DEVELOPMENT OF INTERNET-BASED REMOTE LABORATORY FOR PID CONTROL EXPERIMENTS

BY

HANANI ABDUL WAHAB

A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science in Mechatronics Engineering

Kulliyyah of Engineering
International Islamic University Malaysia

AUGUST 2007

ABSTRACT

In control engineering education, concepts taught through lectures are often complemented by practical laboratory experimentation. However, many control-engineering classes do not include a lab component because of significant expense, space and time considerations. As a result, an interactive experiment with real world systems and equipments needs to improve the motivation of control engineering students and develop an engineering approach to solve practical problems. The Interlab project was initiated in November 2005 at International Islamic University of Malaysia. The aim of the thesis is to develop technologies that enable laboratory equipment to be controlled remotely by students through the Internet. This thesis involved design and development of lab scale missile launcher model, modeling and parameters identification of the plant, design and implementation of PID controller and development of website for remote control laboratory for control experimentation. The laboratory uses a NetMeeting; a streaming server to broadcast live video of the plant. When students do their experiment online, they would get instant feedback of their control action by observing movements of the equipment from the video. This would give students a better feel of the laboratory. Students can perform laboratory experiment on the plant using xPC Target Web Browser Interface from any computer connected to the Internet. The initial result shows that the proposed system worked as expected. The use of laboratory equipment would be optimized and students learning experience would also be enhanced.

ملخّص البحث

فى تعليم التحكم الجهازي بموجات اللاسلكية كما يفهم فى علم الهندسة فى حاجة ماسة إلى تدريب الدارسين بطريقة تطبيقية. ومع ذلك ، أن كثيرا من المحاضرات لم تتوفر فيها الأجهزة المعينة، وذلك لأنها تحتاج إلى دعم مالي صغير فى إيجادها بالإضافة إلى زمن محصور ومكان محدود. ومن هذا، فالتدريب المكثف مع تنظيم البرامج بطريقة فاعلة، وإعداد الأجهزة المتوفرة من عوامل مهمة لإيجاد رغبة الدارسين لدراستها ولحل المشكلات المتعلقة بعمل تطبيقي. وقد بدأ هذا المشروع داخل المخابر منذ شهر نوفمبر سنة 2005 فى الجامعة الإسلامية العالمية بماليزيا. وهذا يهدف لتنشئة التقنية للتحكم بجهاز من بعد الذي يمكن الدارسون أن يقوموا به بوسيلة الإنترنيت. هذا البحث يشتمل على تشكيلي، وتنشئة مطلق الأسلحة بحجم صغير ، وترقيم رياضي والتعرف على دوائر ذلك الترقيم . ويشتمل أيضا على عملية اختراع المحكم اللاسلكي (فى.أي.دي) وبناء موقع شبكة الإنترنيت داخل المخبر حتى يمكن اختبار التحكم على الجهاز من بعد. ويحتاج هذا المخبر إلى استخدام برامج حوار عبر الإنترنيت . فالدارسون عندما يقومون بهذا الاختبار ثم يستعرضونه عبر الإنترنيت حيث يحصلون منه على رد فعل عن عملية التحكم عند مراقبة تطورات الجهاز عبر الشاشة . وبهذه الطريقة تؤدي إلى انشراح صدور الدارسين الذين لهم قدرة استخدام شبكة العرض "xPC Target" من الحاسوبات المتصلة بالإنترنيت. والنتائج البديهية تدل على أن النظام المستعرض يعمل بوظيفته على ما يرام . وانطلاقا ومن هذا يستطيع تحديد استعمال المخابر إلى أقل ما يمكن، وزيادة الخبرة لدى الدارسين فى عملية التعليم والتعلم .

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

…………………………….
Wahyudi Martono
Supervisor

…………………………….
Riza Muhida
Co-Supervisor

I certify that I have read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

…………………………….
Md. Abdus Samad Kamal
Internal Examiner

…………………………….
Khisbullah Huda
External Examiner

This dissertation was submitted to the Department of Mechatronics Engineering and is accepted as a partial fulfilment of the degree of Master of Science in Mechatronics Engineering.

