining operation of a controlled system with a PI controller. • Determining operation of a controlled system with a PD controller. • Determining operation of a controlled system with a PID controller. • Controller setting using the Ziegler-Nichols method.

B113, and LSH/B113: Capacitive proximity switches; VSSL 103: Pressure control tank; PI 105: Pressure transmitter; FIC/B102: Flow transmitter; E104: Heating element; and TIC/B104: Thermistor.

The tank level control system is a closed-loop control system equipped with a reservoir tank and a pump motor subsystem. Based on the assumption that the system is either linear or linearized, the differential equation of this system can be obtained as follows:

$$Cdh = (q_i - q_o)dt \tag{1}$$

where *C* is the capacitance of the tank (m²), *h* is the tank liquid level (m), and q_i and q_o are the tank inlet and outlet flow rates, respectively (m³/sec). Thus (Macancela & Canizares, 2014),

$$Gp(s) = \frac{H(s)}{Qi(s)} = \frac{0.02544}{s + 0.005697} \tag{2}$$

The experiments designed to teach users about process control are given in **Table 2**.

The main purpose of the experiment set is to teach the following skills to the user:

- Working on different process control systems (i.e., liquid level, flow, pressure, and temperature). These processes can be operated individually or as batch processes using manual valves on the set.

- Understanding the process control P&ID diagrams. The system can be diagnosed by following the P&ID diagrams.

- Modeling the behavior of the system. The experimental set allows experiments on all input-output models in the system. Thus, the relationship between the mathematical model and the input-output models can be analyzed.

- Understanding the working principles of different sensors and actuators. There are several types of sensors (pressure, ultrasonic, proximity, and temperature) as well as electrical and pneumatic actuators.

- Controlling the system using a classic ON/OFF or PID controller. Parameters of the controllers can be determined easily using a computer. Thus, the effects of parameter changes on the system performance can be examined.

Mobile Robot. The mobile robot has an embedded PC controller (an I/009 control board with an FPGA) and a microcontroller connected via an Ethernet interface (**Figure 12**). The mobile robot has nine distance sensors, two optical sensors, two proximity sensors, and a camera. Additional features can be included in the structure using the electrical input and output ports.

Figure 12. Mobile robot (photo from Robotino manual (Bliesener et al., 2007)
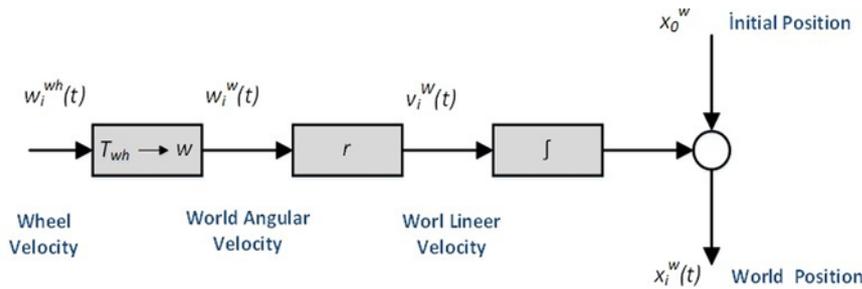

Figure 13. Kinematic model of the mobile robot

The mobile robot uses three engines developed for the Omnidrive drive units. The three drive units allow for motion in all directions–forward, backward, and sideways–and the robot can also turn within its own diameter. **Figure 13** shows the kinematic model of the robot.

The kinematic model of the robotino is:

$$\begin{bmatrix} w_1(t) \\ w_2(t) \\ w_3(t) \end{bmatrix} = \frac{1}{r} \cdot \begin{bmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \end{bmatrix} = \frac{1}{r} \cdot \begin{bmatrix} -sin(\emptyset_1) & cos(\emptyset_1) & R \\ -sin(\emptyset_2) & cos(\emptyset_2) & R \\ -sin(\emptyset_3) & cos(\emptyset_3) & R \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_r(t) \\ \dot{y}_r(t) \\ \Omega(t) \end{bmatrix} \tag{3}$$

Here w_i is the angular velocity of each individual wheel, v_i is the translational velocity of each individual wheel, r is the wheel radius, R is the distance from the center of the robot to the center of wheel, x_r and y_r characterize the robot coordinate system, Ω is the tangential rotational velocity of the robot, and φ_i describes the rotation of the wheel shaft relative to the robot coordinate system equation:

