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On-line Engineering Laboratories: Real-Time Control Over the Internet

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Abstract

The advent of the Internet as a major communication channel has triggered a great deal of interest in real-time communication over packet-switched networks. While store and forward networks such as the Internet were not originally designed to handle real-time traffic, now that this global communication infrastructure exists and is becoming ubiquitous. Computer-based hardware and software subsystems are being designed to transport such real-time services as broadcast audio and video (live or via various streaming media technologies) and even interactive audio and video services. In this paper we propose another step ahead into the realm of remote real-time control over the Internet. We demonstrate the feasibility of using a distributed on-line laboratory to complement and enhance traditional and on-line courses in Control Engineering. It is shown that the distributed laboratory readily enables students to conduct real-time experimental studies and that it is also suitable for live in-class demonstrations. The proposed design is presented as a paradigm for analogous developments in other courses requiring a laboratory component.

I. Introduction and Motivation

The world-wide spread of the Internet and its general acceptance have brought new opportunities in distance learning as well as in traditional education. A large set of instructional documents and video-taped lectures are nowadays available on-line. Tutors can provide support to remote students using electronic mail and video-conference tools. Classical universities as well as emerging virtual universities cope with this evolution by assessing and proposing synchronous or asynchronous distance curricula[1]. This provides students with more flexibility in both place and time and reduces the campus infrastructure needs.

In many disciplines, however, the expositive material typically provided on line is not sufficient to support the complete learning experience. In disciplines such as engineering there is often a need to develop practical experience as a key to becoming an effective professional[2]. In order to address this need we have developed a distributed laboratory to complement and enhance the delivery of on-line courses on the topic of control engineering[3]. This laboratory is expected to serve as a paradigm for the development of analogous on-line services for other disciplines where experimentation with physical systems is an important ingredient in the learning process.

The distributed laboratory enables remote students to perform practical experimentation on real equipment at various geographical locations. The remote users are provided with real-time video views of the equipment combined with virtual reality representations to reinforce the pedagogical efficiency of the experience, and to facilitate the interactivity of the students with the system. Students may carry out a number of pedagogically valuable non-destructive experiments using the on-line laboratory, and individually or collectively observe in real-time the results of their actions.

The same infrastructure used to permit student access to experimental work over the Internet can also be used by the instructor to perform live demonstrations in front of a class during a lecture period. This permits the execution and observation of experiments without incurring delays associated with the relocation of students from the lecture room to the laboratory facilities. Furthermore, a small laboratory space that could not accommodate the simultaneous presence of many students can be effectively made accessible to the entire class, saving on undesirable overhead costs associated with logistics planning and instructor time. We have made use of such live demonstrations during lectures by interspersing them between theoretical presentations, and by limiting each demonstration to a duration of no more than five minutes.

The proposed on-line laboratory paradigm is based on a multiplatform client-server design where personal computers cooperate by sharing information over the Internet and accessing a physical facility that houses the experimental equipment. Much effort has been invested in imbuing the design with high levels of interactivity and interoperability as required for educational purposes[4].

II. The Didactic Environment

The didactic environment is based on a distributed architecture featuring two distinctive parts: a local server and one or more remote clients (Figure 1).