…………………………….
Md. Raisuddin Khan
Head, Department of
Mechatronics Engineering

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as a partial fulfilment of the degree of Master of Science in Mechatronics Engineering.

…………………………….
Ahmad Faris Ismail
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Hanani Abdul Wahab

Signature:............................ Date: ....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

DEVELOPMENT OF INTERNET-BASED REMOTE LABORATORY FOR PID CONTROL EXPERIMENTS

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the permission of the copyright holder except as provided below.

1. **Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.**

2. **IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.**

3. **The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.**

Affirmed by Hanani binti Abdul Wahab

…………………… Signature

…………………… Date

To:

My husband and my daugther

ACKNOWLEDGEMENTS

Alhamdulillah, all praise to Allah, the Most Beneficent and the Most Merciful. It is by the grace of the Almighty Allah that this research work has been completed successfully.

I would like to express my deepest gratitude and appreciation to my supervisor, Associate Professor Dr. Wahyudi Martono for all the guidance and support he had given me throughout the years. His precious advice and encouragement has pushed me through the tough times.

It was also a great working with Assistant Professor Dr. Riza Muhida for his continuous support, advices and suggestions that significantly contribute to the success of this research work

Also a special thanks to the staff of Mechatronics Engineering Department IIUM. They have assisted me in giving advises, idea and technical supports to this research work.

Last and importantly, I would like to thank my family especially my husband for boundless love, patience and endless encouragement to encourage me in pursuing my goals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

a_1	Denominator parameter
a_2	Denominator parameter
e_b	Back emf
g	Gravitational acceleration
i	Current
I	Current
J	Moment of inertia
K	Kinetic Energy
K	motor constant
K_e	Motor back emf constant
K_t	Motor torque constant
K_0	Numerator parameter
K_1	Artificial response constant
K_2	Artificial response constant
K_d	Derivative gain
K_i	Integral gain
K_p	Proportional gain
l	Height of the load from the surface
L	Lagrangian
L_{ind}	Inductance
m_1	Mass of the load
m_2	Mass of the shaft
P	Power motor
P	Potential Energy
R	Resistance
s	Laplace domain function
t	Time
T	Torque
u	Input voltage

V	Voltage
W	Watt
ω	Motor angular velocity
ω_1	Artificial output
ω_2	Artificial output
ω_{ss}	Steady state velocity
ω_{1ss}	Steady state artificial velocity
ω_{2ss}	Steady state artificial velocity
ω_m	Maximum speed
ω_{max}	Maximum speed
Ω	Angular velocity
α	Angular acceleration
τ_m	summation of external torques
θ	Motor rotational angle

LIST OF ABBREVIATIONS

A./D.	Analog to Digital
A.C.T.	Automatic Control Telelab
B.I.O.S.	Basic Input/Output System
U.A.R.T.	Universal Asynchronous Receiver/Transmitter
C.N.C.	Computer Numerical Control
C.P.U.	Central Processing Unit
D./A.	Digital to Analog
D.A.Q.	Data Acquisition Card
D.C.	Direct Current
D.T.E.	Data Terminal Equipment
G.U.I.	Graphical User Interface
H.T.M.L.	HyperText Markup Language
H.T.T.P.	HyperText Transfer Protocol
I./O.	Input/Output
I.B.R.L.	Internet-based Remote Laboratory
I.S.A.	Industry Standard Architecture
I.T.	Information Technology
I.T.U.	International Telecommunication Union
L.A.N.	Local Area Network
L.E.D.	Light Emitting Diode
N.I.	National Instuments
P.C.	Personal Computer
P.C.I.	Peripheral Component Interconnect
P.I.D.	Proportional Integral Derivative
R.A.M.	Random Access Memory
R.L.	Remote Lab
R.p.m.	Revolution per Minute
R.T.W.	Real Time Workshop
S.I.T.	Simulation Interface Toolbox
S.R.O.	Simulink Response Optimization
T.C.P./I.P.	Transmission Control Protocol/Internet Protocol,
V.B.	Visual Basic
V.L.	Virtual Lab
W.A.V.E.S.	Web-based AudioNideo Education System
W.W.W.	World Wide Web

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

As the fast development in modern engineering technology, engineering education becomes an important issue in recent years. In engineering education, control engineering is one of the disciplines that focus on the mathematical modeling systems of a diverse nature, analyzing their dynamic behavior, and using control theory to create a controller that will cause the systems to behave in a desired manner.

