DEVELOPMENT AND EVALUATION OF MECHATRONICS LEARNING SYSTEM IN A WEB-BASED ENVIRONMENT

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ABSTRACT
The development of remote laboratory suitable for the reinforcement of undergraduate level teaching of mechatronics is important. For the reason, a Web-based mechatronics learning system, called the RECOLAB (REmote COntrol LABoratory), for remote learning in engineering education has been developed in this study. The web-based environment is an educational technology for learning the principles and methodology of performing operations on a mechatronics rig at any time and from any location through the Internet. This study concentrates on a color identification experiment as a case study to illustrate the processes involved in the development and evaluation of the remote experimental procedure. The study was carried out with 55 students at National Changhua University of Education, in Taiwan. Students were divided into two groups with an equal number of students at the same academic level in each. One group was labeled as "Traditional" (without RECOLAB support) and the other "RECOLAB" (with support). The evaluation results elicit some relevant facts: (1) Students mainly agreed that the experiment was challenging and interesting and that they learned useful things during the laboratory. (2) Students valued the process performance. (3) Students enjoyed the way that the classes were devised. They valued the fact that participation was encouraged. (4) The students were not content with the number of laboratory practices and the number of hours assigned to the practices. (5) After evaluating the results, the teachers believe that the experiment significantly improved the quality of the laboratory. This study demonstrates RECOLAB's effectiveness in helping students to understand the concepts and master the technologies for the web-based mechatronics monitoring and control learning system. The architecture proposed in this study is not dependent on specific hardware or software configuration, it represents a generic infrastructure.
Keywords: Web-based learning, Mechatronics, Distance education

INTRODUCTION

The mechatronics system sequence integrates fundamental elements of mechanical, electrical, engineering and information to culminate in a powerful, adaptable, interdisciplinary approach to mechatronics. In a mechatronics laboratory, students are often provided with a wide range of sensors, actuators as well as data collection and control tools that allow for multiple solutions to a given design problem. A broad-based approach, involving student-built projects controlled by using a computer, encourages creativity and generates excitement about the subject (Nelson *et al*., 1995; Kaynak, 1996; Serri, 2003). Mechatronics competency is comprised of three components: the student must be able to specify the control; the student must be able to select each subsystem of the application; and the student must be able to integrate each sub-system (Shyr, 2009).

The rise of Internet has led to become an important approach for disseminating various educational materials to students (Demirci, 2010). This emergence of Internet has reformed the concept and means of engineering education. Remote learning utilizing Web features, is increasingly important for education (Isman and Isbulan, 2010; Jou *et al*., 2010). Remote laboratories provide several benefits especially for higher education environments, by supporting current traditional education as well as creating an alternative for distance education programs. The Internet essentially provides an environment to connect with anyone, anywhere, and at any time. The Internet also serves as an infrastructure for industrial applications (Lin and Broberg, 2002; Parikh and Verma, 2002). A web-based environment provides learners with problem-solving assistance and the tools for carrying out experiments (Pedaste and Sarapuu, 2006). From the perspective of education, the Internet is an enabling technology for engineering education and active learning. From an industrial perspective, it is a competitive service for remote measurement, supervision, diagnosis, and control (Stefanovic *et al*., 2009; Stefanovic *et al*., 2009). A distance and e-learning system could play an important role in providing incentives for university teachers to teach distance education courses (Cook *et al*., 2009).

The web enables more flexible delivery (any time), distance education (any place), new visualization possibilities (interactivity), and cost reduction. In engineering and remote control education, web technologies have been playing an increasingly important role, especially in remote learning (Postlethwaite *et al*., 2005). The role of information technology is becoming more important in the instructional domain. Chang *et al*., (2006), who built a web-based teaching material design and development system, tested its effectiveness in helping in-service teachers develop their teaching plans and materials. In the development of remote access laboratories, a significant effort has gone into demonstrating their technical feasibility rather than investigating their implications for engineering pedagogy (Zhuang and Morgera, 2007). A basic requirement in engineering education is a significant number of practical activities where students, can verify and practice analytical concepts and methods learned in theoretical courses, by means of laboratory experiments (D'Andrea *et al*., 2008). Many engineering programs have always considered laboratories as an essential element of education, particularly at the undergraduate level (Ginns and Ellis, 2008; Helander and Emami, 2008). The Internet, on the whole, has also become a popular medium for teaching and learning.

