

TELEPRESENCE: AN OPPORTUNITY TO DEVELOP REAL-WORLD EXPERIMENTATION IN EDUCATION

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Abstract

A would-be autodidact can nowadays find educational material in the form of printed documents or digital supports, or it can access it via the Internet. In the field of automatic control, these media only carry virtual information, i.e., they do not provide real-world equipment. This drawback is the last obstacle to a possible “virtual campus”. The aim of this paper is to present an approach for remote experimentation and to stress its educational and economic benefits. Remote PID control of an electrical drive illustrates the applicability of the approach.

1 Introduction

Traditional classroom teaching gives the students only few opportunities to experiment the subject matter by themselves, which is in fact the best approach to learning. As a consequence, teachers have increasingly integrated into their courses real-world and virtual experimentations, that are based on laboratory-scale processes and Computer-Aided Instruction (CAI) tools, respectively [1]. This experimentation material helps students observe dynamic phenomena and develop an engineering approach to solving realistic control projects [2]. It also allows teachers to organize interactive demonstrations that can improve the motivation for learning [3].

Recently, the growing availability of personal computers at home and on campus has allowed students to exploit CAI tools to learn their own way and at their own pace. Unfortunately, such an independent work is not possible on laboratory-scale processes since these cannot be moved easily or duplicated in sufficient numbers. Hence, experimental work is done in the laboratory according to a predefined schedule, two conditions which educationally speaking are not satisfactory [4].

Both, the recent development of the Internet and the introduction of the World Wide Web (WWW) are opening the way to interactive presentations [5], or even to remote access to real-world equipment ([6], [7]).

The availability and the capabilities of these new communication facilities, combined with the generalization of computer use for data acquisition and control of real processes ([8], [9]), enable the students to change from the presence at equipment location to a more versatile *telepresence*, thereby allowing *remote experimentation*.

This paper discusses components and approaches supporting the introduction of real-world experimentation in distance learning.

The paper is organized as follow: Section 2 gives an overview of an integrated workbench used by students in the laboratory. Section 3 introduces an alternative for remote experimentation, while Section 4 describes improvements to the basic telepresence solutions. Section 5 presents different application scenarios in both local and wide area networks. Finally, an application example is given in Section 6.

2 Integrated Workbench

Plants dedicated to remote experimentation have to be *fully monitored and controlled locally* by computer. It will then be possible to implement a remote access, as it will be shown in Section 3.

The integrated workbench available for automatic control experimentation at the École Polytechnique Fédérale de Lausanne fulfills the above condition [10]. A Power Macintosh, equipped with an universal AD & DA board, provides a complete interface between the user and the real process (Figure 1).

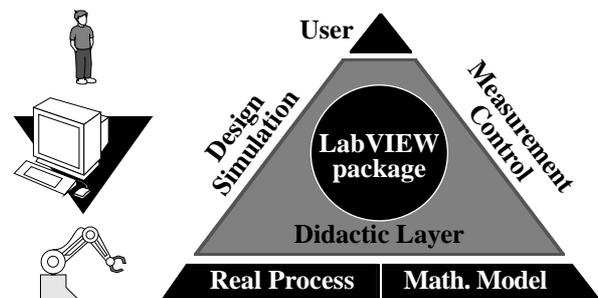


Fig. 1. Architecture of the integrated workbench.