In control engineering education, laboratory work is an important component for a holistic learning experience (Bing *et al.,* 2005). Normally, a control course requires considerable mathematical as well as engineering knowledge and is consequently regarded as a difficult course by many undergraduate students. From the academic point of view, helping the students to improve their learning on the control engineering is an important task which requires careful planning and innovative teaching methods. Traditionally, the didactic teaching approach has been used to teach the students on the concepts needed to solve control problems. This approach is commonly adopted in many mathematics intensive courses; however it generally lacks reflection from the students to improve their learning.

One significant tendency in the field of control practice is the increasing use of virtual instrumentation. In fact in major production facilities, instead of using real plant, operators are often trained in plant operation using a simulation environment of to drive virtual instruments. However, experimentation with a real plant or real object cannot be replaced by a simulation or training simulators, especially the sensations perceived by the trainee/students in the experiment. Practical education needs to be based on errors and irregularities, as occurs in mechanical, electrical or chemical systems, as opposed to the ideal icons and environments represented on a computer display.

In control engineering education, laboratory courses are an essential part of the education. Laboratory works are important for students while they are applying their control engineering theory to the experiment. This is an opportunity for the student to construct their own knowledge and put their theory and practice to get a research experience in the laboratory. However, many educational institutions do not include lab components for control engineering courses because of significant expense, space and time considerations. In addition, since the control engineering is a general subject for almost of the engineering program, the number of students who enrolled is high. As a result, engineering students have to share the equipment in the laboratory. This reduces the time students spend with the equipment and diminishes the purpose of the laboratory (Harjono, 2001) because sometimes there is not enough time for their turn in the laboratory class.

The scenario for control education is changing and new situation has to be addressed. Information technology opens a whole new world of real opportunities. Computers show a great potential to enhance student achievement. A vital aspect of control engineering education is that laboratory and practical work need to provide engineering students with a taste of real situations, measurement and instrumentation, with all their attendant problems. The new idea is allowing the students to perform real experiments, in real time, on real equipment, but over the Internet.

Fortuitously, the Internet world is truly available. The usage of Internet could not be denied. The Internet technology has significant effects on almost every single aspects of daily life and has changed the people performs their daily works. People can move faster, easier, never feel alone and the world is just on their finger tips. The World Wide Web (WWW) technologies and computer-controlled instrumentation presently allow many people to work from home instead of from office. It also has provided the facilities for people to monitor and control machinery from anywhere in the world (Davies, 2002).

Furthermore, with this power of communication, universities around the world are adapting their teaching methods to include computer and Internet technology, such as tele-teaching (Filler *et al.*, 2000). Tele-teaching is a method of teaching through the Internet either by presenting on the Internet some lecture materials, online tutorials or real-time laboratory. The real-time laboratory, which is benefit to students, as it can allow them to perform laboratory experiments on equipment from any computer, connected to the Internet (Davies, 2002). By adopting Internet-based experimentation, the above-mentioned practical experiment problems can be solved. The unique and expensive equipment can be shared between different universities. In addition, the students have the convenience for conducting experiments at their own preferable time (not only during working hours) and place since they are not required physically being at the university during working hours. Study conducted by Barker (Barker *et al.*, 1998) shows that students learn better when they have control over when and where the learning takes place. The less obvious benefit of Internet-based real-time experiments would be reduction of lecturers' and students' time and cost. This will give them to concentrate on more important task such as improving teaching and learning. For the above advantages, the development of Internet-based real-time control laboratory is naturally justified.