Remote laboratory access allows distance learning students to actually operate experimental facilities, collect data and analyze data. Such web-based technologies can also be applied to general remote control systems in many areas of research and engineering. Ko *et al*., (2001) proposed a Web-based laboratory for control experiments. Ko *et al*., (2001) have also developed an internet laboratory about a frequency experiment. You *et al*., (2001) described the design and implementation of a robotic system that utilizes the Internet as an experimental platform. Hayes and Jamrozik (2001) described their experiences with web course development and delivery, as well as developing a set of tools for placing courses on the web. Shin *et al*., (2002) constructed web-based interactive virtual education systems. A system was proposed to provide remote access to laboratory work over the Internet (Colwell *et al*., 2002; Scanlon *et al*., 2004). Casini *et al*., (2004) presented a remote laboratory for automatic control where students interact with physical systems through the Internet. They describe processes for a dc motor, water tank, magnetic levitation system, and two-degrees-of-freedom helicopter simulator. Saygin and Kahraman (2004) presented a web-based programmable logic controller (PLC) laboratory for manufacturing engineering. Mougharbel *et al*., (2006) also evaluated and compared various remote access laboratory installations around the world. Hui *et al*., (2008) suggested that instructors should consider the target knowledge when considering technology-assisted learning options or designing a web-based course.

Many remote experience systems exist and they actually run. Thus, the concept of Web-based laboratory is not new. More importantly, there is still disagreement about whether Web-based learning or traditional teaching is more effective on students' achievement. A lot of studies suggest that there is no difference in test scores between Web-based and conventional format courses, although students may gain confidence in a Web-based course (Leasure *et al*., 2000; Liao and She, 2009). Other studies find that students enrolled in a Web-based course perform worse in a final exam than students educated by conventional instruction (Wang and Newlin, 2000). However, others indicate an apparent increase in satisfaction from Web-based courses (Katz and Yablon, 2002).

Although the above mentioned studies of integration of laboratory based education with internet are effective in supporting a general knowledge about the course, there is a need to find a way to provide hand-on experiment with physical systems. The objective of this laboratory platform is to provide high-quality learning experiences by bringing experiments to the students with the flexibility of time, location and special needs. The architectural configuration of the proposed system is modular and consists of a server, laboratory and experimental modules. The modules are actual systems suitable for remote operation in engineering education. Practical mechatronics examples have been prepared for the system. The users can operate and be monitored in their handling of these examples. The main contributions of this study are as follows: (1) A distance learning platform is developed, and experimentally tested. (2) Learning exercises are specifically targeted to the objective of the laboratory. (3) Mechanisms that further support the students are developed. (4) The system has an intuitive and convenient platform. (5) The technical aspects of the proposed platform are presented.

From a technological point of view, this study focused on the adaptation of concepts and technologies developed in the field of mechatronics and control, and on exploring their implementation in such remote laboratory settings. The evaluation approach of this study emphasized the didactical perspective of such systems, based on specific experimental protocols, combining qualitative and quantitative metrics; a further aim was to assess the effectiveness of these remote laboratories compared to traditional hands-on laboratory learning scenarios. At the technical stage, the platform is a synthesis of the mechatronics system and a learning environment. At the learning stage, the platform builds on modules and functionalities in realistic learning scenarios to introduce the operation of an actual system and to teach skills associated with programming a graphical monitoring language. Finally, at the experimental evaluation stage, a series of experimental studies measures the effectiveness of different learning programs by using a special evaluation protocol combining qualitative and quantitative ratings with the goal being to distinguish different designs for learning and instruction in the field of technology.