The robot velocity can be determined from the wheel velocities by inverting the above matrix. Equation (3.4) can be simplified by replacing the transformation matrix from the wheel velocities to the world angular velocity with the matrix $T_{wh \to w}$. The world velocity of the robot can be determined from the measurements of the angular velocities of the three wheels by inverting the matrix $T_{wh \to w}$. Thus, the estimated position after moving the robot from time t_0 to time t_1 is determined using the following equation:

$$\begin{bmatrix} x_w(t_1) \\ y_w(t_1) \\ \theta(t_1) \end{bmatrix} = \begin{bmatrix} x_{w,0} \\ y_{w,0} \\ \theta_0 \end{bmatrix} + r. \int_{t_0}^{t_1} [T_{wh \to w}]^{-1} \begin{bmatrix} w_1(t) \\ w_2(t) \\ w_3(t) \end{bmatrix} dt \tag{4}$$

where $x_w(t_1)$ and $y_w(t_1)$ are the coordinates in the world coordinate system at time moment t_1, $\theta(t_1)$ is the orientation angle at time t_1, $x_{w,0}$ and $y_{w,0}$ are coordinates in the world coordinate system at time t_0, and θ_0 is the orientation angle at time t_0 (Oltean, Dulău, & Puskas, 2010).

The mobile robot can be programmed with Robotino View software installed on a computer that is accessed via a wireless LAN connection. Because the mobile robot has its own Linux operating system, the user can directly control the omnidrives using Telnet connections. The wheel units have an angle degree of 120 between each other. Robotino View can transmit signals to the motor controller in addition to displaying, changing, and evaluate sensor values. The mobile robot can even be programmed during actual operation via Robotino View (**Figure 14**).
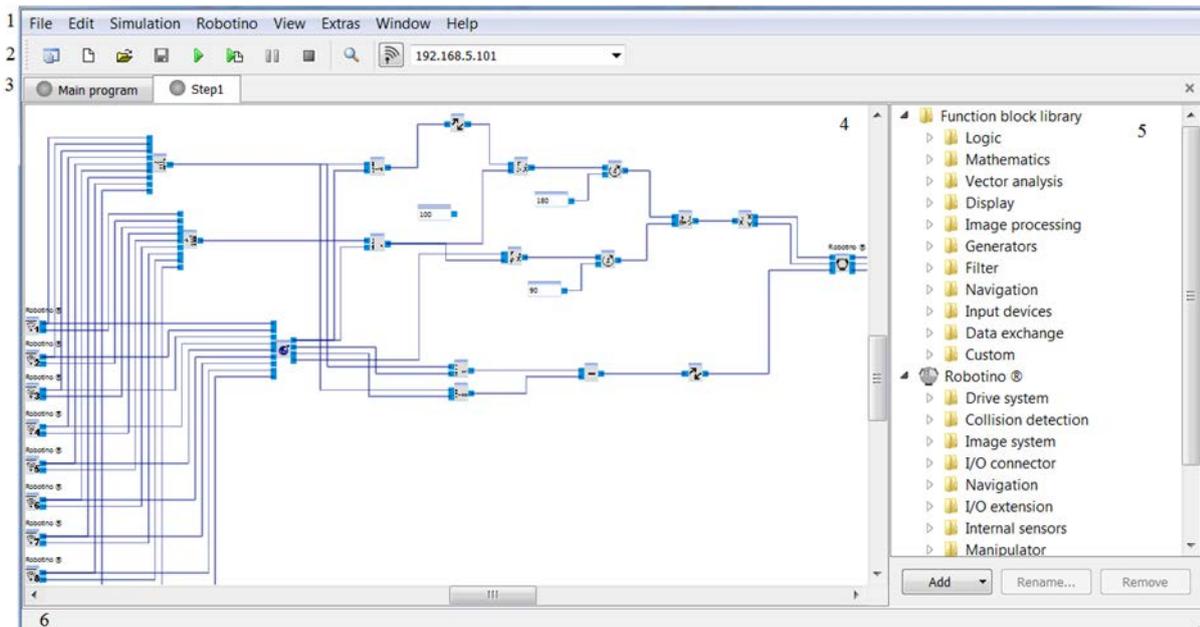
Figure 14. Robotino View

