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Internet-Based Laboratory Platform for Distance Learning in Engineering Education*

WEN-JYE SHYR
Department of Industrial Education and Technology, National Changhua University of Education, No. 1, Jin-De Road, Changhua 500, Taiwan, R.O.C. Email: shyrwj@cc.ncue.edu.tw

This study proposes an Internet-based mechatronics laboratory platform for distance learning in engineering education. The Internet-based laboratory platform enables students remote access to laboratory equipment. This platform established a user-friendly and efficient technology for providing interactive online laboratory experiments for distance students. This study describes the development and use of a novel Website to improve the learning of mechatronics concepts. Preliminary assessment of the laboratory platform was encouraging and demonstrated its effectiveness for helping students understand concepts and master basic technologies for developing Internet-based mechatronics monitoring and control systems. The main contributions of this study are as follows. (1) A distance learning platform is developed and experimentally tested with mechatronics module. (2) Learning exercises are specifically targeted to the objective of the laboratory. (3) Mechanisms that further support the students are developed. (4) The proposed system has an intuitive and convenient platform. (5) The technical aspects of the proposed platform are also presented.

Keywords: Internet-based; mechatronics; laboratory platform; graphical monitoring and control; experimental evaluation

INTRODUCTION

THE MASS PROLIFERATION of the Internet has revealed interesting possibilities for extending its use into new areas. One of these is distance learning, a rapidly growing platform for university laboratory instruction which, incidentally, may also help to accommodate the growing needs of engineering education. The Internet offers the potential for laboratory access by distance learning students, who can participate with no technical equipment other than a personal computer. The rapid growth of the Internet provides tremendous opportunities for Internet-based automation. For example, household electronic devices such as lights, appliances, climate-control systems and surveillance cameras can be linked to the Internet through wired or wireless networks [1]. The Internet can also be used as the infrastructure for industrial applications. For example, an Internet-based control, monitoring and operation scheduling system for heating, ventilation and air-conditioning systems has been proposed [2].

Many engineering programs have always considered laboratories as essential elements, particularly at the undergraduate level [3]. A significant portion of the development effort on remote access laboratories has focused on demonstrating technical feasibility instead of investigating their implications for engineering pedagogy [4–6]. The concepts of remote access to laboratory equipment for educational purposes have focused on the development of remote control laboratories for distance learning students. Such systems are used for teaching control courses over the Internet. This approach allows students to remotely operate control systems; therefore, students can theoretically access the laboratory 24 hours a day, 7 days a week. Laboratory courses are a vital element of engineering education. Conversely, user-friendly, computer-controlled instrumentation which has revolutionized scientific analysis and measurement can also be accessed by students via remote laboratory systems. Such an Internet-based laboratory could, for example, be used in conjunction with a mechatronics system to provide students with hands-on experience. As an added benefit, this technology may offer opportunities for students to work with sophisticated experiments that they are likely to encounter in an industrial setting but which may be too expensive for schools to purchase and maintain. A basic need in engineering education is for courses comprising a significant number of practical activities where the students, by using experimental instruments in a laboratory, could verify and practise all those analytical concepts and methods learnt in the theoretical courses [7]. Unfortunately, there are various problems in meeting this need. Of these, probably the first is the unavailability of a laboratory suitably equipped with experimental instruments, which are usually very expensive.

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Remote laboratory access allows distance learning students to actually operate experimental facilities, and collect and analyse data. These Internet-based technologies can also be applied to general remote control systems in many areas of research and engineering. Increasingly, online learning platforms are being implemented at various educational levels as a form of teaching support. Finally, in addition to promoting flexibility in teaching and permitting the incorporation of new educational materials and resources, distance-learning familiarizes students with the computer as a work tool [8]. Engineering education requires substantial laboratory work, which can be costly and can rapidly become obsolete. Therefore, laboratory experiments have major economic implications for engineering education.