1.2 OBJECTIVES

The main objective of this thesis is to develop an Internet-based remote laboratory for control engineering education, which allows the students to conduct the experiments through Internet connection on their own preferable time and place. To achieve the main objective, it is necessary

a) To develop and fabricate a plant to be controlled in the control experimentation

b) To develop website and video servers for Internet access of the real time control system laboratory

c) To develop and configure software to allow PID control experiments through Internet

1.3 METHODOLGY

In order to achieve the objectives of this study, the following procedures are considered:

a) The research starts with the understanding of control system course syllabus for undergraduate engineering student

b) Selection, design and fabrication of plant to be used as case study in control laboratory experimentation.

c) Development of real-time control software.

d) Development of website and video server for Internet access of the control systems experimentation.

e) Hardware and software integration.

f) Implementation and evaluation of Internet-based remote control laboratory experimentation.

1.4 THESIS OUTLINE

The thesis outline is as follows:

i. Chapter 2: This chapter discusses literature review of technical papers and scientific papers on control system engineering laboratory.

ii. Chapter 3: Development of the hardware and software of the system is described in this chapter. Software development and architecture of the system is described by introducing the software that is used. The development of real-time control system is also to be explained in this chapter. The mathematical modeling, which consists of the model derivation and parameters identification, is explained. A series of experiments is carried out to identify the unknown parameters of the lab scale missile launcher system. Then, the design of PID controller is also discussed in this chapter.

iii. Chapter 4: The implementation of Internet-based Remote Laboratory for real-time control system is described in this chapter. The parameters identification and PID controller implementation results is also discussed in this chapter.

iv. Chapter 5: This chapter summarizes all the results obtained in the previous chapters. New development and improvement are suggested for the further study.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Control engineering education combines both theory and practical experiments. Students thereby achieve knowledge and skills of control system design in order to develop controllers for achieving given performance requirements. Students are confronted with dynamic phenomena that are often difficult to explain in words or in textbooks. In addition, control engineering education faces severe problems because the ideas and phenomena involved in such areas are complex and hard to demonstrate on neither the conventional chalkboard nor the electronic virtual blackboard. Therefore the importance of laboratory experiments in control engineering education could never be overemphasized.

There is no doubt that lab-based courses play an important role in control engineering education. According to Nersessian (1991), Clough (2002) and Magin *et al.* (1986), hands-on experience is at the heart of science learning and laboratory experiences make science come alive. In addition, lab courses have a strong impact on students' learning outcomes. From the laboratory, students can apply their engineering knowledge learnt from the lectures to real engineering situations. The uses of laboratory experiments are a critical important aspect of engineering education. Experience in teaching has shown that a complementary approach in combining theoretical and practical exercise is vital for effective learning.

However, laboratory equipment is usually expensive. As a result, engineering students have to share the equipment in the laboratory. This reduces the time students spend with the equipment and diminishes the purpose of the laboratory. The interactive experiments with real-world systems and plants improve the motivation of control systems engineering students and also develop an engineering approach to solve practical problems. The computer-based laboratory has been introduced in the mid of 1990s to control and monitor the plant elements and devices in the laboratory. This application ranges from computer-based control systems to Internet-based control systems, to be used as an educational tool for distributed control systems teaching.

2.2 INTERNET-BASED CONTROL SYSTEM LABORATORY

Researchers have convincingly argued that Information Technology (IT) has dramatically changed the laboratory education landscape. The WWW is a set of protocols and conventions and a body of software that uses the infrastructure of the Internet. A user only needs a web browser to access all information available in the WWW. The browser provides a standardized framework for user interfaces to access web pages and query databases. Most browsers can run Java applets. Applets are programs written in Java that run inside a browser. To run an applet, a user just has to open the web page that contains the applet. The web can also be used to distribute application software or browser plug-in that have to be explicitly installed on the client computer.

Recent years have witnessed a phenomenological growth of the Internet and the WWW. Diverse array of governmental and commercial activities are now conducted online. Within the education sector, WWW is being exploited for rapid information dissemination and content-rich delivery of educational material to enhance student learning and to revolutionize distance learning.Via the Internet, online laboratories could offer more flexibility to prepare assignments for students that require experimentation with real phenomena. In addition, an Internet laboratory allows a better use of equipment either by local or by remote users since they can access to the labs from anywhere and anytime with just via the Internet connection. This sharing of resources not only brings down the experiment cost per student, but equipment will also be made available to more students since the time and space constraints normally associated with a traditional laboratory can be removed.