Table 3. Experiments for robot control

Experiment	Objectives
Analysis of Mobile Robot	• Electrical motor control learning the mechanical construction of a mobile robot system.
Remote control and programming of the mobile robot	• Learning remote control and basic functions of graphical programming software
Linear running of mobile robot in any direction	• Commissioning of a mechatronic system • Learning electrical motor control
Omnidrive	• Learning electrical motor control/drive unit
Acquisition and scaling of sensor data	• Learning collision protection
Search and approach	• Learning closed-loop control of a mechatronic system
Line follows	• Graphics programming applications for a mobile robot system
Wall follow, search and approach, color tracking	• Analysis of sensor data for various applications

In the Robotino View interface, 1 is the menu bar that contains menus to perform actions such as load/save, edit, view. 2 is the tool bar containing quickly accessible buttons to perform some of the functions from the menus, buttons to start and stop the simulation, an input box for Robotino IP address, and a connect button. In the program selector section (3), the user can switch between the main program and the subprograms of a project. The subprogram "Step1" is visible in **Figure 13**. 4 is the program workspace, where the program is viewed and edited. The library of function blocks available for programming is labeled 5. The status bar (6) shows information about the project and the application status.

After learning the basic principles of the mobile robot, the experimental stage can commence. A list of experiments starting from simple tasks and extending to complex applications is shown in **Table 3**. However, the applications that can be developed with the mobile robot are not limited to this list; after the experimental stage, the user may develop further applications.

Electrical and Pneumatic Handling Station. Material flow is a sub-function of the handling station. Additional sub-functions are conveying and storing. Users who access the computer remotely via a VPN can run the PLC software using Simatic Manager through a multi-point interface (MPI) adapter. The electrical handling station is equipped with a flexible two-axis handling device. The inserted workpieces are detected in the retaining device by an optical reflex light sensor.

The electrical handling device fetches the workpieces from the retaining device with the help of a pneumatic gripper that is fitted with an optical sensor. The sensor differentiates between "black" and "non-black" workpieces. The workpieces can be deposited on different slides based on these criteria. The electrical handling station comprises a receptacle module, a PicAlfa module, a slide module, a profile plate, a trolley, a control console, and a PLC board (**Figure 15**).
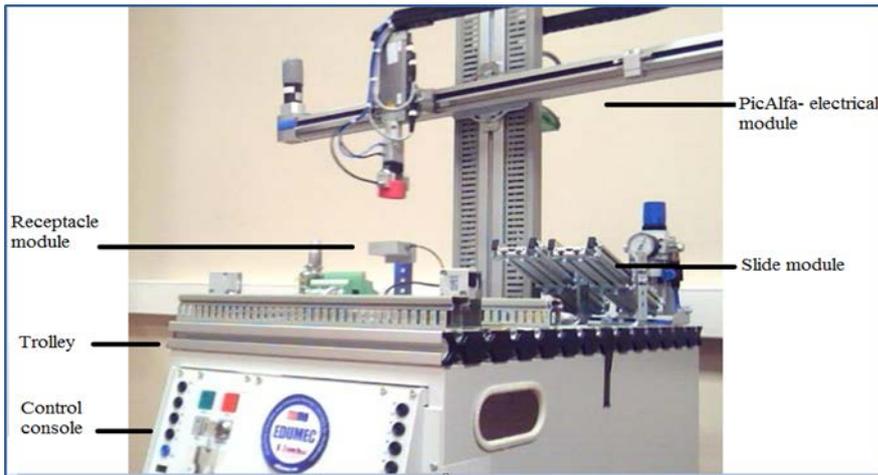
Figure 15. Electrical handling station

Table 4. Experiments for electrical handling station

Experiment	Objective
System activations	• Understanding fully by analyzing the scheme of Electrical Handling Station
	• Learning fundamentals of Programmable Logic Circuit using S7- 300
	• Learning the connection of electrical handling station to the computer by using PLC-S7 PC-adapter with USB/MPI converter.
	• To control start and stop activities.
Separating of the different components	• To make an error detection
	• To perform emergency stop system.

