Remotely controlled multi robot environment

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***Abstract* — The current study introduces updating of the educational process in higher educational institutions and raising the vocational qualification of engineers in companies. Modern networking e-environment requires broad-minded employees who have a perfect core education and who can understand the main principles of work in related disciplines. The objective of the study was the development of an integrated inter-disciplinary e-curriculum concentrated on Mechatronics, supported by mobile laboratory sets that can save study time and resources. New concepts of integrated engineering areas and information technologies are introduced in this paper.**

I. INTRODUCTION

Globalisation, modularisation and e-learning are essential terms affecting both industry and academic world. European economy demands mobility of professionals and students. Therefore universities must be ready for accepting the rapid change described by Bologna declaration. In practice several EU programmes like Erasmus offer students mobility for studies abroad. When study materials in written form are easily transferable then laboratory equipment of universities can be rather different. Therefore possibilities for high quality education can be also varying as every educational organisation has its own research interests. One possible solution to change this drawback into a win-win situation is to develop network of modular remote laboratories, prepare relevant study materials available all over Europe, and establish joint e-curricula supporting Leonardo and Erasmus mobility projects.

The current paper describes results of Leonardo da Vinci (LdV) pilot project "Advanced E-Curricula and Mobile Tools for Interdisciplinary Modular Study" having acronym InterStudy [1]. The idea was to use results of previous LdV projects "Development of the innovative database model for adding innovation capacity of labour force and entrepreneurs of the metal engineering, machinery and apparatus sector" (INNOMET) [2] and "Integrated knowledge-based interdisciplinary study program" (IIDSP) [3]. In IIDSP was developed an integrated knowledge-based interdisciplinary study program which offers an integrated approach both for students in universities/colleges and engineers in companies to acquire the knowledge which is at the boundaries of neighbour domains - mechanical engineering and computational sciences, where the company employees need the newest information, data and methods. Particularly, the results of this project were useful for the combined management-engineering studies that are very popular in several European universities now.

In the current study was targeted another interdisciplinary study like Mechatronics, which is rapidly developing and bringing together Mechanical Engineering, Computer Science and Electronics Engineering. It complements IIDSP network and web site.

To establish connections with engineering industry the results of INNOMET were implemented. INNOMET consists of a database system, where industrial enterprises can define their workforce competencies and estimate the difference between existing and needed level of skills or knowledge. In last development [4] the system enables to order courses form universities and offer vocational education for enterprises. Offered dynamic and updated recommendations in internet-based form (generated reports) presented to the vocational and higher educational institutions as proposals of changes of study programs have a concrete impact on the existing vocational and higher educational system. This will result in increased quality and competitiveness of the vocational and higher education system.

In this research a new target was set – to improve the existing system with module of Mechatronics and add feature of composing a learning path – the possible list of courses to be passed for obtaining certain educational level, including courses from different universities.

II. REMOTE LABS

In today's ICT focused world exist tremendous possibilities for improving and widening the study process. Lots of activities in e-learning field have been already in use for a many years. From lecture notes in web to sophisticated teleoperation more and more study activities are performed over the public Internet.

In Technical University of Kaiserslautern the remote experiments have made use of commercially available interfaces (e.g. from Leybold Didactic) and of specially developed computer (web server) programs for controlling the experiment parameters (e.g. laser on/off, moving of motors). Attempts to implement low-cost interfaces, such as 'Intelligent Interface' from Fischer Technik were not satisfactory, since these kind of interfaces are limited when used to transfer data (I/O-channels) or of minor precision to control electromechanical devices. There was also used Open Source software and common standard hardware components (e.g. ATmega16 microcontroller from ATMEL). One of the most important reasons for this decision was to enable teachers and students to build their own remotely controlled laboratory (RCL) at school [5].

In Technical University of Madrid was made a remote laboratory for teaching embedded real time systems. The students have to develop a control program that is going to run in an embedded computer with the free real time operating system RTEMS. Any student can accesses to this lab via Web by using a normal Internet browser. The students count with two different live views of the robots, in order to realize where it is placed at each moment. With these tool students can work at home via the Internet as if they were in the lab. Furthermore the teacher has full control of what the students are doing, because all the events were storage into a database. This permits distance evaluation. All the software used and made is free and it is distributed under the GPL license [6].