Shin *et al.* [9] constructed Web-based interactive virtual education systems. You *et al.* [10] described the design and implementation of a robotic system that uses the Internet as an experimental platform. Hayes and Jamrozik [11] described their experiences with Internet course development and delivery, and developed a set of tools for placing courses on the Web. Hui and Cheung [12] examined a method for developing a Web-based learning environment for building energy-efficient solar power systems. Takanobu *et al.'s* [13] project performed on interactions between humans and humanoid robots. Mougharbel *et al.* [14] also evaluated and compared various remote access laboratory installations around the world. Scanlon *et al.* [15] and Colwell *et al.* [16] proposed a system to provide remote access to laboratory work over the Internet.

The word 'mechatronics' was first coined by a senior engineer at the Japanese company, Yaskawa, in 1969, as a combination of 'mecha', for mechanisms, and 'tronics', for electronics. Mechatronics has since taken on a wider meaning, and is now defined as 'the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes' [17–18]. The mechatronics course sequence integrates the fundamental elements of mechanical and electrical engineering and information systems to culminate in a powerful, adaptable, interdisciplinary approach to mechatronics. In the laboratory, students are often provided with a rich supply of sensors, actuators and data collection and control tools that allow for multiple solutions to a given design problem. A broad based approach, involving student-built projects controlled using a computer, encourages creativity and excitement about the subject [19–21]. Mechatronics competency comprises four 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.

The laboratory platform proposed in this study is an educational tool for teaching students the basic principles and methodologies for performing experiments in mechatronics and control systems at any time and from any location via the Internet. This study developed an Internet-based laboratory platform that students can access remotely. The architectural configuration of the proposed system is modular and consists of a server, a laboratory and experimental modules. The modules are actual systems that are suitable for remote operation for engineering education. Practical mechatronics examples, especially prepared for this, are available. The users can operate and monitor these examples.

LABORATORY PLATFORM LEARNING OBJECTIVES IN ENGINEERING EDUCATION

The Internet provides a novel environment for developing educational applications. This study implements an Internet-based laboratory platform for distance learning for engineering education in mechatronics. The proposed platform can contribute to student understanding, because it is highly adaptive and flexible. The system can train students to adapt easily and quickly to the changing industrial environments they will meet after graduation.

The general aim of this work was to develop an Internet-based laboratory platform for teaching mechatronics manipulation and control technologies from any remote location via the Internet. The socio-economic benefits of providing facilities for any-time/any-place laboratory experimentation have clear economic benefits. From a pedagogical point of view, such a system would also provide a consistent and complete high-quality learning environment.

Internet-based platforms were developed for laboratory instruction in operating and programming complex mechatronics manipulators. From a technological perspective, this research focuses 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 in this study emphasized the didactical perspective of such systems, based on specific experimental protocols and combining qualitative and quantitative metrics. A further aim was to compare the effectiveness of the remote laboratory with traditional hands-on laboratory learning scenarios.

The learning goal is to enable students to remotely practice actual mechatronics manipulator programming tasks. The platform encourages active participation by students in contrast with traditionally passive methods of learning mechatronics motion principles. The objectives were to demonstrate the practicality and feasibility of offering an Internet-based laboratory for engineering instruction in mechatronics and control and provide a platform for students to remotely design and implement their own systems.

At the technological level, the platform integrates mechatronics systems in a learning environment. At the learning level, the platform builds on modules and functionalities in realistic learning scenarios to introduce the operation of actual systems and to teach skills associated with programming a graphical monitoring language. Finally, at the experimental evaluation level, a series of experimental studies measures the effectiveness of different learning programs by using a special evaluation protocol combining qualitative and quantitative ratings; the aim is to distinguish different designs for learning and instruction in the technology field.

The Java-based graphical user interface shows the following panels: (1) a real-time video streaming panel showing the actual movement of an Internet-based remote manipulator; (2) an interactive panel providing an exact emulation of the mechatronics manipulator; (3) a control/command editing panel and (4) status and feedback panels providing real-time textual information.

