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## NETLAB—An Internet based laboratory for electrical engineering education\*

ZHANG Shu (张 姝)<sup>†</sup>, ZHU Shan-an (朱善安), LIN Qun (林 群),  
 XU Zhi-wei (徐志伟), YING Shao-dong (应绍栋)

(Department of Systems Science and Engineering, College of Electrical Engineering, Zhejiang University, Hangzhou 310027, China)

<sup>†</sup>E-mail: zhangshuzju@sohu.com

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**Abstract:** This article describes an Internet based laboratory (NETLAB) developed at Zhejiang University for electrical engineering education. A key feature of the project is the use of real experimental systems rather than simulation or virtual reality. NETLAB provides remote access to a wide variety of experiments, including not only basic electrical and electronic experiments but also many innovative control experiments. Students can effectively use the laboratory at any time and from anywhere. NETLAB has been in operation since July 2003.

**Key words:** NETLAB, Internet based laboratory, Electrical engineering education, Inverted pendulum

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### INTRODUCTION

In electrical engineering, laboratory experience is an integral part of the educational process. In fact, the amount of resources required to design and construct innovative experiments for electrical engineering education is relevant, and the number of installations is often limited due to economic factors (Corradini *et al.*, 2001). As a result, the possibility of experimental training for all the students is extremely reduced.

With the rapid progress of Internet technology and its increasing popularity, there exists now an international effort concerning the use of Internet for performing real-time experimentation. This new paradigm can provide remote laboratory users the opportunity to conduct live experiments off-site, reducing the experiment cost per student and making experiments available to more users (Bohus *et al.*,

1996).

NETLAB, developed at Zhejiang University, is an Internet based laboratory for electrical engineering education. It allows users to perform a variety of experiments covering most important subjects and researches in electrical engineering. In order to project the in-laboratory experience, all the experiments are based on real systems rather than computer simulations or virtual reality.

### COMPARISON WITH RELATED RESEARCH WORK

During the last decade there has been a trend towards increased use of simulation in engineering education such as the Universal Virtual Laboratory (UVL) at Temple University (Duarte and Butz, 2002), which was aimed at creating an environment similar to a real electrical engineering laboratory, but totally based on simulation and limited in circuit experimentation. Our NETLAB, in contrast, allows the

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students to work on real equipments (no virtual reality and no ideal simulation!).

The laboratory set up by the Department of Telecommunications and Signal Processing at BTH (Blekinge Institute of Technology) enabled the students to perform real experiments remotely (Gustavsson, 2002). However, it only focused on basic electrical experiments for undergraduate education, with no moving control systems. Our NETLAB provides remote users the opportunity to conduct a variety of experiments including not only electrical and electronic experiments but also many innovative control experiments such as the rotary inverted pendulum experiment, the fan and plate process, the elevator control, etc.

Control system design is typically part of electrical engineering. Presently, there is a lot of activity in trying to develop Internet based labs for performing control experimentation (Corradini *et al.*, 2001; Hahn and Spong, 2000; Irawan *et al.*, 2001; Martinez-Garcia and Garrido, 2001; Miele *et al.*, 2001). However, most of the recently developed remote labs only allow users to send set point commands to the physical plant and perhaps alter the control gain (i.e., the controller structure remains fixed) (Dixon *et al.*, 2002). The remote laboratory at the Universities of Ancona and Lecce allowed the student to design his/her own controller using a Matlab-like language (Corradini *et al.*, 2001). Considering that C is a more efficient language compared with Matlab, NETLAB provides a second-development interface based on C language for user-designed custom control algorithms. The second-development interface is very easy to master since it only includes 3 functions which require the student to implement in C language and then compile into DLL. The DLL file can be uploaded to the server computer and then be tested on the actual plant. Particularly, the control site program has the ability to check the DLL file before being executed (e.g., check whether any unknown function exists in the DLL).

Because of Internet traffic and bandwidth, telepresence features have become an argument in Internet laboratory experience. Australia's Telerobot on the Web, developed by University of Western Australia, allows a remote user to control a robot arm by supplying the desired  $x$ ,  $y$ ,  $z$  positions to the server in a HTML form (Taylor and Trevelyan, 1995). The

server will capture and transmit monochrome images of the robot to the user, only at the end of each move, which means that users cannot view the movements of the robot in real time, but only the images of its final position. In contrast, NETLAB allows users to view the full motion of moving control systems in real-time and in color. Moreover, NETLAB provides users the opportunity to record video sequence remotely for later observation, which is independent of Internet traffic and bandwidth.