Nowadays, the development of virtual labs (VL) and remote labs (RL) which can be considered as a mature technology is an alternative for conventional hands-on labs. There are many well-known approaches and solutions for providing students with remote access to simulations or didactical setups across the Internet. A number of researches and papers have been dedicated to both types of laboratories: VL and RL. Several papers also discussed the reason for using real time process laboratory over the simulation. Although it is possible to use the simulation to teach many practical skills to students, however there are several situations where students have to interact with the real experiments. To solve this problem, a camera is used. The first hardware device that could be accessed through the WWW was a camera that was pointed at a coffee machine Trojan in 1991 (Quentin *et al.*, 1997). In 1994, the Mercury Project developed the first telerobots were connected to the web and then Australia's Telerobot on the Web (Telerobot (1994), Taylor and Trevelyan (1995), Taylor and Dalton (2000).

There are some differences between VL and RL. The main difference between them is that VL allows to remotely running simulations with possible animations of the controlled system (Merrick and Ponton, 1996; Lee *et al.*, 1999; Schmid, 1998). The VL is good to assimilate theory but cannot replace real processes, while the RL

BIBLIOGRAPHY

Bing.D, K.V Ling, Habib.M, M.Hossein and Robert K.L (2005). *An online laboratory framework for control engineering course.* School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.

Canfora, G., Daponte, P., and Rapuano, S (2004). *Remotely accessible laboratory for electronic measurement teaching.* Comput. Standards and Interfaces 26, 6, 489–499.

Canizares, C. A. and Faur, Z. T. (1997). *Advantages and disadvantages of using various computer tools in electrical engineering courses.* IEEE Trans. Education 40, 3, 166–171.

Clough,M. P. (2002). *Using the laboratory to enhance student learning. In learning science and the science of learning.* R. W. Bybee, Ed. National Science Teachers Association, Washington, DC, pp 85–97.

Cooper,M., Donnelly ,A., and Ferreira,J.M (2002b). *Remote controlled experiments for teaching over the internet: A comparison of approaches developed in the PEARL project.* In Proceedings of the ASCILITE Conference 2002. Auckland, New Zealand.

Dalton, B. and Taylor, K. (2000). *Distributed robotics over the internet.* IEEE Robotics and Automation Magazine, Vol 7:2, pp 22-27.

Davies, T. (2002). *Software system for controlling web-based laboratory.* BE Thesis, School of Mechanical Engineering, The University of Western Australia.

Deborah A. M, Benjamin P, John T. W. (2001). *An internet-based remote laboratory for control education.* Proceedings of the American Control Conference Arlington, VA.

Denis Gillet / Christophe Salzmann / Haniph A. Latchman / and Oscar D. Crisalle. *A distributed laboratory: Supporting practical experience in distance learning.* Swiss Federal Institute of Technology, CH - 1015 Lausanne, Switzerland / University of Florida, Gainesville, FL - 32611, USA.

Dorf. R & Bishop.R. (2001). *Modern control system.* New Jersey:Prentice Hall.

Dorsey, J. (2002). *Continuous and discrete control systems.* MGraw-Hill, pp.212-227.

Exel, M., Gentil, S., Michau, F., Rey, D., (2000). *Simulation workshop and remote laboratory: Two web-based training approaches for control*. Proceedings of the American Control Conference, v5, 2000, 2000 American Control Conference, Jun 28-Jun 30 2000, Chicago, IL, USA, p 3468-3472.

Faria, A. J. and Whiteley, T. R. (1990). *An empirical evaluation of the pedagogical value of playing a simulation game in a principles of marketing course*. Development in Business Simul. Experiential Learning 17, 53–57. ACM Computing Surveys, Vol. 38, No. 3, Article 7, Publication date: September 2006.