The remote laboratory platform is based on client–server architecture. Moreover, the system supports multiple students connected via the Internet using TCP/IP sockets for servers either as observers, or as administrators, in which case actual control of the TCP/IP sockets for communication and real-time data exchange with the mechatronics manipulator is obtained.

Thus, a key task is supporting the remote laboratory platform with the main objective being to provide students with experience in actually creating and implementing a complete mechatronics manipulation program in a real-world task scenario. In this context of deploying a remote mechatronics laboratory platform, this research is currently focused on the following two main issues.

1. From a technological perspective, adaptation of concepts and techniques are explored for possible implementations in remote laboratory settings.
2. From an educational perspective, teaching mechatronics manipulation principles requires familiarizing students with mechanical and control engineering concepts and skills.

LABORATORY PLATFORM STRUCTURE

Hardware structure

As Fig. 1 shows, students are connected to the server through the Internet. Figure 1 shows the hardware structure of the laboratory platform. In this example, a client PC is remotely accessing the laboratory through a connection to the HTTP server as part of its Internet toolkit, which hosts the Website conducting the experiment. The ADAM4571 converts the COM Port of 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.

IP-CAM control

The IP_CAM is mounted on a pan and tilt unit, which can be controlled through a circuit board. The board is in turn connected through RS-232 to the serial port of the controller PC. Internet-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 of the circuit board. At the client end, a Java applet sets up the sockets for TCP communication with the server. When the student clicks a button intended for camera control, an applet procedure is invoked, which 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 Internet-based control systems requiring frequent parameter adjustments.

The server and user units

The students are connected to the server via the Internet. The server and user units must have main characteristics that can be used without problems. After connecting to the server, they navigate to the Web page of the Internet-based laboratory platform for engineering education.

The students can run the actual mechatronics systems via the PLC. In other words, they can

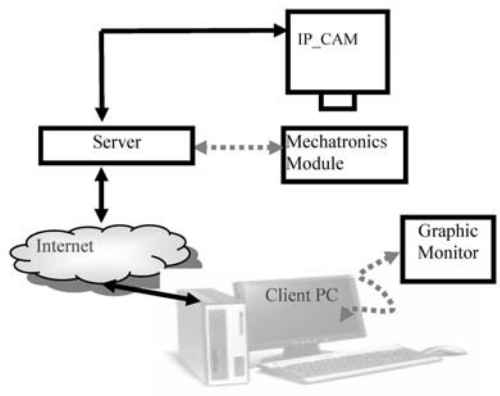

Fig. 1. The hardware structure of the laboratory platform.

apply their control software to actual mechatronics systems and can follow the operation of the system via the IP_CAM installed in the laboratory and simultaneously view the actual system on their monitors.

THE MECHATRONICS EXPERIMENTAL MODULE FOR LABORATORY

The Internet-based laboratory can be set up by designing the experimental content such as the user interface for a remote laboratory and instructions. The student follows the instructions to conduct the remote experiment.

The experiments can be performed by connecting to the Web page of the Internet-based laboratory platform. The students use software to prepare their own control programs for the mechatronics system. The mechatronics system module, which is an important part of the Internet-based laboratory, consists of robotic capture, proximity sensor, transmission belt, limit switch, air compressor and IP-CAM.

Figure 2 presents a robotic capturer mechatronics instrument for use in a laboratory experiment. The experiment was performed as follows. The transmission belt moves any material on it. When the material has moved to the end of the transmission belt, the proximity sensor receives a signal. When the proximity sensor signal is on, the robotic capturer catches the material and moves it to the right. When the robotic capturer has shifted to the farthest right end, the limit switch sensor receives a signal. When the limit switch sensor signal is on, the robotic capturer releases the material, and returns to its original position to stand by for additional processing. An IP-CAM also displays the operating process on the screen of the laboratory platform.

The laboratory part consists of twelve experiments. The mechatronics experimental module is simple 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 the robotic capture experiment as a case study to illustrate the processes involved in the development and evaluation of the remote experimental procedure.