Another unique feature of NETLAB is that it permits two experiment modes: synchronous mode and asynchronous mode. In synchronous mode, users interact actively with the real experimental device in real time. In view of the limited bandwidth and characteristics of Internet, we also offer an asynchronous experiment mode, in which user only needs to send his/her request. The server will send the request to the control site immediately once the control site is not occupied. Then the control site sends the results back to the server after completion of the experiment. The server will send the result to the user as soon as it finds the user is online. The user can also query and download the historical result of the asynchronous experiments. This asynchronous mode is oriented towards the user in areas with low network transmission speed.

## REMOTE EXPERIMENTS

NETLAB offers more than 30 experiments, which can be put into four categories generally: electrical and electronic group, power electronic group, automatic control group and electromotor group, covering the four important areas in electrical engineering education at Zhejiang University. The list of the experiments is presented in Table 1.

The former three groups aim at basic training in electrical and electronic fundamentals, as well as the classical control elemental experiments and the frequency response experiment in the control group. When students select a certain experiment, they are required to configure the circuit by choosing different kinds of symbolized graphical components from the experimental toolbar such as resistors, capacitors, amplifiers, etc. The specific components are fully adjustable to a range of values found in an ordinary

electrical engineering laboratory. The selection of components and values corresponds to controlling the analog switches on the physical experimental equipments.

In electrical engineering domain, besides learning different aspects of electrical and electronic circuits, the ability to design and implement effective controllers for real physical plants is also very important. NETLAB provides remote users the opportunity to conduct many innovative control experiments such as the rotary inverted pendulum experime-

nt, fan and plate process experiment, the elevator control experiment, etc.

ARCHITECTURE OF NETLAB

The system architecture of NETLAB is shown in Fig.1. Generally speaking, NETLAB is comprised of three important parts which are client site, server and control site. The control site and server are in the Intranet, communicating with each other in SOCKET. Students have two ways to access the server; either by application or web browser.

Table 1 List of the experiments in the laboratory

Experiment group	Experiment list
Electrical and electronic group	Analogue circuit experiments
	Digital circuit experiments
Power electronic group	Rectification and inverse converter experiments
	Zero voltage transfer experiments
Electromotor group	Experiments of electromotor operation
Automatic control group	Classical control element experiments
	Frequency response experiment
	Servo system experiment
	Inverted pendulum experiment
	Fan and plate experiment
	Step motor control experiment
	Coupled-tank control experiment
Elevator control experiment	

Client site

There are two ways to support the user interface on the client side, the application and standard web browser. The latter has not finished yet, so we only introduce the user interface of application, which is shown in Fig.2.

To operate remotely, the user needs to install the application on the client computer. The user can select an experiment he/she is interested in by single-clicking the corresponding experiment item in the experiment list tree. Then the corresponding experiment window will be shown for user to design. The wave of the returned data from the control site can be observed in the experiment window and the video feedback can be shown in the video window. The user's operation during the experiment is recorded in the experiment log window for future diagnosis in case the system breaks down.