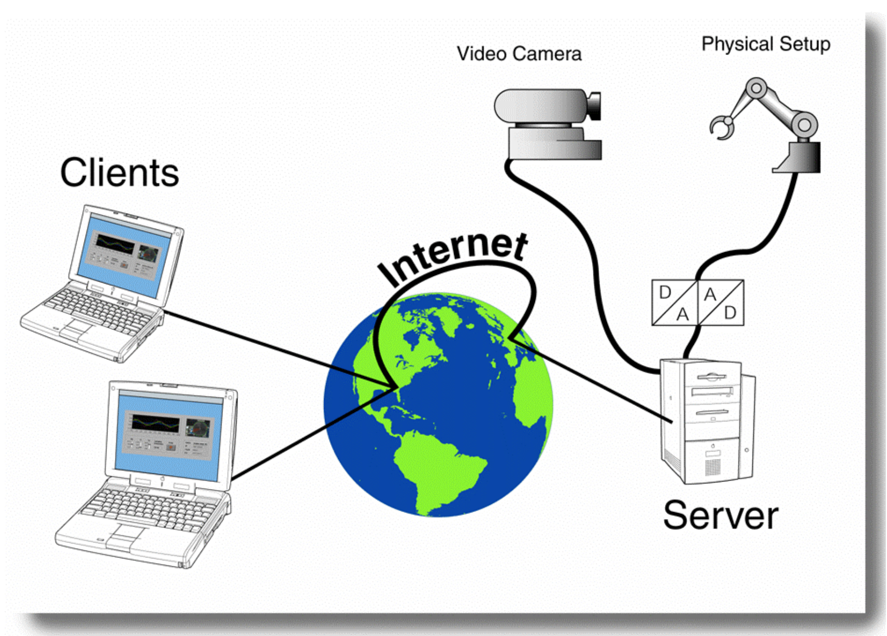

Figure 1. Client–server architecture. The local server is directly connected to the physical process. Remote clients are able to interact with the process by communicating with the server over the network.

The local server is a computer located near the physical process. It is equipped with the hardware interface required to communicate with the sensors that capture measurements from the process and the actuators that implement actions on the process. A video camera and microphone are available as additional sensors to provide visual and audio sensorial experience. The server software receives commands issued by the client over the Internet, and transmits them to the real process. The server is also responsible for returning to the client the value of several variables that define the state of the physical process, including a video image.

The remote client is a computer equipped with the functionality to observe and to act on the physical process. The control software is a Virtual Instrument (VI) built using LabVIEW [5] and compiled for the target platforms. This VI provides a complete interface between the user's computer and the real process. It is utilized to generate commands in the form of excitation signals and to receive the corresponding responses. The client interface is designed with the objectives of providing the remote users with a general view of the state of the physical process, permitting the observation of the evolution of the system state as a response to user-issued commands, and allowing full access to the operation of the physical process.

III. The Learner Interface

On the client and server platforms the user is presented with a visual interface designed to permit easy access to the physical process and to display the state of the process. Figure 2 shows the interface designed for carrying out experiments on a servomechanism. The interface is organized into four different areas responsible for managing and displaying distinct streams of information.

The *scope area* (denoted by the number 1 in Figure 2) enables the user to follow the time evolution of all signals relevant to the experiment (for example, the rotational speed of the servomechanism, or the internal states of the controller).

The *visual area* (number 2) provides a video feedback of the real process enhanced with a virtual representation of the process. The virtual image is created by the client, and consists of a series of markers (triangles, angles, and a rim) that are positioned using the measurements received from the server. The intention is to provide the user with supplementary information that assist in the easy identification of target values, desirable operating zones, etc. The virtual image must be mixed with the video image provided by the video camera.

The *parameters area* (number 3) allows the user to make adjustments to the physical process through the specification of appropriate values of adjustable parameters. Inputs given in this area are issued as commands that are in turn transmitted to the local server. The button bearing the label "push" is designed for issuing a command that introduces a perturbation on the physical system. Some representative adjustable parameters in a control engineering experiment include, for example, the controller gain, the integral constant, and the derivative constant.

The *administrative area* (number 4) allows the management of the different connection stages such as user login and logout from the session, for example.

High-level security precautions are handled by the client software. For example it prevents the user from selecting physically unrealizable parameters.