The following steps are performed to operate the robotic capture mechatronics remotely:

1. Connect to the home page of the Internet-based remote laboratory.
2. Obtain user authorization on the Web server side, and obtain a valid session ID for the remote laboratory.
3. View the corresponding Web pages.
4. Run the remote experiment, and view real-time images of the experiment in the browser.
5. End the session by closing the server connection and the session ID.

REMOTE PANEL FOR MONITORING AND CONTROL

This section describes the remote panel for the graphic monitoring and controlling platform with mechatronics experimental module shown in Fig. 3. Figure 4 shows all indicators of the PLC signal. In Fig. 5, the JavaScript monitoring panel shows the input (X) or output (Y) states. Figure 6 integrates the panel described above in an all-in-one laboratory platform. When students log into the system over the Internet, they can monitor and control both the computer and the mechatronics experiment. An IP_CAM can also be used for live broadcast of the actual experiment. Students can perform the experiment whether they are on the campus itself or on the other side of the world. To achieve the remote monitoring and control features, a client–server distributed environment was designed.

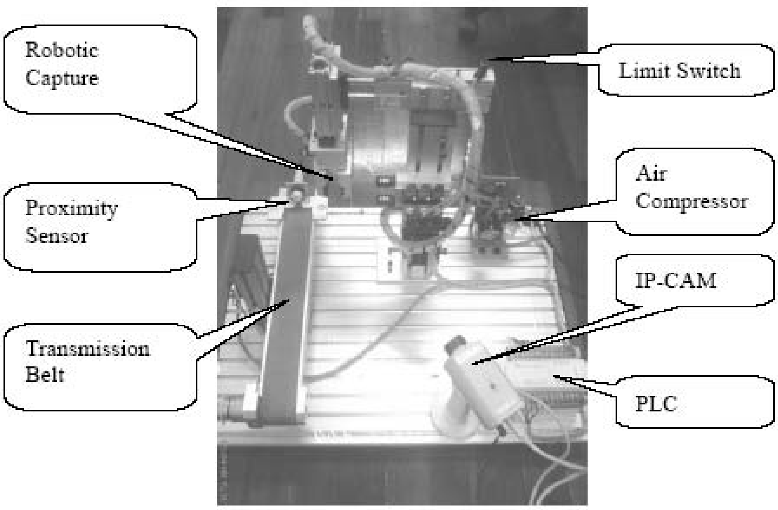

Fig. 2. Robotic capturer mechatronics instrument for use in the laboratory.

Fig. 3. Graphic experimental module.

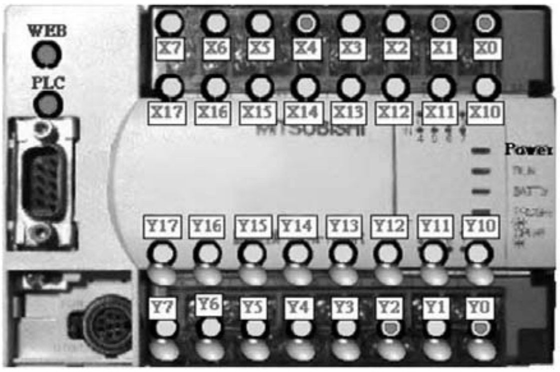

Fig. 4. All indicators of PLC signal.

