

An undergraduate course – Internet-based instrumentation and control¹

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Abstract - *In this paper, the objective, strategy and implementation details of a new undergraduate course, Internet-based Instrumentation and Control, are presented. The course has a companion laboratory that is supported by the National Science Foundation. It is offered to senior-level undergraduate engineering students who are interested in sensing, instrumentation, control and web programming and want to learn more about the integration of these technologies for solving real-world engineering problems. It will also be offered to gifted high school seniors as a vehicle to attract them to engineering disciplines. Preliminary assessment of the first offering of the course is encouraging and has shown that the course has achieved success in helping students to understand concepts and master basic technologies for developing Internet-based automatic systems.*

Index terms – Internet programming, Control over the Internet, Networked Control, Distance Learning, Undergraduate Education

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I. Introduction

The rapid growth of the Internet provides tremendous opportunities for Internet-based Automation. Household electronic devices such as lights, appliances, climate-control systems, and surveillance cameras are linked to the Internet through wire or wireless networks (Figure 1). It is predicted that Internet-connected home area networks will soon penetrate domestic life [1].

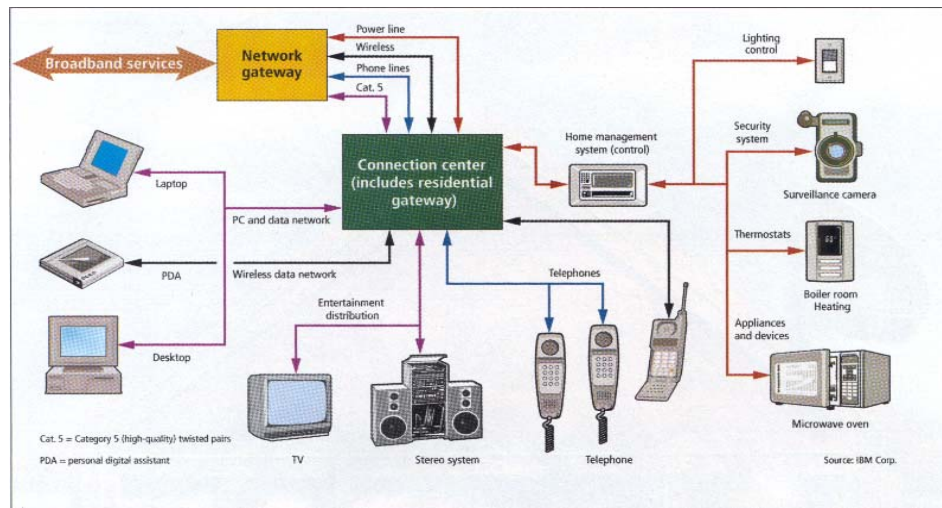


Figure 1 A conceptual home networking system (from [1])

Due to the tremendous growth in the Internet over the past decade, professionals trained in aspects of Internet programming for Instrumentation and Control are in high demand. However, materials that fit classroom teaching and lab experimentation for undergraduate students in this area are very scarce.

The goal of this study is to prove the concept of offering an undergraduate course with a companion lab that teaches students to design and develop tools for Internet-based Instrumentation and Control. The following objectives have been pursued: (a) demonstrate that it is practical and feasible to offer engineering undergraduate students a course, Internet-based Instrumentation and Control, which involves recent technological innovations, and (b) demonstrate that the proposed course can be effectively conducted with two integrated components: classroom lecturing and hands-on practice.

Researchers have been working in the area of remote control suitable for classroom teaching for a numbers of years. In 1997, Zimmer and his coworkers [2] proposed the concept of utilizing web-based instrumentation tools. The main advantages according to the authors are the facts that students can be exposed to new and advanced instruments that are not facilitated in a pure classical university courses. Laboratories that are normally closed during the night can offer “night services” for students who live across time zones [2].

Two years later, Overstreet and Tzes described in [3], a design of generic virtual instruments used for real-time experimentation at the control engineering laboratory of Polytechnic University in a remote access environment. Their approach is with the control algorithm being performed at the client side.