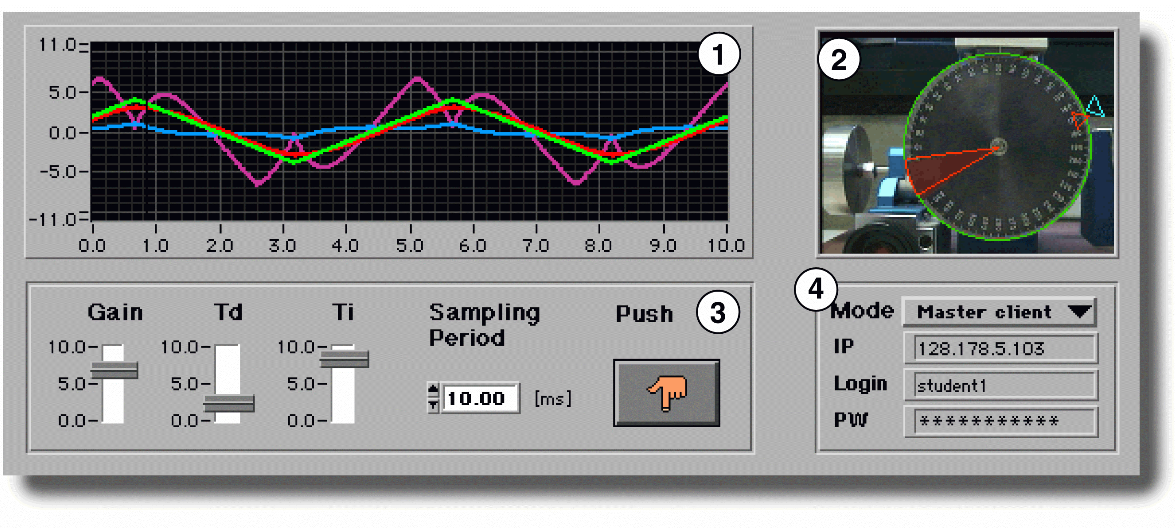

Figure 2. The learner interface as seen by a client for an experiment involving the control of a servomechanism. The interface features four distinct areas: (1) the scope area, (2) the image area, (3) the parameters area, and (4) the administration area.

IV. Implementation

The communication between the client and the server is effected via a local area network and/or over the Internet. Since most of the current communication channels are shared by several users, the channels do not have easily predictable responses due to the variability of the traffic load. To overcome this lack of determinism, the real-time control applications need to constantly adapt to the available channel.

A measurement of the network load can be obtained by quantifying the percentage of packet loss. This information is fed back by the client to the server which in turn adapts the transmission of its various streams of information based on specific requirements, priorities, and specifications [4]. The streams involved in the process are classified into four groups, namely, a parameter stream, a data stream, an administrative stream, and an audio/video (A/V) stream. The A/V stream takes most of the bandwidth (up to 90 %) and therefore is the one to be adapted downward at first. To lower the bandwidth needs, the video images can be compressed at higher compression factors and the transmission rate of the images can be reduced. If these measures prove to be inadequate, then the other streams will also need be compressed, or other more aggressive measures adopted.

If the communication channel is so congested that most of the packets of information are lost, the client application can make use of a model of the physical process and execute a real-time simulation experiment to reconstruct the missing packets. This allows the user to continue with uninterrupted experimentation even if the client falls temporally off-line.

V. Pedagogical Approach

Remote experimentation is used regularly to complement the teaching of the introductory automatic control courses taught at the Swiss Federal Institute of Technology in Lausanne, and more recently also at the University of Florida. The intention is to motivate, illustrate, and enlighten the presentation of the subject matter addressed in the lecture. Students from electrical engineering, mechatronics, mechanical engineering, and computer science attend this course simultaneously. Swiss Federal Institute of Technology the lecture is delivered to approximately 160 students in a large auditorium. At the University of Florida the remote experimentation facility is used in student projects and for in-class demonstrations. The client software is installed on a portable computer manipulated by the teacher. The students can watch a copy of the computer screen projected onto the wall (Figure 3).