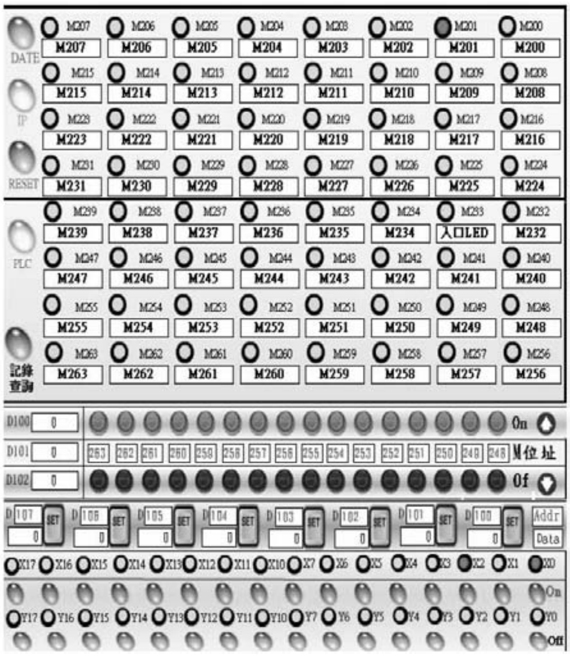

Fig. 5. JavaScript monitoring panel.

EVALUATIONS

Procedures

The three-credit mechatronics laboratory course included lectures and laboratory experiments. The course was managed by one teacher and one graduate assistant (GA). The GA was available for help both online and in person during office hours. Twenty students (one female and nineteen male; average age 19 years) participated in the mechatronics course. They were drawn from the population of undergraduate students. Students were required to prepare before the laboratory and write a report upon completing the laboratory experiment. After completing the laboratory exercises, students were given the option of taking a final test or completing a project. The experiments and projects focused on essential aspects of Internet-based mechatronics applications and realization of control logic with proper hardware components. Upon graduation, most students enter the private sector or work in government agencies or graduate schools. An understanding of the technologies that are offered in the presented course is a valuable aid for teaching students to solve real-world problems as the Internet has penetrated almost every aspect of daily life.

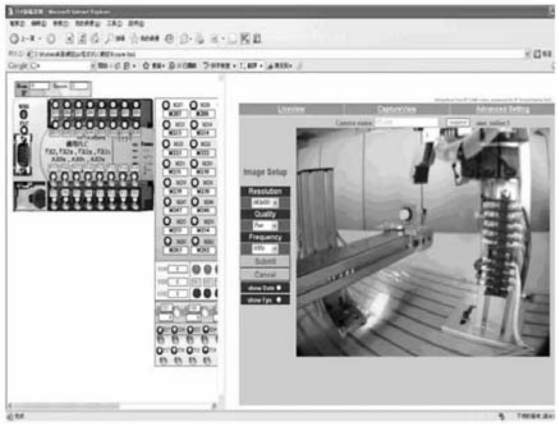

Fig. 6. Integrated laboratory platform.

Measures

A learning evaluation system is used to test the efficacy of the system in terms of teaching, learning and student achievement. The evaluation aspects have a marked impact on student motivation and encourage teachers to explore ways of improving individual learning attitudes. The system requires students to continually evaluate their own performance and that of their peers [22]. User evaluation is a domain that is not as well articulated and explored as assessing whether a system is usable, or whether it actively increases work productivity [23].

The remote laboratory platform was designed for an educational application. A system evaluation was performed to capture the students' likes and dislikes, and whether the system met their needs. The platform was first tested and evaluated. The mechatronics module was tested for accuracy and completeness, and the generated output data were checked and validated. Second, the outcome was evaluated once the laboratory platform was

Table 1. Evaluation questionnaire results.

Evaluation items	Students (*n* = 20)		Experts (*n* = 10)		Difference between experts and students Mann–Whitney U test (significance level)
	M	*SD*	*M*	*SD*	
1. The platform guide was organized	4.00	0.459	3.90	0.316	–0.611 (0.713)
2. The platform guide was easy to follow	4.35	0.489	4.20	0.632	–0.601 (0.548)
3. The platform goals were clear	3.90	0.308	3.80	0.422	–0.747 (0.455)
4. The platform was appropriate for my level	3.95	0.510	3.40	0.516	–2.541 (0.011)*
5. The background information was useful for understanding the platform	4.10	0.447	3.20	0.422	–3.944 (0.000)*
6. The background information for the platform was clearly written	4.15	0.489	4.00	0.000	–1.019 (0.308)
7. The key terms for the platform were explained, understandable and useful	3.80	0.523	4.10	0.316	–1.639 (0.101)
8. The material was helped in the teaching of the platform	4.10	0.308	3.80	0.422	–2.086 (0.037)*
9. The platform was more interesting than traditional textbook learning	4.40	0.503	4.10	0.316	–1.662 (0.097)
10. The platform was more exciting than traditional textbook learning	4.30	0.470	4.20	0.422	–0.574 (0.566)
11. The assessments, overall, provided useful feedback on your progress	4.15	0.366	4.30	0.483	–0.952 (0.341)
12. The learning was useful and motivating overall	4.25	0.444	4.00	0.664	–1.096 (0.273)