Summing up, integrating engineering education into the Web is usually achieved through the following methodologies: (1) employing websites to house various online functions and facilitate management; (2)

providing remote laboratories to replace physical equipment; and (3) offering web-based laboratories that enable students to set up parameters and undertake equipment from remote locations.

ARCHITECTURE OF RECOLAB

The architecture of the RECOLAB (REmote COntrol LABoratory) is focused on maximum simplicity for the students' benefit, while allowing complete control of the process. That is, the main goal is to make all of the PLC inputs and outputs accessible through any web browser; in addition, downloading new programs to the PLC in a remote way should be possible. Client/server architecture has been implemented to achieve these goals. This allows remote users to connect to a HTML page (using any web browser) that resides in a server with Windows powered by Microsoft's Internet Information Server (IIS).

The architecture can be applicable to the monitoring and control of any industrial process. Next, the hardware and software architectures are detailed.

Hardware Structure

Fig. 1 shows the distribution of the elements used in the laboratory setup. The laboratory is composed of a mechatronics module, a PLC, a server PC, and an IP_CAM.

In this example, a client PC is remotely accessing the laboratory through a connection to the HTTP server as part of its Web toolkit which hosts the web site conducting the equipment. The ADAM4571 converts the COM Port of the PLC (programmable logic controller) into an RJ-45 communications interface, which provides the PLC with network functions. The mechatronics module responds to commands from the server by means of the controller. The students can run and monitor the mechatronics module. Authorized students can also prepare new graphical software and apply it to the mechatronics module.

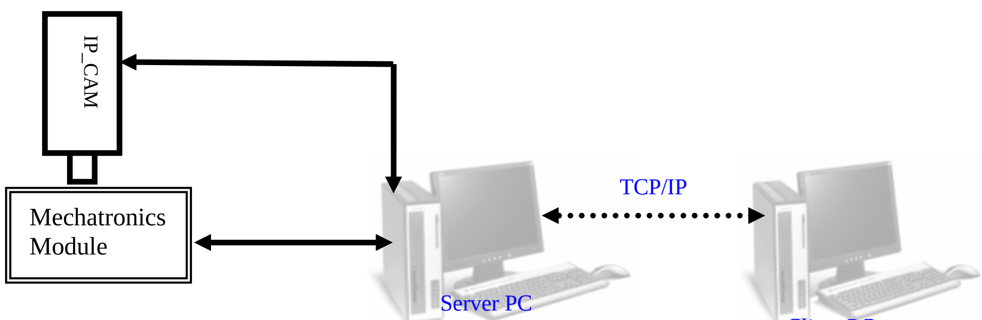

Figure. 1 The hardware structure of web laboratory

The Server and User Units

The students are connected to the server by the Web. The server and user units' main characteristic must be problem-free use. After connecting to the server, they navigate to the web page of the web-based laboratory platform for engineering education. The students can run the actual mechatronics systems via the PLC. Restated, they can apply their control software to actual mechatronics systems and can follow the operation of the system via an IP_CAM installed in the laboratory and simultaneously view the actual system on their monitors.

When students log in to the system over the Internet, they can monitor and control both the computer and the mechatronics rig. An IP-CAM remote monitoring panel can also be used for live broadcast of the actual rig. Students can perform the experiment whether they are on campus or at any remote location. To achieve the remote monitoring and control features, a client-server distributed environment has been implemented.

IP-CAM Control

An IP_CAM has been employed, allowing the students to watch the real-time state of the mechatronics systems. The IP camera is connected through an RS-232 to the serial port of the web server. Web-based control is implemented by continuously running a camera control program on the machine housing the http server to receive command strings from the client for local control. At the remote client user end, Advantech Studio software sets up the sockets for TCP communication with the web server. When the student clicks a button intended for camera control, it generates the corresponding command string and writes it to the TCP connection. Combined with the IP_CAM video camera, the function of the entire factory is clearly visible on the screen.

TCP for Client Server Communication

This popular method of TCP is used to implement client-server communication. The TCP connection established by a client with a server remains connected until closed by the client. Since establishing a TCP connection implies that the connection is available unless the client closes it, TCP is the ideal communication protocol for implementing web-based control systems requiring frequent parameter adjustments.