Franklin, G.F., Powell, J.D., Emami-Naeini, A. (2002). *Feedback control of dynamic system.* Prentice-Hall.

Grant, A. (1995). *The effective use of laboratories in undergraduate courses*. Int. J. Mechanical Eng. Education 23, 2, 95–101.

Harjono (2001). *Telelab: Online temperature control laboratory mechatronics engineering honours thesis.* The University of Western Australia.

Henry, J. (1996a). *Controls laboratory teaching via the world wide web.* ASEE Annual Conference, Session 3513, available from National Instruments Academic Resources CD-ROM 2001 Edition.

Henry, J. (1996b). *Running laboratory experiments via the world wide web*. ASEE Annual Conference, Session 3513, available from National Instruments Academic Resources CD-ROM 2001 Edition.

Hutzel, W. J. (2002). *A remotely accessed HVAC laboratory for distance education.* Int. J. Eng. Education 18, 6, 711–716.

J.C. Martinez-Garcia and R.Garrido, (2001). *Mechatronics hands-on training through the development of an internet based automatic control laboratory.* Proceedings of the 2001 IEEE International Conference on control application, pp 131-134 Mexico City, México.

Jin W J,GTA, Ali K. (2005). *To use simulink*. Department of Electrical and Computer Engineering.The Ohio State University.

K. Barker, A. W. Bennett, G. E. Stokes, M. Lucas, M. V. Swaay (1988). *Goal-oriented laboratory development in CS/EE.* Proceedings of the nineteenth SIGCSE technical symposium on Computer science education Atlanta, Georgia, United States ISSN:0097-8418 pp 267-267.

K. Brady & T. J. Tam (1998). *Internet-based remote teleoperaton*. Proc. IEEE Int. Conf: on Robotics and dufomation, vol. 1, pp. 65-70.

Kin Yeung and Jie Huang, (2001). *Development of internet based control experiment.* Proceedings of the 40th IEEE Conference on Decision and control, pp 2809-2814 Orlando,Florida USA.

Knight, C. D., DeWeerth, S. P. (1997). *A distance learning laboratory for engineering education.* ASEE Annual Conference & Exposition, Milwaukee, WI.

Lee, K. O. (1999). *IT enabled innovative learning.* In Proceedings of the conference on IT in education and training (pp. 16-25). Hong Kong: IEE Hong Kong.

M. Casini, (1999). *Designing a tele laboratory for control of dynamic systems through internet.* M.S. thesis, Università degli Studi di Siena.

M. Casini, D. Prattichizzo, and A. Vicino.(2001). *The automatic control telelab: A remote laboratory of automatic control.* Proc. 40th IEEE Conf. on Decision Control, pp. 3242–3247.

M. Casini, D. Prattichizzo, A. Vicino (2003). *E-Learning by remote laboratories: A new tool for control education.* Preprints 6th IFAC Symposium on Advances in Control Education, pp. 95-100, Oulu, Finlandia.

M. Casini, D. Prattichizzo, and AntonioVicino.(1999). *The automatic control telelab: A userfriendly interface for distance learning.* Technical report, Universit_a di Siena, Italy.

Magin D. J., Churches A.E. and Reizes, J. A. (1986*). Design and experimentation in undergraduate mechanical engineering.* In Proceedings of a Conference on Teaching Engineering Designers. Sydney, Australia. Institution of Engineers, pp 96–100.

Magin, D. J. and Kanapathipillai, S. (2002). *Engineering students' understanding of the role of experimentation.* European J. Eng. Education 25, 4, 351–358.

Marwan K. A (2002). *Modeling and control of a magnetic levitation system.* Bradley University.

Mclellan, H. (1995). *Situated learning perspectives.* Educational Technology, Englewood Cliffs, NJ.

Merrick, CM and JW Ponton (2002). *The ECOSSE control hypercourse.* Comp and Chem Eng 20, S1353-1358.

Nersessian N.J. (1991). *Conceptual change in science and in science education. In history, philosophy, and science teaching*, M. R. Matthews, Ed. OISE Press, Toronto, Canada, pp 133–148.