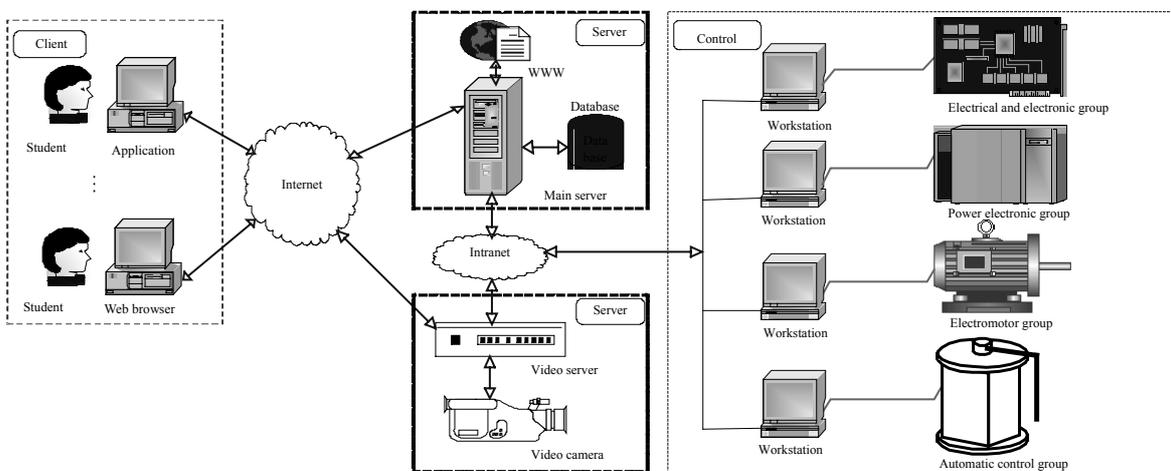


Fig.1 System architecture of Netlab

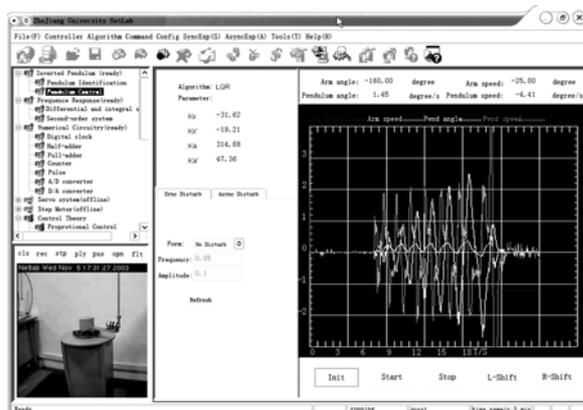


Fig.2 User interface of client application

The client application is designed to be modular. All the experiments are embedded in the client framework as independent modules, which can be downloaded, installed and deleted. So newly developed experiment module can be integrated into the system without affecting the already existed experiments.

### Server

The server is composed of three parts: the main server, the database server and the video server. The main server handles user requests, communicates with the database server and the control computer on the control site. The main server can also be accessed via WWW. The database server handles user information, keeps track of every user and stores experimental data. These two servers run on an XEON 2 G\*2 computer with 2 G RAM. The last server is the AXIS 2400 video server. Four color CCD video cameras are connected to the video server for video feedback.

### Control site

The control computer and the physical plants compose the control site. The software package installed on the control computer includes a control program and a supervision program. The control program handles actuator/sensor signals to/from the plant and all communication with the remote user. The supervision program checks the control program and the server status periodically for system safety. For example, if the server reboots, the supervision program will command the control program to connect the server automatically. If the control pro-

gram terminates exceptionally or falls into any infinite loop, the supervision program will reboot the control program. In this way all Internet experiments are self-resetting, so that the system has the ability to reboot itself and resume operation without local human intervention.

### INVERTED PENDULUM EXPERIMENT

In this paper, we will present the inverted pendulum experiment. The inverted pendulum is a state-of-the-art plant in control education, which is useful for illustrating how to design effective algorithms for swing-up and balance. The pilot plant used in this laboratory is a rotary inverted pendulum, which consists of: 1) an arm which rotates in a horizontal plane; and 2) a pendulum bob rod at one end of the arm which can rotate in a vertical plane orthogonal to that of the arm. The apparatus is presented in Fig.3. Two experiments are designed based on the inverted pendulum: parameter identification experiment, swing up and balancing experiment.

### Parameter identification

A built-in swing-up phase starts at the beginning of the identification experiment. Once the pendulum is balanced by the default controller, the student can select the input signal to be applied to the inverted pendulum apparatus. Available inputs are: Gaussian white noise, random binary signal, pseudo-random binary signal (PRBS), multi-sine, swept sinusoid (chirp signal), which are typical choices of waveforms in identification. The properties of the input signals



Fig.3 Rotary inverted pendulum apparatus

such as amplitude, frequency, etc. can be set by the user. The user can observe the behavior of the pendulum apparatus via real-time video over the Internet, and subsequently download the time-series of the input and output data onto the local hard disk for off-line processing. As these data are collected in a text format file, with raw values recorded, the student can learn and appreciate the need for scaling and unit conversion, filtering out the noise in the data in order to achieve a successful result for parameter estimation.

### Swing up and balancing

Using the model identified, the user can proceed to perform the swing up and balancing experiment. The algorithm can be applied to the pendulum in the following modalities: 1) using the built-in swing-up algorithm and the default controller; 2) using the built-in swing-up algorithm and set the controller parameters which the user has calculated based on the model obtained from the parameter identification experiment; 3) using self-designed swing-up algorithm and default controller; 4) using both self-designed swing-up algorithm and control algorithm. In NETLAB, the user can implement self-designed algorithms with the second-development interface based on C language. After being implemented in C language and compiled into DLL, the user-designed algorithm can be uploaded to the server computer and controls the inverted pendulum. Again the student

could see, via real-time video window on the user interface, the behavior of the inverted pendulum throughout the experiment and at the same time watch the wave of the experimental result via the experiment window. Fig.4 shows the response of the inverted pendulum from swing-up to balance.