MECHATRONICS EXPERIMENTAL MODULE FOR LABORATORIES

The laboratory part consists of twelve experiments. The mechatronics experimental module is easy to develop, and other mechatronic systems can be integrated with this module. This module can even be reconfigured for different laboratory work. This study concentrates on a color identification experiment as a case study to illustrate the processes involved in the development and evaluation of the remote experimental procedure.

The web-based laboratory can be set up by designing experimental content, such as a user interface, for a remote laboratory with step-by-step instructions. The students follow the instructions to conduct the remote equipment. The experiment can be performed by connecting to the web page of the web-based laboratory platform. The students use the software to prepare their own control programs for the mechatronics system.

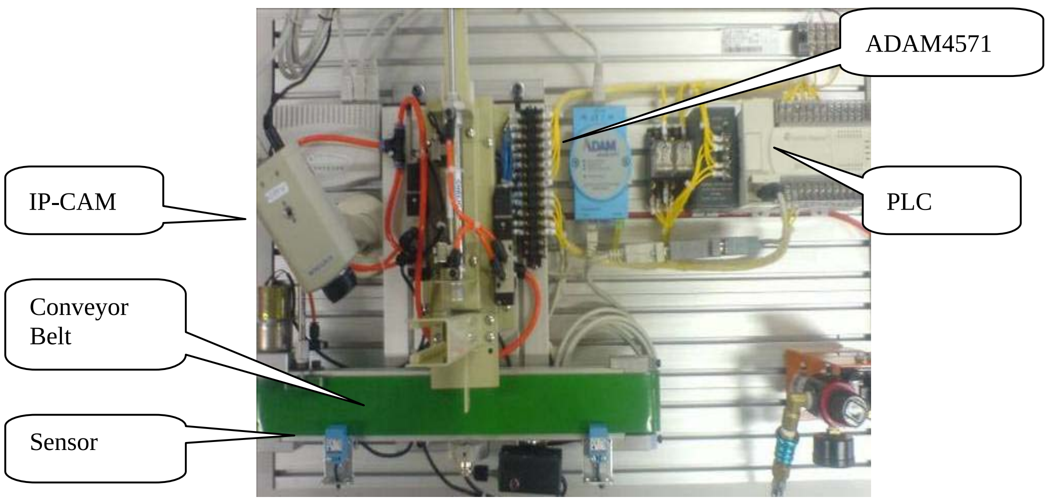

Figure. 2 Color identification module for use in the laboratory

Figure 2 presents the experiment to introduce the use of sensors in a remote laboratory and then uses the sensors to implement a program. Some decisions had to be made according to the state of inputs from the sensors. The use of sensors and actuation corresponding to the state of input is common in PLC programming. A cyclic process is chosen so that students can use the platform during the day or night, when nobody can attend the platform. Different colored devices are placed in the storage area. A pneumatic cylinder deposits one of these pieces on a conveyor belt. At the end of the conveyor belt, another pneumatic cylinder transfers the piece to the tooling area. Two different cylinders and a barrier work in the tooling area. First, a cylinder pulls the piece when the piece is red, and then another cylinder pulls it when it is black. An IP-CAM also displays the operating process on the screen of the laboratory platform.

STUDENT EVALUATION AND EDUCATIONAL RESULTS

Laboratory experiences, which imitate the complexity of real life practices, are essential elements in engineering education. In practical sessions, students learn not only by listening, like in theoretical courses, but also through "learning-by-doing." Learning styles vary among individuals. Some individuals can learn simply from reading materials, while others require hands-on experience. However, psychological investigations have demonstrated that individuals generally only remember about 10% of the content when read and 90% when actually experienced. Students typically learn and retain information well when they are engaged with instructional material. Students generally learn 20% of the material taught via hearing, 40% via seeing and hearing, and 75% via seeing, hearing and doing. Well-designed teaching modules offer the possibility of achieving this 75% goal (Reisman and Carr, 1991; Shyr, 2007). When students interact with laboratory plants, they have the opportunity to verify what happens when they modify and manipulate the experiment.