Ramakrishnan and his coworkers [4] reported the implementation of a web-based laboratory experiment concerning a “Coupled Tank Apparatus”, using the Transmission Control Protocol (TCP) for communication. The web server that hosts the web page to be displayed (at the client side) is written in the LabView ‘G’ language. Three available controller types are assumed to be available at the web-server side: PID controller, state space controller, and fuzzy logic controller.

In 2001, Zhang [5] reported the design and implementation of a series of controllers for helicopter maneuvers through a web-based laboratory. The strategy is similar to the one used in [4]. The client can remotely set the controller type, controller parameters and control objective. The control algorithm is performed at an application/web server.

One can see from the above discussion and other references [6-12] that researchers have focused on the development of remote control laboratories with various approaches. In our studies, however, the emphasis is to teach undergraduate students to develop, rather than use, Internet-based automation systems. This requires that the students master knowledge on sensing, control, and actuation, as well as Internet programming. This range of material traditionally comes from different engineering disciplines.

II. Fitting to the Curriculum

The target of the course is mainly students from the disciplines of electrical and Computer Engineering. At Florida Atlantic University, Electrical Engineering and Computer Engineering are in two different departments. We do not believe that our results are in any way limited by this particular arrangement and apply equally well to the situation in which there is a single Electrical and Computer Engineering Department. Naturally, students from the Department of Computer Engineering take more courses on the software side, in addition to basic electrical engineering courses (such as Electronic Circuits and Digital Circuits). On the other hand, students from the Department of Electrical Engineering have very little training in computer languages (all students must take Introduction to C), although they have much more exposure to electronics, instrumentation and control. There is now a college wide engineering design course sequence (Engineering Design I and II) which students from both the disciplines must take.

The new course, Internet-based Instrumentation and Control, fits very well in the intersection of the two departments' curricula. It provides Computer Engineering students much needed knowledge on sensors, actuators, and data acquisition tools. On the other hand, it greatly improves electrical engineering students' programming skills. The projects students conducted in the class are integrated in nature; therefore, they serve as a rehearsal for more broad engineering design projects at a later time.

When students in our college graduate, they will go mostly to industries, and to a lesser extent, to various government agencies and graduate schools. The understanding of technologies offered in the course will be a valuable asset for these students to solve real-world problems as the Internet has penetrated almost every aspect of our daily life. Students will be better prepared for undertaking design and implementation of projects in the networked world.

The wide range of subjects covered in the course can result in potential problems. For instance, programming exercises assigned at the beginning of the class seem easy for students from Computer Engineering, while they may pose challenges for Electrical Engineering students. On the other hand, simple feedback control concepts can be confusing for students from Computer Engineering. Additional materials that provide

background materials are essential for the smooth offering of the course. Balance between internet programming and instrumentation is a fine act that will provide all students with valuable knowledge and skills.

III. Methods

A. Architecture of Internet-based Control

The Internet can be used as the infrastructure for industrial applications. A Web-based application (an example is illustrated in Figure 2) has the following elements:

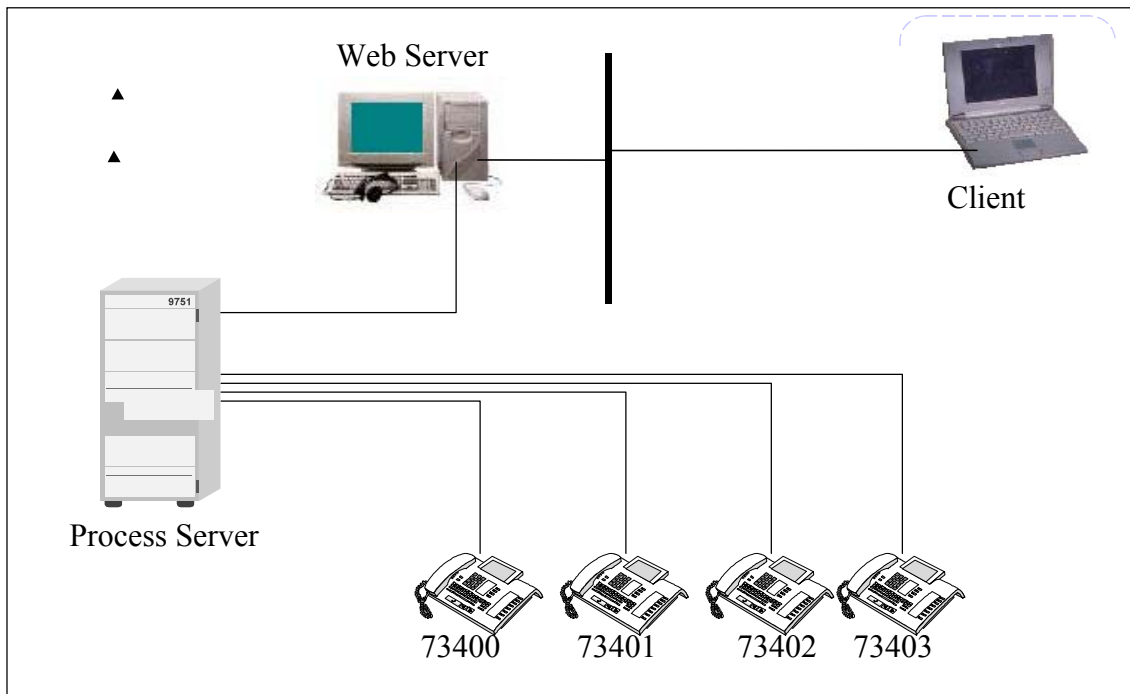


Figure 2 A typical web-based application (note that the numbers are extensions)

- Computers that serve as web servers, where HTML, scripting and other programs reside.
- Computers that serve as application servers, where the programs that compute business logic reside. They connect to web servers on one side and process hardware on the other.
- Process hardware that gets the job done at the remote side.
- Databases that store information critical to the operation of the system.
- Client computers with which users access web sites. They are connected to web servers through either the Internet or corporate intranets.

We will discuss the feasibility of training an engineering student to be prepared for design and implementation of web-based commercial/industrial applications by presenting the curriculum development plan in the next sections.

B. Development Plan

The Internet-based Instrumentation and Control course has a companion laboratory, which hosts 12 workstations that are inter-connected via the campus LAN. Each workstation consists of a PC, a data acquisition board and other equipment. A web server and an application server run on every workstation. A couple of web cameras are installed in the lab. Students are able to conduct relevant experiments and Internet users are able to navigate to the lab site to witness the progress of the laboratory development.

The course has three credits, with two for lecture and one for lab experimentation. The lab portion of the course consists of six experiments and a project. Each experiment requires approximately two to three weeks of lab time. Students need to do some preparation before the lab and write a report upon completion of the lab.

In terms of the lecture material, the course addresses the following topics:

- Web Programming Environment

- Web Programming Tools
- Sensors and Actuators
- Data acquisition
- Monitoring Processes Over the Internet
- Control Processes Over the Internet
- Security and Fault Tolerance
- Case Studies

The following considerations are given in the preparation of the course/lab development plan:

- *The courses/lab will be multidisciplinary in nature.* In order to develop a web-based industrial application, students will need to master relevant knowledge from various engineering disciplines. More specifically, students will need to understand the interactions among client computers, web servers, application servers, and process plants. They will be required to implement software components that perform specific engineering tasks. Further, issues that are unique for web-based applications will be addressed in depth. These include unpredictable time delay, security, and fault tolerance required for a reliable system over the Web.
- *Most of the process-related labs and projects will be open-ended,* encouraging students to find more effective solutions. For instance, there are many important issues involved in applications. These issues cannot possibly be all solved in the course. However, any attempt by students to attack some of the issues will be promoted in the class.
- *The lectures and labs will be highly correlated,* to reinforce concepts students have learned in the classroom. This will be critical to student learning, as the lab is a companion part of the course. Experiments will be arranged in a sequential order. This way, students will apply what they have learned to the later experiments.