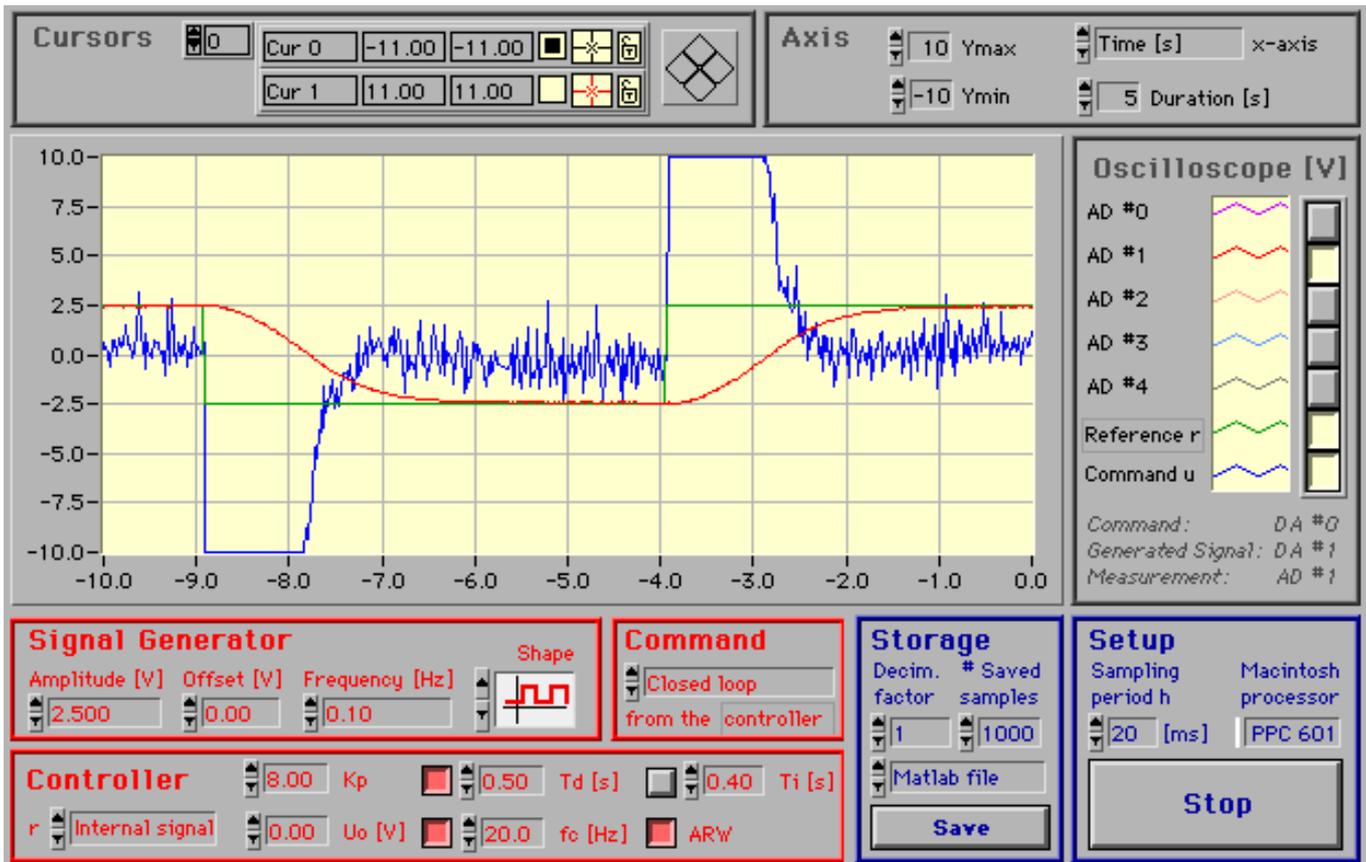


Fig. 2. User interface of the local PID Controller.

A software suite built within LabVIEW® [14] is provided to perform both real and virtual operations simultaneously, i.e., the control of a real process and of its mathematical model. *Virtual instruments*, which are specific software components, are used by students to generate excitation signals and observe corresponding responses.

The user interface of virtual instruments forms a didactic layer that includes all the functionalities in a cockpit-like fashion. The main idea of such an interface is to provide a complete view of what is happening in the real process, and to allow full control of the operations.

The user interface of the PID software component used to control various processes in our Laboratory is presented in Figure 2. It consists of an oscilloscope for signal visualization, a signal generator providing either the reference signal in closed-loop mode or the control signal in open-loop mode (which can be selected in the Command field), parameter settings for the controller, storage parameters to specify when and how to save the data, and a setup for the real-world interface specifications.

LabVIEW® built-in cursors can be moved to specify the measurement intervals, which is useful to evaluate time constants or overshoots. If time is usually displayed on the x-axis, another signal can be selected instead, for example to generate a phase plane.