Evaluation is utilized in order to elevate the standards in terms of teaching, learning, and student achievement. Evaluation quality has a marked impact on student willingness to work hard and encourages teachers to focus on ways of improving individual learning attitudes. Evaluation occurs continually, since judging oneself and others is common practice. For a system, more than two methods may be combined together, which could give extra confidence regarding the result's accuracy by concurrency of data produced from these evaluation methods. Methods of questionnaire survey, interview, and observation were used in the evaluation. A questionnaire survey was used to collect evaluation data from the participants. Observation and review were used in conjunction with the questionnaire survey as data collection methods.

Questionnaire Survey Results

Implementation and introduction of web laboratories in educational practice in the Department of Industrial Education and Technology at the National Changhua University of Education (NCUE) in Changhua, Taiwan, started in the first semester of 2008. Experiments supported by the web laboratory are a part of the mechatronics course. For the purpose of this survey, students were divided into two groups with an equal number of students at the same academic level in each. One group was labeled as "Traditional" (without RECOLAB support) and the other "RECOLAB" (with support). The survey period covered three semesters: 2008/I (the first semester in 2008), 2008/II (the second semester in 2008), and 2009/I (the first semester in 2009). The number of students included in each group of the experiment is presented in Table 1.

Table 1. Number of students included in experiment

Year/ Semester	Number of Students	
	Traditional	RECOLAB
2008/I	18	18
2008/II	18	18
2009/I	19	19

The RECOLAB was tested and evaluated by 55 undergraduate students in their second year of study. All of the students had previously attended courses and performed the same experiment in a laboratory. The questions asked of the students and their opinions are given in Table 2 (Boix *et al*., 2008). Students were asked to rate nine questions for both units on a five-point scale. Table 3 shows the results of the evaluation.

Table 2. Questionnaire

Q1. Was the experience challenging and interesting?
Q2. Have you learned more than you expected?
Q3. Is the quality of the lab materials high, and easy to understand?
Q4. Were the instructions provided easy to follow?
Q5. Would you recommend system to other students?
Q6. Would you apply concepts learned in your future career?
Q7. Were you able to easily connect to the platform?
Q8. Was the supervisory system appropriate?
Q9. How would you rate this lab?

Table 3. Results of the evaluation (The marks correspond to 1 = strongly disagree, 2 = disagree, 3 = unsure, 4 = agree, 5 = strongly agree)

	Traditional						**Using RECOLAB**					
	1	**2**	**3**	**4**	**5**	**Mean**	**1**	**2**	**3**	**4**	**5**	**Mean**
Q1	0	0	4	20	31	4.49	0	0	3	15	37	4.62
Q2	0	1	5	22	27	4.36	0	0	3	14	38	4.64
Q3	0	1	3	32	19	4.25	0	2	2	26	25	4.35
Q4	0	0	4	26	25	4.38	0	0	4	18	33	4.53
Q5	0	0	4	28	23	4.35	0	0	3	13	39	4.65
Q6	0	0	3	26	26	4.42	0	0	2	14	39	4.67
Q7	0	1	4	25	25	4.35	0	2	4	16	33	4.45
Q8	0	0	5	27	23	4.33	0	0	5	14	36	4.56
Q9	0	0	3	25	27	4.44	0	0	4	13	38	4.62

To determine if there was a significant difference between the "Traditional" and "RECOLAB" groups, an independent t-test at the 0.05 significance level was performed. Table 4 presents these test results. A close examination of Table 4 reveals that the "RECOLAB" group produced score averages that differ significantly from those of the "Traditional" group. The "RECOLAB" group obtained a higher average mark than the "Traditional" group did. The results of this test exhibit significant statistical differences between the groups ($t=4.51$, $p<0.05$).