Nise, N.S., (2000). *Control systems engineering.* United States of America. John Wiley and Sons, Inc.

Papathanassioun, A., Oster, J., and Baier, P. W. (1999). *A novel simulation concept of reduced computational cost for TD-CDMA mobile radio systems with adaptive antennas.* In Proceedings of the Vehicular Technology Conference (VTC 1999), Fall. Amsterdam, the Netherlands. 218–222.

Parush, A., Hamm, H. and Shtub. (2002). *Learning histories in simulation-based teaching: The effects on self-learning and transfer*. Comput. and Education 39, 319–332.

Quentin Stafford-Fraser (1997). *Where it all began: The trojan room coffee pot.* WebSight magazine.

Rohrig, C.; Jochheim. (1999). *Remote control of laboratory experiments*, Proc. of the 19th ICDE World Conference on Open Learning and Distance Education, Vienna.

Rohrig, C.; Jochheim. (1999). *The virtual lab for controlling real experiments via internet,* Proc. IEEE International Symposium on Computer-Aided Control System Design, CACSD'99, Hawaii

Scanlon E., Colweel C., Cooper M. and Paolo T. (2004). *Remote experiments, reversioning and rethinking science learning.* Comput. and Education 43, pp 1–2, 153–163.

Schmid, C. (1999). *A remote laboratory using virtual reality on the web, simulation.* Vol. 73, No. 1, pp. 13-21.

Shaheen, M., Loparo, K. A and Buchner, M. R. (1998). *Remote laboratory experimentation.* In Proceedings of the 1998 American Control Conference. Philadelphia, PA. 1326–1329.

Shin, D., Yoon, E. S., Lee,K. Y., and Lee,E. S. (2002). *A web-based, interactive virtual laboratory system for unit operations and process systems engineering education: Issues, design and implementation.* Computers and Chemical Eng. 26, 2, 319–330.

Smith, P. R. and Pollard, D. (1986). *The role of computer simulations in engineering education.* Comput. and Education 10, 3, 335–340.

Sonnenwald,D.H., Whitton, M. C., and Maglaughlin, K. L. (2003). *Evaluating a scientific collaboratory: Results of a controlled experiment.* ACM Trans. Comput. Hum. Interact 10, 2, 150–176.

Stefani, R.T., Shahian, B. (2002). *Design of feedback control system.* New York: Oxford University Press.

Taylor, K. and Trevelyan, J. P. (1995). *Australia's telerobot on the web.* 26th Symposium on Industrial Robotics, Singapore, October 1995, pp 39-44.

Timm J. Filler, Jörg Jerosch, Elmar T. Peuker (2000). *Live interdisciplinary teaching via the internet.* Computer Methods and Programs in Biomedicine, Vol. 61, pp 157-162.

Tor A Fjeldly, Micheal S. Shur, (2003). *On the web running real electronics experiments via the internet.* Wiley Inter Science, Canada.

Warren E. D,Darren M. D,B. T. Costic, & Marcio S. de Queiroz. (2002). *A MATLAB-based control systems laboratory experience for undergraduate students: Toward standardization and shared resources.* IEEE Transaction on Education.

Whiteley, T. R. and Faria, A. J. (1989). *A study of the relationship between student final exam performance and simulation game participation.* Simul. Games 21, 1, 44–64.

Windows NetMeeting 3.0 Help, Microsoft Corporation 1999.

Zimmerli,S.,Steinemann,M., and Braun, T. (2003). *Educational environments: Resource management portal for laboratories using real devices on the internet.* ACM SIGCOMM Comput. Commun. Review 53, 3, 145–151.

http://www.mathworks.com/

http://prt.fernuni-hagen.de/virtlab/

http://mechatronics.poly.edu/MPCRL/

http://chem.engr.utc.edu/webres/Stations/controlslab.html

http://telerobot.mech.uwa.edu.au/

http://cim3.mec.ua.pt/

http://www.dii.unisi.it/~control/act/experiments.php

http://chem.engr.utc.edu/

http://vlab.ee.nus.edu.sr/vlab