The electrical and pneumatic handling station is designed to improve the user's PLC programming knowledge. Users can create a scenario using electrical or pneumatic actuators according to the signals coming from different sensors and switches. Experiments built on the electrical and pneumatic handling station are listed in **Table 4**.

A connection is made between the test set and the computer via a PLC-S7 PC adapter with a USB/MPI converter by clicking on the monitor on/off button in the toolbar. OB1 is the main organization module. The process orders of the other programs and data modules are assigned in this main module. In emergencies, such as an electrical short, loss of Internet connection, and other faults, the emergency stop module is activated and the entire system stops. In the case of an emergency stop the emergency stop program block is called which resets the operating panel outputs and station outputs.

Evaluation of the System

A total of 41 persons participated to the pilot training for the EDUMEC project and 25 persons successfully completed it. Pilot training was attended by Computer, Electrical, Electronics and Mechatronics students at EQF level 3, 4 and 5, which were our target group. 23 % of these students participated in the survey that done to analyze the conceptual and formative knowledge of the target groups in the first stage of the study. Certificates of achievement through the EDUMEC project were given to them at the end of the training.

A questionnaire including 23 questions was prepared to evaluate the participants' opinions about the adequacy, quality, efficiency, understandability, accessibility, and benefits of the pilot training.

The evaluation criteria and the results for three different experiment sets are shown in **Table 5** (values are expressed as percentages of users responding). The pilot training received positive approval from around 65% of the participants, showing that the mechatronics field is very difficult to study for beginners.

Table 5. The results in percentage for three different experiment sets

	1. Disagree	2.	3.	4.	5. Completely Agree
The contents of the training correspond to the training goals					
Process Control	6.45%	0.00%	0.00%	12.90%	80.65%
Robotic	16.67%	3.33%	0.00%	3.33%	76.67%
PLC and motion control	7.50%	2.50%	2.50%	10.00%	77.50%
Exercises are adequate					
Process Control	6.45%	3.23%	6.45%	16.13%	67.74%
Robotic	13.79%	6.90%	6.90%	6.90%	65.52%
PLC and motion control	7.50%	2.50%	12.50%	5.00%	72.50%
E-test are adequate					
Process Control	12.50%	6.25%	3.13%	9.38%	68.75%
Robotic	13.33%	3.33%	0.00%	13.33%	70.00%
PLC and motion control	5.26%	5.26%	2.63%	5.26%	81.58%
I estimate the whole e-learning contents as excellent					
Process Control	9.68%	3.23%	9.68%	25.81%	51.61%
Robotic	16.67%	0.00%	10.00%	20.00%	53.33%
PLC and motion control	12.50%	0.00%	12.50%	10.00%	65.00%

Table 6. Questionnaire Results for Learning Portal

	1. Disagree	2.	3.	4.	5. Completely Agree
Learning portal is well organised	7.89%	2.63%	10.53%	18.42%	60.53%
The learning time is close to the predicted learning time.	15.79%	0.00%	5.26%	13.16%	65.79%
I appreciate that I can learn anytime and from any location	7.89%	2.63%	5.26%	2.63%	81.58%
I think that gained knowledge will be useful in my future career.	15.79%	0.00%	2.63%	15.79%	65.79%
I would participate in the advanced training	21.05%	2.63%	5.26%	15.79%	55.26%
I have (or will) recommend the training to my friends.	15.79%	2.63%	7.89%	10.53%	63.16%
	Distance Learning	Educational Booklet	Free of Access	Experiments	Everything
Which aspects of training and materials did you like the most.	60.47%	11.63%	4.65%	9.30%	13.95%

Finally, in this project, the possibility of successfully completing experiments performed by remote control was proven (**Table 6**). The results demonstrate the success and quality of the EDUMEC Project educational materials, pilot training, and mechatronics remote laboratory infrastructure.

CONCLUSIONS

Remote access to a laboratory in the field of mechatronics, which was previously limited in availability, has now been established through the EDUMEC project at Marmara University. Access to the EDUMEC laboratory is available globally, allowing users to conduct real-time mechatronics experiments. On the EDUMEC platform, a remote access laboratory and 50 different courses are made available in an asynchronous format.

The effectiveness of the designed education model was primarily tested through pilot training with a set of students. Certificates of achievement were given to the students who successfully completed their training. After the pilot phase of training, the platform was opened through the EDUMEC webpage to offer asynchronous education free of charge for five years in the interest of ensuring the project's continuity. Hence, the project has accomplished its goals successfully.