Table 4. t-test for group difference

Group	N	M	SD	t
Traditional	55	4.37	0.07	4.51*
RECOLAB	55	4.57	0.11	

* $p < 0.05$

The students' open-ended opinions are presented below:
1. Web-based educational tools are attractive enough to be examined in a new light.
2. Using web-based educational tools exposes students to new challenges in learning.
3. Supporting learning with animation makes comprehensible learning more effective.
4. Performing experiments in a real-time web platform enables better and faster learning and provides different experiences with web-based technologies to obtain course goals.
5. Web-based experiments are perceived as safer and the environment is more relaxed when compared to traditional experiments.
6. It is possible to perform experiments repeatedly, independent of time and space limitations.
7. RECOLAB allows students to improve their self-learning capabilities.
8. Monitoring the experimental setup, with a real-time laboratory environment using a camera, helped students understand the experimental environment more concisely.
9. Students appreciated the RECOLAB and were happy and highly motivated to make use of and benefit from it.
10. Most students were willing to use such online applications not only for mechatronics but also for other courses.

Summary of Student Interview Results

As a result of the interviews conducted with students in an unstructured manner, it has been determined that the students can easily use the system for learning technologies presented in this study. In the experiments, the students learned: (1) to specify the control, (2) to select each subsystem of the application, and (3) to integrate each sub-system.

Analysis of the Results of Observation

It was observed that the students enjoyed using the system. However, some students encountered a problem operating the modules at the beginning of the laboratory exercise and required assistance. Reminding the students to read the operation rules first and giving them a chance to practice the operation before beginning, alleviated the problem.

Limitations

Although these results provide insight into effective distance learning initiatives, a number of limitations must be addressed when interpreting them. First, this study represents the test of a theoretical model and should be subjected to further testing with different participants, contexts and technological architectures. Second, the participants were undergraduate students who were completing the course as part of a degree requirement, so these results may not reflect the results of other settings and contexts. Issues of motivation for research participation by undergraduates can also influence results. Third, owing to the course requirements and the focus of the research questions, the research could not completely capture the richness of the reciprocal relationship between social presence and interaction.

DISCUSSION AND CONCLUSIONS

The web-based platform, called RECOLAB, is an effective alternative to setting up a conventional laboratory to support courses in engineering education. This platform can be run in real time through the Web from anywhere in the world, and the actual system can be monitored using an IP-CAM. The platform is flexible and can easily be adapted to different engineering education departments. This study discusses the implementation of such a framework and the evaluation of its success in teaching.

The results of this study present that the students who received a RECOLAB learning system significantly performed the traditional group of students. More importantly, there is still disagreement about whether Web-based learning or traditional teaching is more effective on students' achievement. Many studies suggest no difference in test scores Web-based and traditional courses. Although students gain more confidence with computer use in a Web-based course (Leasure *et al*., 2000), other studies find that students enrolled in a Web-based course perform worse in a final exam than students educated by conventional instruction (Wang and Newlin, 2000). And still others indicate an apparent increase in satisfaction on Web-based courses (Katz and

Yablon, 2002).

Most students involved in this research consider RECOLAB to be effective tool in understanding mechatronics. Use of this technology has the following benefits: (1) it reduces costs by sharing laboratory equipments; (2) it gives students greater exposure by allowing them to perform various experiments based on real equipment, and (3) it enables students to overcome the restrictions of time and space.

The evaluation results elicit some relevant facts: (1) Students mainly agreed that the experiment was challenging and interesting and that they learned useful things during the laboratory. (2) Students valued the process performance. (3) Students enjoyed the way that the classes were devised. They valued the fact that participation was encouraged. (4) The students were not content with the number of laboratory practices and the number of hours assigned to the practices. (5) After evaluating the results, the teachers believe that the experiment significantly improved the quality of the laboratory. Furthermore, students from the RECOLAB group had better final grades than did students from the traditional group (it is important to emphasize that both groups were equal in all respects). Previous questionnaire surveys have also given positive results as to whether web laboratories and remote control can improve the quality of education and contribute to a better fulfillment of educational goals.

Future improvements could include the expansion of materials. Reliability of the results could also be strengthened by applying this study to more extensive student groups.

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