3 An Alternative for Remote Experimentation

Given its fully computer-based implementation, the described integrated workbench can easily be expanded for remote experimentation. The main idea in turning the locally-controlled set-up into a remotely-controlled one consists in moving the cockpit away from the experiment (Figure 3). There results two distinctive parts: the remote client and the local server.

- The *remote client* is a computer equipped with the cockpit functionalities. The client software allows the users to observe and to act on the remote experiment.
- The *local server* is the computer located near the real process and equipped with the hardware interface to the sensors and actuators. The server software receives the client commands and transmits them to the real process. It also returns the state of the real process to the client.

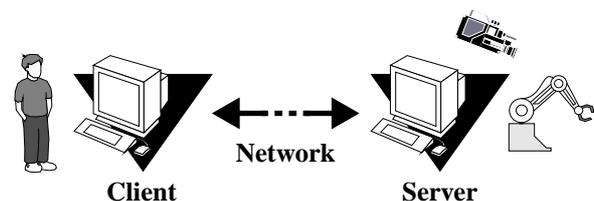


Fig. 3. Sharing of resources in remote experimentation.

The direct contact with the physical process, which remote users are deprived of, is replaced by broadcast images and sound. This operation can be performed by adding a digital camera and a microphone onto the server, and by sharing this information with the client through the network.

According to the expected performance in remote experimentation, two approaches can be chosen to implement the proposed distributed client-server architecture. They differ by the client behaviors, and are referred to as terminal-like approach and intelligent approach, respectively. In the terminal-like approach, the information is simply shared without any specific processing, whereas in the intelligent approach, appropriate actions are performed in order to optimize the communication traffic.

A **terminal-like approach** suffices to share cockpit parts and video image(s). With a UNIX-X11 implementation, the remote client simply receives and provides information on a X windows terminal [7]. With an implementation on a personal computer, commercial software packages can be used. They allow a remote client to display a clone of the server screen and to mimic the user actions with the mouse and with the keyboard. Thus, the user virtually works on the server peripherals. Timbuktu Pro and Look@Me [13] are such software products available for both MacOS and Windows95 as stand-alone applications or as Web Browser plug-ins.

The server components detailed in Figure 4 correspond to the instrument implemented for local experimentation with, in addition, the video image(s). The top components in Figure 4 are the user interface parts (rounded rectangle). The intermediate components are data (oval) shared between the user interface and the running computer tasks (rectangle).

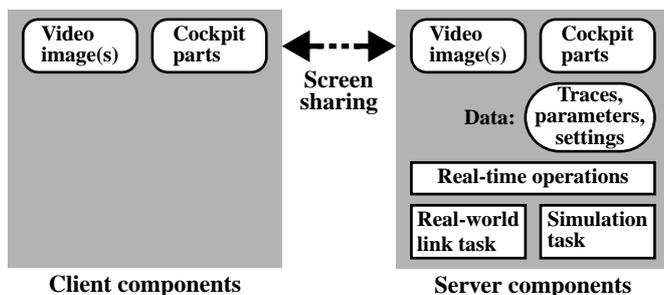


Fig. 4. Sharing of resources with a terminal-like approach.

This terminal-like approach is well suited for a first try in remote experimentation, because no additional developments are needed. Nevertheless, information is treated as pixels instead of structured data, which is inappropriate to achieve high performance. For example, when the oscilloscope is updated, all the corresponding pixels are transmitted instead of just the numerical values of the new samples. Moreover, solutions based on commercial packages can be too expensive for general use with students.

An **intelligent approach** needs more software engineering to provide the capabilities for remote experimentation. The client software is based on the instrument implemented for local experimentation, where the link to the real world is replaced by the communication capabilities (diamond). These communica-

tion capabilities must also be integrated into the server as shown in Figure 5. Traces, parameters or settings are transmitted only when a change occurs, such as an update of the oscilloscope traces or a parameter change requested by the user.

Standard video-conferences software products, which are already well optimized, can be used to overcome the need to integrate video components as a cockpit part. Bandwidth can be split between the transfer of both data and image(s) according to the desired responsiveness. For example, a higher refresh interval can be chosen for the oscilloscope than for the real process viewing.