The scientists from laboratory at Technical University of Catalonia have been developed an educational platform around a robotic arm that allows emulating a practical laboratory in which engineering students can confirm their theoretical results comparing them with the real paths traced by the robot. All the project applications need a connection to MySQL database [7].

These solutions have shown the way, but for further development is needed more comprehensive solutions. In current paper we focus on the remote lab developed in the Tallinn University of Technology. The problem is not only the access to certain device but it has been grown much wider. In terminology several overlapping expressions are used. In our research we distinguish terms as follows:

- Virtual lab – lab experiment is carried out in the server and can be controlled or monitored by the user over the Internet. The experiment is simulated and no real equipment involved in process.
- Distance lab – the real equipment exists in laboratory and this can be monitored or device can programmed over the Internet. Usually it includes the visual feedback from Internet camera to see what really happened when program is executed.
- Teleoperated lab – laboratory equipment (for example manipulator) which can be controlled in real time over the Internet. Visual feedback is absolutely necessary.
- Remote lab – common term for all above.

The system described in the next chapter supports all types of remote labs. Device manipulation examples are selected for the distance lab types – in particular of multi robot equipment programming.

The following chapters describe the multi-robot environment which is remotely controlled by the user. Robots can be either conventional industrial manipulators including conveyors and rotating tables, or autonomous mobile units without any wired connection. The latter have an on-board intelligence and user uploaded functionality program. The system development theoretical background is studied on the related parallel researches: “Mechatronic and Production Systems Proactivity and Behavioural Models” [8] and “Development and Integration of Mechatronics Modeling Methodology” [9].

III. LAB PORTAL

On recent years the remotely controlled and virtual labs are increased rapidly. The labs have very different interfaces and technical realizations. Some have integrated into general study environment, some has just separate web interface to program the device. Already now one university may have several virtual labs controlled over the Internet. This has bring on the fore the new issue - how to manage these Internet connected labs and devices on the particular lab. Different issues like booking the device; managing the rights; controlling and validating the user inputs; etc. have to be solved. One possible solution for all this kind of problems is the portal type remote lab management environment. On the support of EU project a complete distance lab management and programming environment is developed. The functionality connected with remote lab is as following:

- user and group management,
- location, lab and device management,
- source code validation and version management,
- wireless device communication, including external reset and programming,
- device booking and booking rights.

Having a broad view in mind the system supports three levels of grouping:

- Location – this is organizational level where different type of devices and labs can exist,
- Lab – the virtual room where physically or virtually different devices can be located,
- Device – a set of same type devices in one location.

Devices have additionally grouped into several sub-groups according their type, e.g. mobile robots, manipulators, frequency converters, etc. An example of the list is shown on the Fig. 1.