- *The lab will promote both individuality and team spirit.* The experiments designed in the courses will enhance the student's ability to solve problems independently, while the term projects will promote a spirit of teamwork. To achieve this, we will require that students perform lab experiments individually and term projects with groups.
- *The lab will provide remote accessing capability.* Students will be able to complete most of the assignments at home with a computer, while achieving the objective of testing their implementation using devices in the lab. This will be feasible because most of the web project development tools now allow developers to work on a project in either the master mode or the local mode. In the master mode, students must work on the web server computer. On the other hand, in the local mode, the students can work on any computer that has a network connection and a simplified development environment. A significant portion of the labs outlined later of this section can be conducted in the local mode. This will stretch the boundary of the lab beyond the university campus.

The experiments and projects focus on essential aspects of web-based applications such as multi-tier architecture, object oriented programming, client side and server side programming, database management, and realization of control logic with proper hardware components.

C. Lab Equipment

There are two basic setups for the lab experiments and projects conducted in the course. The first experimental setup is made up of a simple physical plant and a computer in which a controller resides. The physical plant consists of a Parallax Boe-Bot robot and a Parallax Basic Stamp II Board of Education. The controller is implemented in the Basic Stamp II microcontroller mounted on the Board of Education. The exercises on this and the other setup are developed in the Visual Basic.NET environment, a very powerful and user friendly tool.

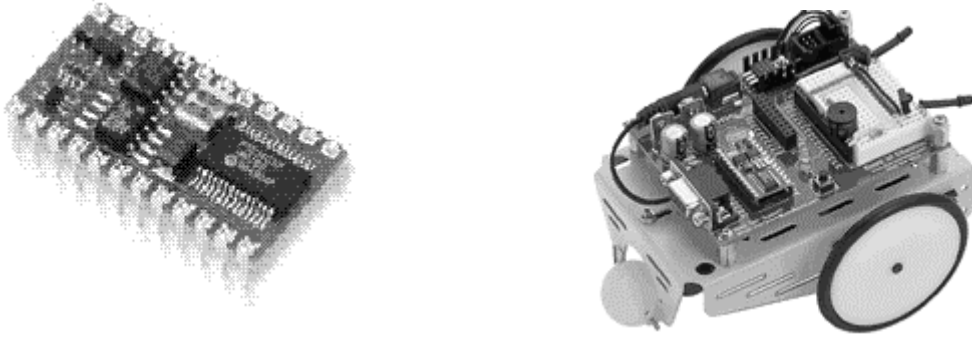


Figure 3 Basic Stamp II and Boe-Bot Robot

The second setup is mainly made up of an Educational Servo ES 151 (including a Servo Box and an Actuator Unit shown in Figure 4) manufactured by Feedback Co. and a data acquisition board from National Instruments (NI).



Figure 4 Educational Servo ES 151

The Actuator Unit is comprised of the following components: A pre-amplifier that accepts two voltage inputs at sockets; a servo amplifier that accepts the pre-amplifier's output and uses this to control the power to the motor; a command input generator that is the large calibrated disc at the left and is attached to an internal potentiometer which

allows a command voltage to be produced; control circuitry; and a meter that indicates the current being supplied to the motor.

The Educational Servo box contains two major components, namely physical plant and sensor as seen in the figure. The plant consists of a 24 V dc electric motor, a gearbox, a worm and wheel used to drive an output shaft, and a tachogenerator, which is attached to the motor and generates a voltage related to speed. The sensor is composed of an output disc and potentiometer. This disc is calibrated to indicate output shaft position (angular) and has stroboscope tracks that can be used to determine certain speeds. Behind the disc is a sensor which will give an voltage output that is related to the shaft position.

The data acquisition board from NI provides a set of functions that control all of the National Instruments plug-in DAQ devices for analog I/O, digital I/O, timing I/O, and others. The NI-DAQ software package has both *high-level* DAQ I/O functions for maximum ease of use, and *low-level* DAQ I/O functions for maximum flexibility and performance. Examples of high-level functions are streaming data to disk or acquiring a certain number of data points. Examples of low-level functions are writing directly to the DAQ device registers or calibrating the analog inputs.