### Experiment system safety and robustness

Since the experiment is based on actual inverted pendulum, safety concerns should be addressed. First, the control computer has the ability to detect and avoid problems such as mistakes when a user uploads an “unsafe” controller that results in an unstable system or mistakes when any unknown function exists in the user-designed DLL. In this scenario, we adopt a “simulate first” criterion, where the student’s algorithm must pass the simulation test before being implemented on the pendulum. If the algorithm cannot pass the simulation, the user will be notified that his/her self-designed algorithm has failed. In this way faulty algorithms will not occupy the pendulum, allowing more access for users who have designed successful algorithms. Second, the software package installed on the control computer includes a control program and a supervision program. The control program handles actuator/sensor signals to/from the plant and all communication with the remote user. The supervision program checks the control program and the server status periodically for system safety. For example, if the server reboots, the supervision

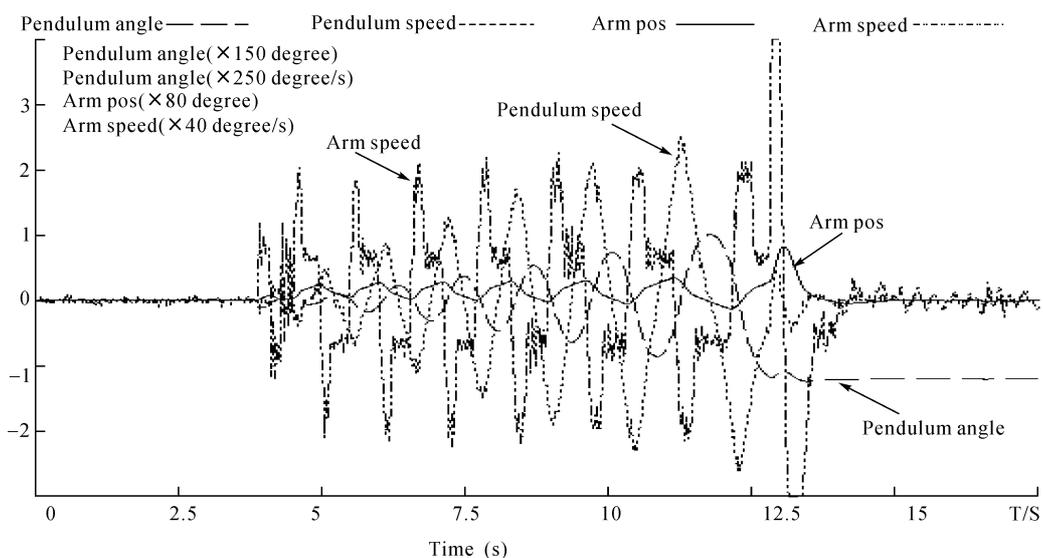


Fig.4 Response of the inverted pendulum from swing-up to balance

program will command the control program to connect the server automatically. If the control program terminates exceptionally or falls into any infinite loop, the supervision program will reboot the control program. In this way all the Internet experiments are self-resetting, so that the system has the ability to reboot itself and resume operation without local human intervention. Third, there is a monitor thread in the control program, checking the status of the pendulum to insure safety. If the pendulum is detected to over-speed, the monitor thread will stop the servo and terminate this experiment automatically. Hence, system safety and robustness is assured while allowing maximum flexibility for the user in designing swing-up and control algorithms. Another feature is that the inverted pendulum experiment is allowed to run only for a preset duration. This requirement is necessary for system security and accessibility, because some students may run the inverted pendulum experiment for excessive periods of continuous time, blocking other remote students from accessing the plant. Concerning the possibility that the inverted pendulum experiment may become popular among remote institutions, we also incorporated a booking procedure into our NETLAB.

## CONCLUSION

The Internet based laboratory is an effective alternative to setting up a traditional laboratory to support class courses in electrical engineering education. It has the advantage of: 1) reducing costs by sharing laboratory equipment; 2) allowing users to have greater oversight in electrical engineering by performing a variety of experiments based on physical plants; 3) allowing users to access at anytime and from anywhere. This paper presents the Internet based laboratory called NETLAB, developed at Zhejiang University. The aim is to make the laboratory available to as many students as possible for experimental train-

ing, supporting electrical engineering education. Today, NETLAB is being practiced and evaluated by different educational institutions in China. The results have been encouraging and have helped confirm the viability of the Internet based laboratory for distance learning.

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