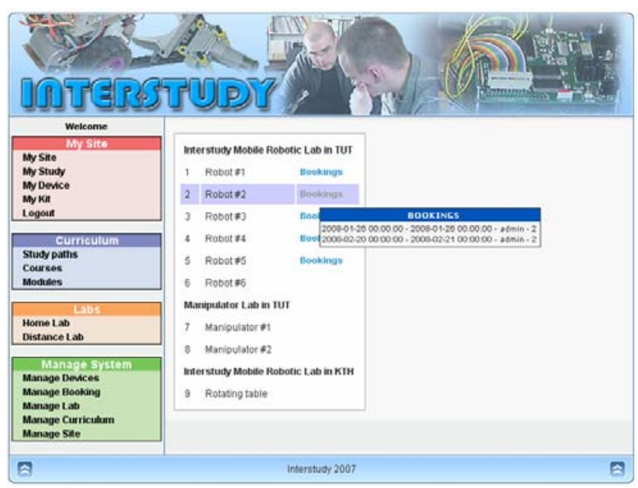

Figure 1 Distance lab list and booking information

In this figure also the booking system is shown. Managing different devices is not trivial problem and needs several functional solutions. When creating a new device or enabling existing one the lab supervisor have to give specific right and timetable for the user or user group (i.e. the legal participants of the particular course). When the user starts the booking procedure the system lists available devices and information about the bookings by other users. In the Fig. 1 is seen an example where device *Robot#2* is booked by the user for the two periods while device *Robot#6* is not booked at all. The user has a choice to select the device and book it for the available time. When booking a device, system will perform several validation checks procedures. Starting with the rights check and several timing conflict checks all conditions have to be satisfied to get the positive result. In Fig. 2 the validation output in case of two different results is shown.

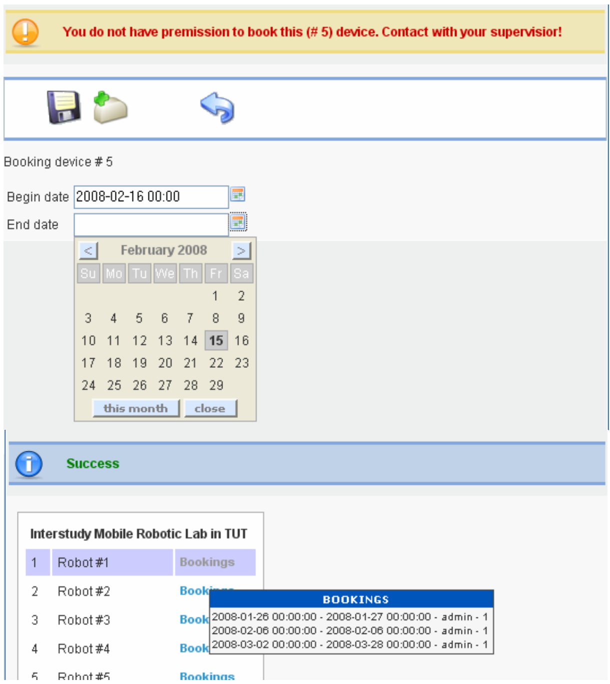

Figure 2 Results of remote device booking

The main concept of the e-environment is the user focused approach. It means that when the student/user logs in to the system he or she has special personalized content. The special menu *My site* is shown where the student can connect with the distance labs, study material, curriculum and other functions provided by the portal.

IV. MULTI ROBOT ENVIRONMENT

The remote lab management and study portal described above has an interface to access mobile robotic distance lab. The multi robot environment is developed as a pilot by the support of the project. The overall schema of the system is shown on Fig. 3.

The multi robot environment is located in the university and consists of number of similar robots equipped with short range wireless communication module. The site is fitted with web camera and server which communicates with the robots.

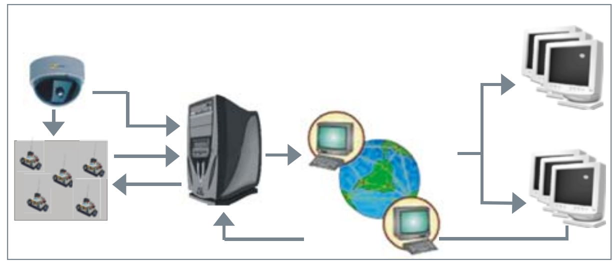

Figure 3 The structure of distance lab system

Server has a master communication unit which can be contact with any robot on the field and reprogram it at any time when needed.

The site server is connected with the portal server passing and validating the communication between the robot and user input. The programming interface is shown on the Fig. 4.

Figure 4 User interface of programming robot

It is foreseen that user can insert a source code for example in C language and compile it online (no compiler is needed in client computer). When the code is compiled and validated against rules it can be downloaded to the robot. After successful download user can watch the video and see how the robot performs in reality. If improvements are needed, user can reprogram the device at any time by executing new version of code.

The experiment hardware can vary quite large range of application. On this particular environment the prototype is mobile robot car which has wireless programming link. The robot prototype is shown on the Fig. 5.