D. Lab Activities

Lab activities are divided into two types: lab exercises and projects. Suggested lab exercises are described below:

1. *Visual Basic – Console Programming.* Visual Basic, a powerful yet easy to learn programming language, is widely used by engineers and others. In this course, Visual Basic is mainly used to write software components for specific tasks. Since it will be used extensively in the entire course, in this and the next couple of experiments, students will study basics of Visual Basic programming.

In this experiment, students will be familiar with the programming environment, which includes Toolbox, Resource, Solution Explorer, etc. They will be able to create a new project in VB.NET and write simple Visual Basic program with correct data types, statements and operations. In the later stage of this experiment, students are required to use all kinds of control statements to form complicated conditions.

2. *Visual Basic – Windows Programming.* In this experiment, the students will learn to program a procedure for a typical computing problem, say, a math tutorial for first graders. Specific tasks requested by the user will be entered and execution results will be presented both through a GUI. An individual subroutine/function is used to handle each task. For instance, routines are written to fetch and save data from/to a file. Later in another experiment, database techniques will be introduced to provide the student with an alternate means for data management.

3. *Visual Basic – Web Programming.* In this experiment, the student will practice the concept of internet programming through writing simple web pages using Visual Basic. The pages will be decorated with graphics/image files such as logos and photos of the laboratory. From the pages, one shall be able to fetch documents, such as lab instructions, and navigate to other locations with ease. In the process, the student will get familiar with the web programming environment.

4. *Basic Stamp II.* Basic Stamp is a single-board microcontroller that runs the Parallax PBASIC language interpreter. The developer stores all the code in an EEPROM, which can also be used for data storage. The PBASIC language has easy-to-use commands for basic I/O, such as turning devices on or off, interfacing with sensors, etc. More advanced commands let the Stamp interface with other integrated circuits, communicate with each other, and operate in networks. In this experiment, students will learn how to program Basic Stamp II, build a simple plant (i.e. a robotic cart and some parallel LEDs) and write a PBASIC program to control the plant.

5. *Control the Robot with Wireless Links.* Once students are familiar with Basic Stamp microcontroller, it is ready to let them implement a simple control system. First, they will design a GUI as a Windows application in Visual Basic similar to the one shown in Figure 5. The buttons in the GUI mean the connection or disconnection of the communication link and the actions to be taken by the plant (such as move the robot left or right). The telephone symbol represents a communication component in Visual Basic. They then write code to communicate the control commands and feedback signals via two Basic Stamp microcontrollers, both of which are interfaced with a pair of transceivers, as shown in Figure 6.