At the beginning of the project, the efficiency of the system is only questionnaire questioned. The system will be updated with this questionnaire during the sustainability phase of the project. In addition, after the system has been applied for at least 2 years, feedback will be received from course trainees and employers.

Practical training in areas that require expensive equipment such as mechatronics can be performed using remote-access devices as an effective solution to provide this training. While EDUMEC offered users an option to take 50 theoretical courses in the field of mechatronics at EQF levels 3, 4, 5, and 6, they also had opportunities to

apply some of the learned skills such as robot control, process modeling, controller design, and PLC programming, in real time.

The EDUMEC project represented a successful example of a project in this area. Future work in improving the EDUMEC project in cooperation with the Turkey Ministry of Education will aim to expand the project to reach more institutions and people.

REFERENCES

Basso, M., & Bagni, G. (2004). Artist: A Real-Time Interactive Simulink-Based Telelab. *Proc. IEEE International Symposium on Computer-Aided Control System Design*, pp. 196–201. https://doi.org/10.1109/CACSD.2004.1393875

Bliesener, M., Weber, C., Kling, K., Karras, U., & Zitzmann, D. (2007). *Festo Robotino Manual*. Denkendorf, Germany: Festo Didactic GmbH & Co. KG.

Casini, M., Prattichizzo, D., & Vicino, A. (2004). The automatic control telelab—a web-based technology for distance learning. *IEEE Control System Magazine, 24*(3), 36–44. https://doi.org/10.1109/MCS.2004.1299531

Castellanos, A. R. S., Hernandez, L., Santana, I., & Rubio, E. (2005). Platform for Distance Development of Complex Automatic Control Strategies Using Matlab. *International Journal of Engineering Education, 21*(5), 790–797.

Corradini, M. L., Ippoliti, G., Leo, T., & Longhi, S. (2001). An Internet Based Laboratory for Control Education. In: *Proc. IEEE Conference on Decision and Control*, pp. 2833–2838. https://doi.org/10.1109/CDC.2001.980703

EUROSTAT, Education and Training, Statistical Data. (2013, March 19). Retrieved from http://epp.eurostat.ec.europa.eu/portal/page/portal/education/data/database

Fernandez, G. C., Borrego, R. C., Merino, P. P., Lopez, M. A. S. C., Ruiz, E. S., Gil, M. C., & Perez, F. M. (2015). Mechatronics and Robotics as Motivational Tools in Remote Laboratories. *IEEE Global Engineering Education Conference*, pp. 118-123. https://doi.org/10.1109/EDUCON.2015.7095960

Ferreira, J. M., & Müller, D. (2004). The MARVEL EU project: A Social Constructivist Approach to Remote Experimentation. *1st Remote Engineering and Virtual Instrumentation International Symposium, Villach, Austria*.

Gadzhanov, S. D., Nafalski, A., & Nedic, Z. (2014). LabVIEW Based Remote Laboratory for Advanced Motion Control. *11th International Conference on Remote Engineering and Virtual Instrumentation*, pp. 129-136. https://doi.org/10.1109/REV.2014.6784237

Habraken, J. (2008). *Reference Architecture for e-Learning Solutions* (Master Thesis). Open University, Faculty of Computer Science.

Hercog, D., Gergic, B., Uran, S., & Jezernik, K. (2007). A DSP-Based Remote Control Laboratory. *IEEE Transactions on Industrial Electronics, 54*(6), 3057–3068. https://doi.org/10.1109/TIE.2007.907009

Ko, C. C., Chen, B. M., Chen, J. P., Zhang, J., & Tan, K. C. (2005). A Web-Based Laboratory on Control of a Two-Degrees-Of-Freedom Helicopter. *International Journal of Engineering Education, 21*(6) 1017–1030.

Macancela, A. H. I., & Canizares, C. M. P. (2014). *Construccion de Una Platadorma de Instrumentacion Virtual Sobre Labview* (Master Thesis). Universidad Politecnica Salesiana Sede Cuenca.