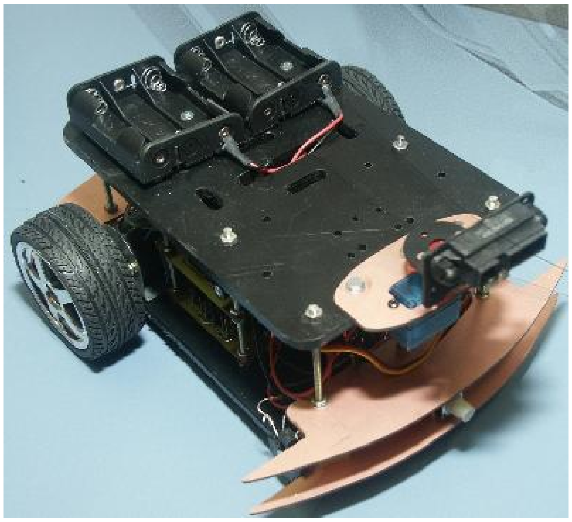

Figure 5 Mobile robot device

The mobile robot is self developed two wheel reconfigurable platform. The device includes bumpers on the front and back to sense the direct contact with obstacles or other robots. In addition it has non contact sensors under the bumper to detect the ground colour difference (e.g. following the line) and on the top long distance infrared (IR) sensor. The IR sensor is able to measure distances between 10 and 80 cm and is mounted on the RC servo motor so it can be used as radar. It can turn constantly ±90 degrees. The robot is driven by two DC motors combined with gearbox and encoder. The electronic equipment architecture has a modular structure enabling to add different functionality with standard connections.

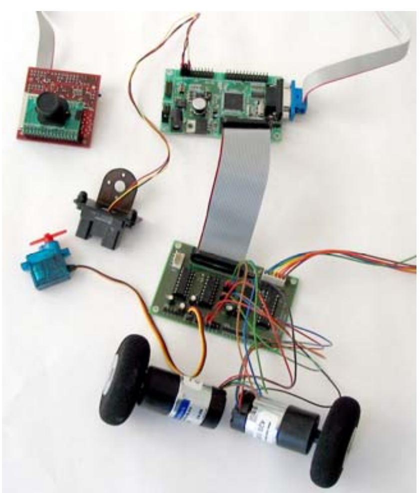

Figure 6 Mobile robot module skeleton

Add-on modules are developed for sensors, machine vision, communication (Bluetooth, ZigBee and Ethernet), and manipulator. The main controller module of the robot is AVR ATMega128 with custom motherboard. In standard configuration robot has an actuator module (enables to drive four dc motor, two RC servo, two unipolar and one bipolar stepper) and supply board. The supply board includes the voltage measurement circuit enabling to control robot charging behaviour. The main components and vision module without chassis and bumpers is shown on the Fig. 6.

In addition to mobile device the system is intended to use with standalone remote manipulator control. The manipulator has similar set up and access interface as mobile device, expect the wired programming link in hardware side and special programming interface in software side.

V. COURSE INTEGRATION

The overall system described above (web portal & multi-robot environment) is a part of larger study system. In addition of components described in this paper the complete system takes care of student study process according to defined curriculum.

User can combine the study modules provided by the different universities and develop a personal learning path. During the study process the results of every course are imported to the system and central evaluation is performed. When working with hands-on tools the student can contribute in different remote labs. The multi robot remote lab is in addition supported by the home lab which includes the mobile tools to practice microcontroller programming at home.

With the prototype hardware, several start up tasks are intended to establish. In particular with the mobile robot equipment two different courses in Tallinn University of Technology will be entrained. Courses are “Mechatronics” for Master students of mechatronics, electronics and ICT and “Mechatronics – project” for Bachelor students of mechatronics. In these courses every group of students can book one device for two weeks to test basic navigation (moving and sensing) algorithms in the beginning of the course. In addition one task is developed for “Machine Vision” course. The task is to use mobile robot equipped with vision module (CMUcam3) detecting and following the moving objects (different colour balls).

The basic set up of robots can have different tasks in different levels. Some examples: student(s) have to program robot for the tasks as follows.