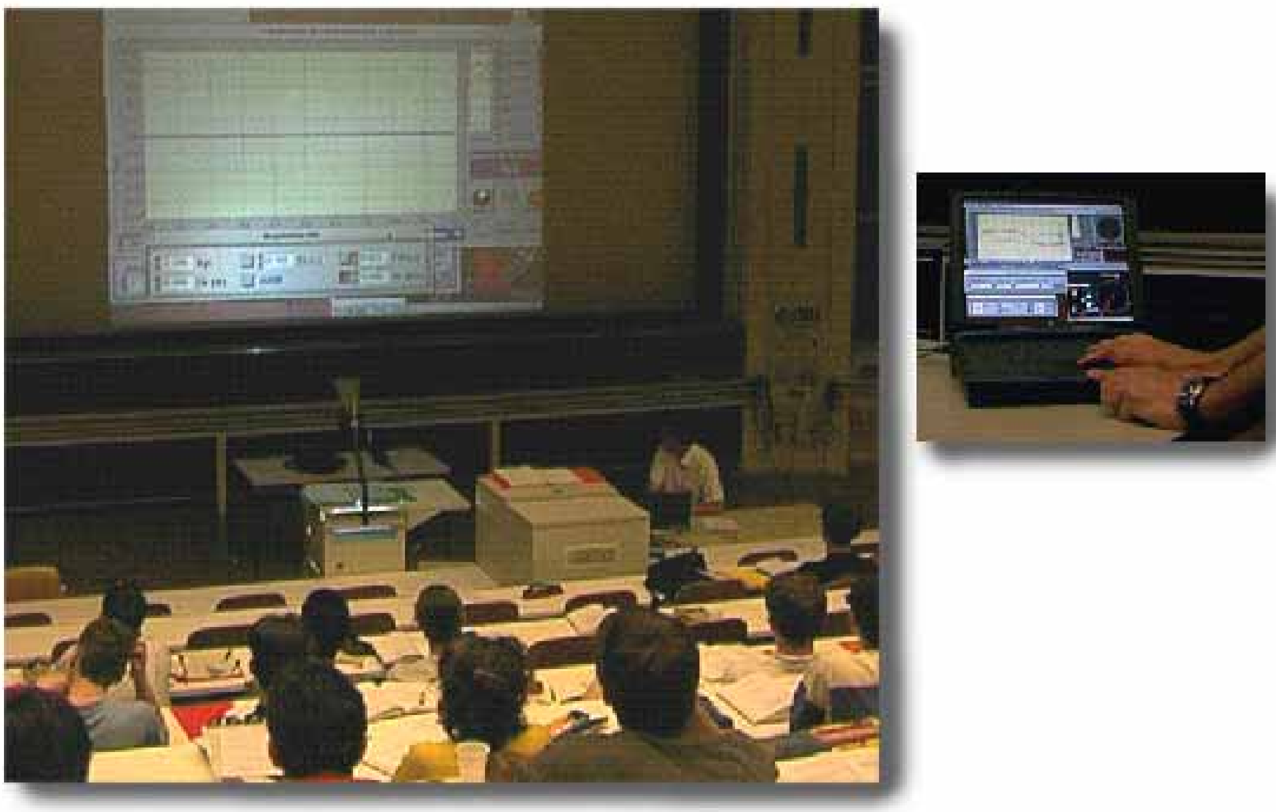

Figure 3. The instructor uses the prototype distributed laboratory set up proposed to carry out an experimental demonstration during a lecture session. The photograph on the right shows a detail of the portable computer used by the instructor to execute the client software.

The proposed set up has also been used for overseas connections between Switzerland and the United States. Instructors at the University of Florida and at Rice University in Texas have successfully accessed experimental facilities located at the Swiss Federal Institute of Technology to carry out real-time demonstrations during lectures. It is anticipated that in the future the use of remotely located facilities for real-time instructional purposes across national boundaries is likely to grow.

VI. Conclusions

The proposed prototype for on-line laboratories demonstrates the feasibility of using real-time control over the Internet to allow remote students to carry out real-time experimental studies as well as live in-class demonstrations. The system can also be used locally by placing the client platforms in a computer room located away from the laboratory facilities, leading to an economy of space and maximizing the accessibility to the experiment over large periods of time. Compared with experimentation in virtual reality, remote manipulation on real processes is easier to implement and more versatile. In fact, adding or selecting another physical setup does not involve the elaborate development of complex mathematical models and graphical representations. Finally, remote experimentation is not limited only to education. In research and industry, remote accesses also represents an interesting opportunity to meet the growing need of scientists who wish to share unique or expensive equipment, and to enable support engineers to operate equipment located in remote customer facilities. The client/server paradigm solution enables teachers to implement remote manipulation in a really efficient manner, both from a time and resource point of view.

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