Oltean, S. E., Dulău, M., & Puskas, R. (2010). Position Control of Robotino Mobile Robot Using Fuzzy Logic. *Automation Quality and Testing Robotics (AQTR), IEEE International Conference on*, Volume: 1. https://doi.org/10.1109/AQTR.2010.5520855

Rodriguez, F., Castilla, M. D. M., Sanchez, J. A., Pawlowski, A., & Moreno, J. C. (2015). Architecture to Develop Semi-Virtual Industrial Laboratories for the Interactive Learning of Process Automation. *Computer Application Engineering Education, 24*(3), 335-346. https://doi.org/10.1002/cae.21709

Rojko A., Hercog D. & Jezernik K. (2011). E-Training in Mechatronics Using Innovative Remote Laboratory. *Elsevier Mathematics and Computers in Simulation, 82*, 508-516. https://doi.org/10.1016/j.matcom.2010.10.017

Salzmann, C., Gillet, D., & Huguenin, P. (2000). Introduction to Real-Time Control Using Labview With An Application To Distance Learning. *International Journal of Engineering Education, 16*(3), 255–272.

Sanchez, J., Dormido, S., Pastor, R., & Morilla, F. (2004). A Java/Matlab-Based Environment for Remote Control System Laboratories: Illustrated with an Inverted Pendulum. *IEEE Transactions on Education, 47*(3), 321–329. https://doi.org/10.1109/TE.2004.825525

Shetty, D., Kondo, J., Campana, C., & Kolk, R.A. (2002). Real-Time Mechatronic Design Process for Research and Education. *Proceedings ASEE Annual Conference*.

Tan, K. K., Lee, T. H., & Leu, F. M. (2000). Development of a Distant Laboratory Using Labview. *International Journal of Engineering Education, 16*(3), 273–282.

Valera, A., Diez, J. L., Valles, M., & Albertos, P. (2005). Virtual and Remote Control Laboratory Development. *IEEE Control System Magazine, 25*(1), 35–39. https://doi.org/10.1109/MCS.2005.1388798

Welp, E. G., Labenda, P., & Jansen, S. (2006). Teaching Theory and Practice in Mechatronics Engineering. *International Design Conference - Design Dubrovnik - Croatia.*

Xu, C., Ming, A., Kanamori, C., Aoyama, H., Li, H., Xu, L., … Wong, C.-C. (2013). Internet-Based Crossover Robot Remote Control Competition among Asian Countries. *Elsevier Mechatronics, 23*(8), 933–941. https://doi.org/10.1016/j.mechatronics.2013.06.003

APPENDIX

List of Courses

English	Turkish	Czech	Slovenian	French
Modelling and Simulation of Mechatronic Systems using MATLAB Simulink			Modeliranje in simulacije mehatronskih sistemov z uporabo MATLAB-Simulink	
Digital Electronic	Sayısal Elektronik	Digitální elektronika	Digitálne elektronické	Digital Électronique
Closed -loop Control of Mechatronic Systems	Mekatronik sistemlerin Kapalı Devre Kontrolü			
Modeling Multiphysics Systems by Bond Graphs		Modelování Multifyzikálních Systémů Pomocí Bond Grafů		
Electrical Circuits	Elektrik Devreleri	Elektrické Obvody	Električna vezja	Circuits électrique
Real Time System		Systém Reálného času		
Introduction to Computer Vision				
Computer Vision / image Processing / Image Analysis				Introduction au Cours de Traitement d'Images
Introduction to Robotic Vision				Introduction à la Vision pour la Robotique
Introduction to Mechatronics	Mekatronik sistemlere Giriş	Servomotor v mechatronice	Uvod v mehatroniko	Introduction à la mécatronique
Mechatronic Devices	Mekatronik Cihazlar	Mechatronická zařízení	Mehatronske naprave	Appareils mécatroniques
Servomotor in Mechatronics			Servomotor v mehatroniki	
Artificial Intelligence	Yapay Zekâ		Umetna Inteligenca	Intelligence artificielle
Introduction to Process Control and Sensors	Proses Kontrole Giriş ve Algılayıcılar			
Process automation MPS® PA Compact Workstation Manual	MPS® PA Proses Kontrol Eğitim Seti			
Robotics	Robot Bilim	Robotika	robotické	Robotique
Basic Experiments for ROBOTINO	ROBOTINO Temel Deneyler			

http://www.ejmste.com