Beginner level task: Robot has to follow the line on the ground and avoid the obstacles and other robots (standard – follow line task). In this exercise the students can practice robot driving and short distance sensor readings. Avoiding other robots and obstacles students can use long distance sensor. The challenge is to integrate all the subtasks into one - robot control algorithm.

Advanced level task: Robot has to work in co-operation with other team mate robot and push the object to opposite corner of the arena. Two other robots are opponents and have to push the object to other corner of the arena. The object is too heavy for one robot but suitable to move by two robots. In this exercise the students can practice the co-operation algorithms and communication between robots. The communication module is ZigBee.

Between these two tasks many other teamwork and standalone tasks can be implemented. It is also possible to have dynamically reconfigurable arena with moving walls and rising bridges. This can be developed by standard pneumatic components.

In the first run (autumn semester in 2008) of distance mobile lab it is expected to have 30 students in general to participate in groups of exercising remote labs and tests. After first experience and further development some more students can be accessed to the distance lab. In summer vacation time it is possible to give the free access for gymnasium pupils or enthusiasts all over the world to programming the devices. However we are expecting to face with some problems and drawbacks in establishing free use of the lab. The main concern is the foolproof charging system and also malicious users who might want to ruin the device or arena. For prevention we will implement main software routine which nests the user program. The main routine detects the voltage level and when it is too low, interrupts the user program and executes the charging sub-routine. In addition the downloaded source code will be validated against rules which are maintained by the supervisors and can be improved constantly. Nevertheless we expect the great interest and more interesting mechatronics study for students and even younger prospects.

Implementation of conventional manipulators is an important task towards higher productivity in industry. The online booking of remote manipulators enables students to program the manipulators and learn to solve industrial problems from distance. The manipulators are used in several laboratories of the university (Lab of Mechatronics, CNC, Robotics) and implementation common of booking system would enable to share the resources bottlenecks of current system where student groups of different curricula subjects have to queue to make the laboratory works. To control of servo motors an online form is proposed (see Fig. 7).

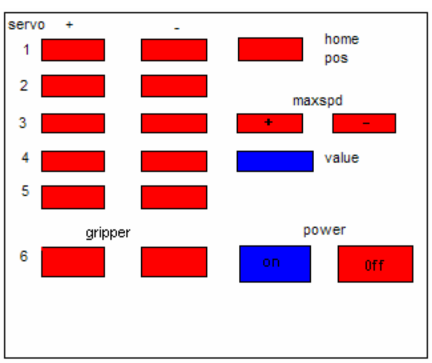

Figure 7 Online control board for industrial robot

This enables to make a program for the servo-based manipulators. Servo motors can be rotated in both directions and essential positions are saved for further program composition. Students can build own modular robot cell CAD models using online libraries. A set of two manipulators built from constructor set modules and servos is shown on Fig. 8. The configuration enables 4 degrees of freedom and control of gripper for each manipulator. The visual feedback from manipulators is sent over WWW by webcam (see Fig. 8). The Axis 207W cameras enabling WiFi and sound transfer are mounted to share views from top and side direction.

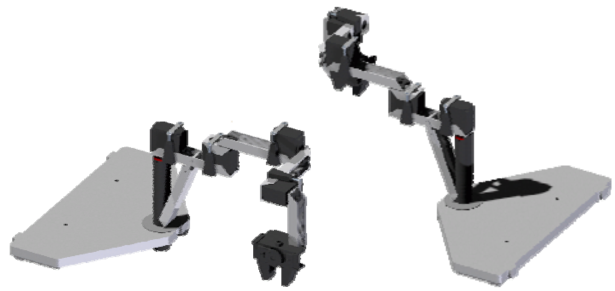

Figure 8 Modular industrial robots (3D model)

The exemplary task is depicted on Fig. 9. Two modular robots (standard Robix constructor set) are connected to common controller. The tasks are to compose the virtual robots for playing TicTacToe game, and after understanding the basics work out program for the manipulators to play the game independently.