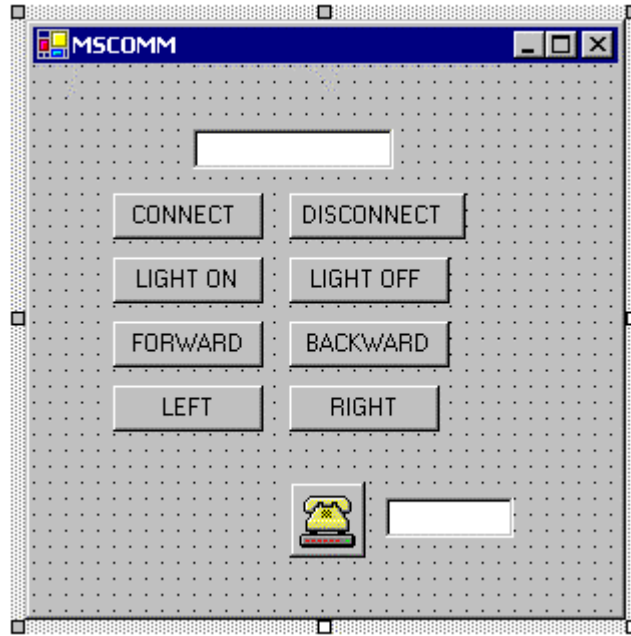


Figure 5 GUI for Local Controlling the Robot

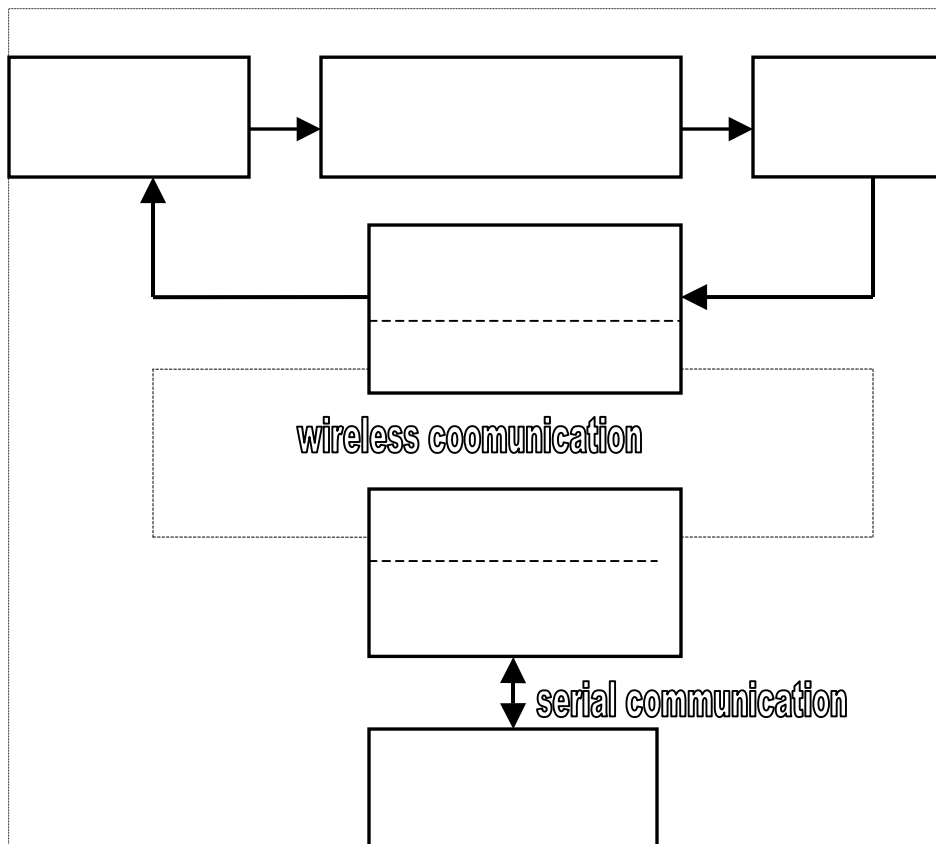


Figure 6 Remote Control of Robot

6. *Robot Control System via the Internet.* Once the robot is properly controlled locally, the entire routine developed for the system will be ready to be moved to the Web. In this experiment, students will control the robot remotely using web applications with transceivers and Basic Stamps. They are required to interface the robot with the application server through the transceivers and perform communications between the application server and the web server. They will also program the web camera to send image sequences of its environment to the remote user, providing visual feedback to the user.