* $p < 0.05$.

constructed. Several approaches to evaluating the system are possible. The teaching and learning platform was evaluated by measuring teacher and student satisfaction. An evaluation form was designed to evaluate the usability and effectiveness of the system on a five-point Likert scale from 1 for 'Strongly disagree' to 5 for 'Strongly agree'. The scores on items measuring the effectiveness of the laboratory platform measured whether the system accomplished its objectives. The scores on the items measuring the usability of the laboratory platform reflected its usefulness. Student satisfaction was measured from the scores given to these questions, and was adopted as an indicator of the success of the laboratory platform.

Expert evaluation

Domain expert evaluations were used to help determine the accuracy of the embedded knowledge and the effectiveness of the online teaching system. The laboratory platform was validated by a group of ten participants. All were university professors and/or researchers with an average of more than three years' experience in teaching mechatronics; therefore each expert had a strong background in engineering education. Overall, the expert evaluations were generally positive.

Student evaluation

Evaluations by the students were used to help determine the acceptability of the project according to the following criteria: usability of the laboratory platform, the extent to which the students gained hands-on experience in mechatronics, and whether the project helped students learn about mechatronics. The evaluation form was distributed to all students who had taken this course in the Department of Industrial Education and Technology at National Changhua University of Education. Most students successfully undertook the remote experiment, and responded positively to the system. They reported that they enjoyed performing the task and found it interesting. Most students found the quality, size and detail of the video feeds acceptable, although the video feed had to be improved. Two key findings were drawn from these student trials in relation to the remote control aspect of the experiment: (a) additional feedback was stipulated on events in the laboratory, and (b) delays between the initiation and execution of an action in the laboratory sometimes caused confusion.

Evaluation results

Table 1 summarizes the expert and student responses to the questionnaire. Both groups rated the Internet-based laboratory platform for distance learning highly based on the results of the evaluation.

A further analysis was conducted to investigate whether or not experts and potential users differed in their mean ratings of the effectiveness and usability of the system. Since the sample size is small, the Non-parametric Mann–Whitney U tests were used and the results are presented in Table 1. The level of significance α is selected to be 0.05. The corresponding two-tail critical value is ± 1.96. Except for items 4, 5 and 8, the mean ratings of the experts regarding the effectiveness and usability of the system did not significantly differ from those of the students' system.

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 generalize to 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.

CONCLUSIONS

In this study, the development of a remote laboratory platform for a mechatronics course has been presented. This remarkable effort developed novel strategies for distance learning and remote laboratory via the Internet. The available system can be run in real time through the Internet from anywhere in the world, and the actual system can be monitored by the IP_CAM. This platform is flexible and can easily be adapted for different engineering education departments. This study proposes a generic and modular architecture for remotely-accessible laboratories, based on a convergence of remote access technologies. It also discusses the implementation of such a framework, and the evaluation by students of its learning outcomes. The Internet-based platform is an effective alternative to setting up a conventional laboratory to support laboratory courses in engineering education. It has the following benefits.

1. It lowers costs by sharing laboratory equipment.
2. It gives students greater oversight by performing various experiments based on real plants.
3. It enables students to solve restrictions of time and space.

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Wen-Jye Shyr is an associate professor in the Department of Industrial Education and Technology at National Changhua University of Education. He received his Ph.D. from the National Changhua University of Education. He is currently registrar in the office of academic affairs. His current research is in the mechatronics, artificial intelligent and technology education.