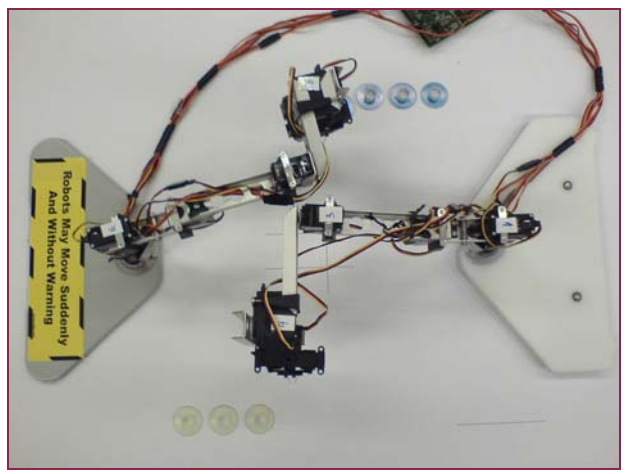

Figure 9 Camera feedback from the student task : playing TicTacToe by two manipulators

The robot solution for playing cards is shown on Fig. 10. It is a student group work, where most part of the time was spent for programming task. If programming enabled by WWW the time of university laboratory opening hours will be not restriction and the workload of students can be shared more evenly. Didactically playing with robots gives students courage and experience to implement the same technology also after graduation in real world – industry.

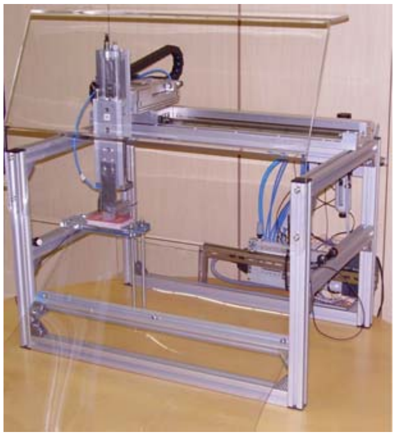

Figure 10 Modular robot for playing cards

The development of remotely controlled multi robot environment is highly connected with development of so-called e-Manufacturing. E-Manufacturing as a term was introduced some years ago by semiconductor industry, enabling to handle large production quantities in different locations [10]. E-Manufacturing can be determined as IT-based manufacturing model, optimising resource handling over entire enterprise and extended supply chain. Despite semantic confusion of this new term it is however agreed that e-Manufacturing can impact both the fundamental customer value produced by the manufacturing process and the core efficiency of the process itself E-Manufacturing differs from e-Business and e-Commerce the same way as manufacturing is different from business and commerce. They are highly related, but not the same [11]. Trends of 21st century like globalization and mass customization are possible only by e-Manufacturing. It is expected that remote monitoring and control of industrial equipment and processes will grow and students of today as engineers of tomorrow should be ready for such a major change.

CONCLUSIONS

The described system has many innovative solutions and combines the theoretical e-content with hands-on tools and distance labs. The technical solution includes novel communication technologies and innovative software solution. The system is developed in open manner and the base system can be applied in several other fields. In a way it enhances university networks cooperation and gives students equal possibilities for top level education.

Web-enabled and information technologies play indispensable roles in supporting and enabling the complex practices of design and manufacturing by providing the mechanisms to facilitate and manage the integrated system discipline with the higher system levels such as Supply Chain Management and ERP. Proactive solutions are major pillars that support the success of the integration of e-Manufacturing and e-Business.

The further research step is to implement the base technology behind the distance lab system into industrial e-Manufacturing field.

To realise it a common framework should be developed to plan and control manufacturing in a cluster of enterprises. Information exchange is performed on web-base. This includes the wireless monitoring of production lines and intelligent self-communicating sensor system. Booking of industrial device as CNC machine tool or robot welding system is thus a scenario for factories of the future. If a company buys expensive machinery it is interested to fully implement it and is eager to sell available machining time. This in turn will speed up SME-s development as manufacturing can be redistributed between smaller units. The implementation elaborated remotely controlled laboratory environment will have positive effect for society as students are expected to realise experience from academies in the real manufacturing.

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