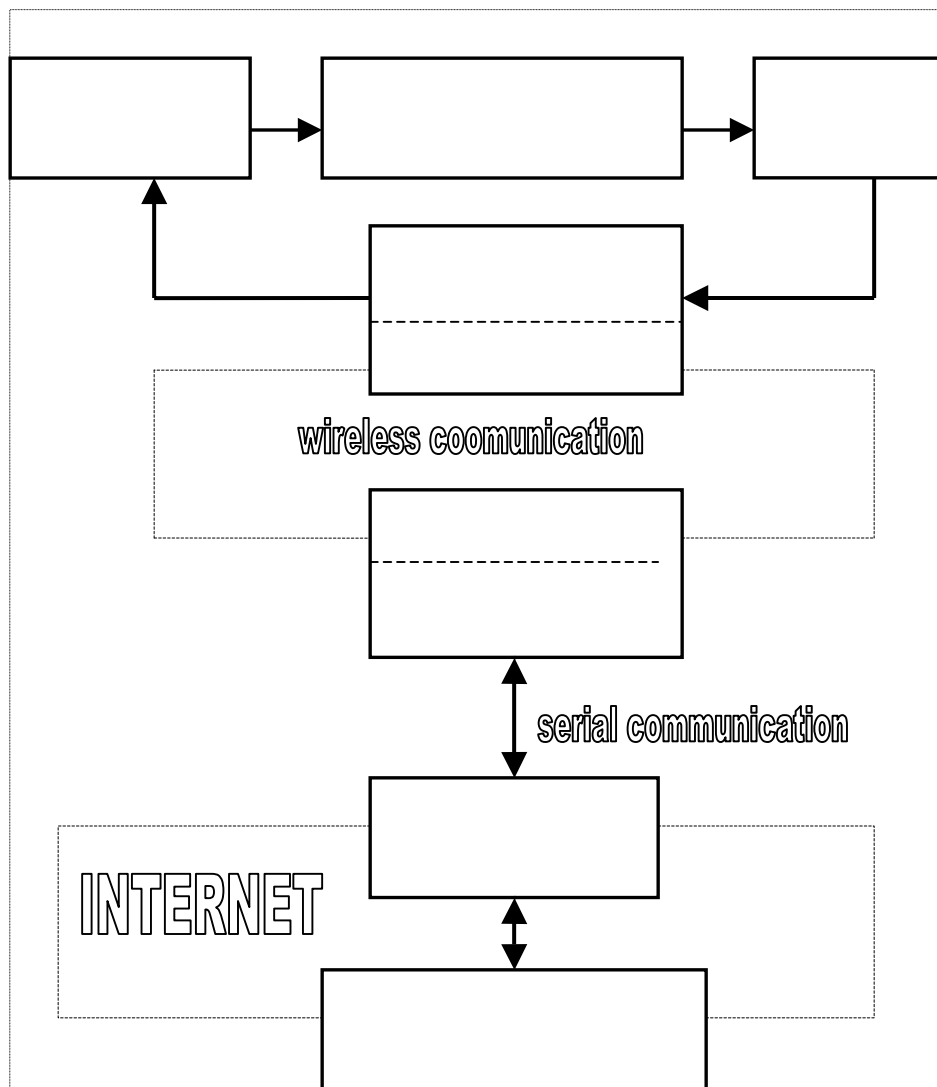


Figure 7 A Typical Control Diagram

A block diagram of the control strategy is given in Figure 7. In the control block diagram, ASP stands for Active Server Page, which is a Microsoft tool for creating web pages. The block diagram is self-explanatory.

After the completion of the lab exercises, students have the option of taking either final examinations or completing a project. Projects are conducted with either the robotic system (Figure 3) or the servo system (Figure 4). A typical GUI is given in Figure 8. It includes PD parameter settings, Graphing and other functionalities students want to add on. Moreover, the control plant is monitored by a web camera that is installed in the laboratory.

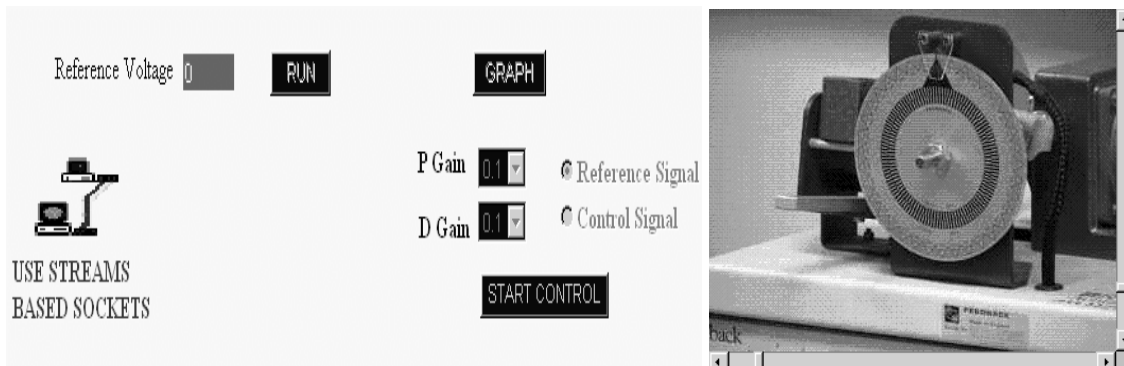


Figure 8 A Typical Graphic User Interface

IV. Evaluation and Discussion

Last summer we offered this course for the first time to our junior/senior engineering students after about a year of preparation. The course was conducted in a six-week period, including classroom instruction and lab exercises. At the end of the class, we distributed a questionnaire to the students. The answers to sample questions are compiled and given below.

Question: What was your original intention of taking the class?⁴

- To control electrical devices via the Internet (5)
- To learn user-friendly computer languages such as Visual Basic (5)
- Need an elective (4)
- To learn how to program microcontrollers such as Basic Stamp (3)
- It sounds very interesting to topic (2)
- To learn computer interface (2)
- To have a class with practical application and hands-on experience (2)

Most students expressed a desire to explore and learn new things. A student stated that she would like to find out more about web-based control to see if she would be more interested in it for the field (work). There were a few students that just wanted to have an elective to fulfill graduation requirements.

Question: Was the original objective achieved after taking the class?

All the students except one stated that their original objectives were met. Many voiced that this was an interesting class that opened their minds up. They also stated that the knowledge learnt could be applied to other classes like Engineering Design I and II. However, a majority of students pointed out that six weeks were too short to cover the materials in depth and more time was needed. The student who answered no to the question also explained that he needed more time to digest the material.

Question: What is your opinion on the method of alternating between lecturing and lab exercises?

A vast majority of students favor the integration of lecturing with the lab exercises. They stated that the lab exercises provide much needed hands-on experience which reinforces the learning. Some students even suggested that the lectures should move to the laboratory. One student suggested that the material provided in the lecture should match more closely what was exercised in the laboratory. The only student who gave a negative reply to the question proposed to have the first half semester on the theory and the second half semester on the lab exercises.

⁴ The number in the brackets are the number of responses

Question: What is your opinion on lab equipment?

Most of students thought the lab setup is good. Basic Stamp is a very user-friendly microcontroller, and Microsoft Visual Basic .Net is a very powerful, yet easy to learn tool to create web applications. Some students complained that Basic Stamp educational boards and the robots we used in the laboratory were not sturdy enough. Some stated that we need more computer stations to let everyone exercise independently.

Question: What is your opinion on the lecturing?

Most of students gave positive responses to this question, though they have in general more favorable opinions on the lab exercises than the lectures. They like practical examples more than pure theoretical discussions. They prefer more simple demonstrations to show them step by step how things work. They want to see also some more discussion on the equipment used in the laboratory. Some complained that letters on the slides are too small to view.

Question: What is your opinion on the lab exercises?

Students have in general very favorable opinions on these lab exercises. They stated that the way to arrange the lab exercises from simple to more complex ones was thoughtful. The fact that the last lab was an integration of the previous labs was especially well received. Some students were very excited about the success of controlling a robot through a wireless link over the Internet. One student said that creating a website to control something was very educational as he never made any website before.

Question: Any other comments?

- Sample answers to this question are given below:
- This should be one of the first courses students are given.
- Overall good educational class.
- Great tool for my senior design project.
- Very good class. One of the few classes I have taken with a practical application.
- Time went by too fast.
- Good class. Nice to see some more current technologies in (other) classes.
- Best wishes next year.

We are currently offering this course for the second time to our undergraduate students. About 30 students registered in the class, half from Electrical Engineering and another half from Computer Engineering. Based on the comments from the students of the previous offering, we are further improving the class in the following aspects: a) The course is taught now in a regular semester. This time it will last about 16 weeks. b) More demonstrations and examples are given in the lectures to motivate students. c) More lab exercises with smaller steps are given in order to allow students to digest the materials. d) Students are given a choice between taking a final examination and completion of a term project. In the first offering, we did not have enough time to let students do a term project. This time, students can design and implement a website that controls a remote device of their choice.

The primary consideration of this paper is to develop a course for undergraduate engineering students, who are interested in applying internet programming technology to tasks in instrumentation and control. Based on the overwhelming positive response of the students who took the course, it is our belief that the course will be a viable elective engineering course that fits Electrical and Computer Engineering curriculum very well. Future work includes writing a textbook for this unique course, disseminating the results to other engineering colleges, and offering a similar course to high school students who are interested in pursuing engineering degrees.

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