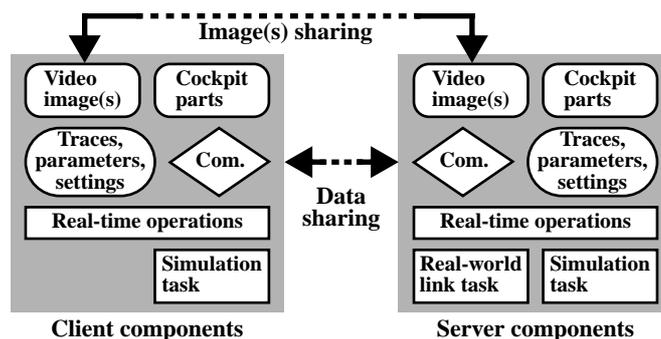


Fig. 5. Sharing of resources with an intelligent approach.

Instruments built within LabVIEW® can be easily adapted to integrate the needed modifications, because high-level communication functions are available into the development environment. Moreover, multiplatform stand-alone clients can be produced with no need to pay royalties for educational applications.

Although, implementation of an intelligent client-server architecture is quite straightforward, refinements can be made to improve the efficiency of remote experimentation. They are described in Section 4.

4 Refinements in Remote Experimentation

Access to an audio-video representation of the physical process is a key point in remote experimentation. In fact, this is the only way that makes the remote user feel that a real experiment is running. However, high quality and high refresh rate are not essential since the video image mainly acts as a reminder of the reality. **Virtual representation** is preferred to catch the dynamic evolution of the real process efficiently. Such an animated and simplified representation is free of unnecessary and disturbing details. Moreover, the animation is driven by the real process or by a simulation. This will be detailed later. Finally, it is less expensive to broadcast the state of the process to reconstruct a virtual view of the setup than a full video image.

At this point, it should be stressed that electromechanical processes that have mobile parts are better suited for remote observation, since the dynamic behavior has to be monitored by cameras and microphones. This constraint can be overcome in the case of visually static systems, such as thermal systems, by

the use of sensors that modify their appearance according to the measured state. This way, it becomes possible to broadcast an image. In any case, on-line remote operations have to be preferred to off-line remote operations in order to preserve the advantages of the **live and interactive experimentation**.

In some particular cases, it can be necessary to improve the **perception** of the reality by allowing the remote user to select appropriate view points and appropriate image magnifications. These can be either predefined or open configurations. To achieve this purpose, additional actuators have to be integrated into the setup in order to manipulate the environmental sensors, and control means have to be introduced into the client cockpit. Multiple cameras are also necessary, mainly for processes evolving in a three dimensional space.

Since it is not possible for the remote user to apply direct disturbing action, additional actuators have to be integrated into the remote setup. This type of **Remote “Finger”** is necessary for observing the regulatory behavior of the controlled process. Some disturbances can also be emulated artificially by introducing wrong measurement samples or spoiled control signals, which is a cheaper solution compare to the use of additional actuators.

If the network transmission slows down or is momentarily interrupted, it can be convenient to maintain the feeling of the process dynamics by using a **prediction** of the lacking measurements for driving the animation. The simulation engine that has to be introduced for this purpose needs to work in real-time in order to guarantee smooth transitions between virtual and real modes of experimentation. Simulation models can be predefined in the client software or sent when starting the experiment. Later predictions can be improved by using new real measurements to update the current model. A simulation engine is also an interesting feature for a first virtual test before performing the real experimentation or while waiting for an access to the real equipment. Moreover, **fault detection** can be performed by using the simulation engine concurrently with the reception of real measurements. The solution implemented in LabVIEW® for real-time control and data acquisition [11] can be used as such to provide the proposed **real-time simulation** capabilities. Unfortunately, real-time operations paced by software or hardware interrupts are usually platform-dependent, a condition which reduces the potential universality of the client software. These latter refinements may have to be discarded because of this restriction.

Specific **security** measures must be taken for the physical equipment. In fact, an hazardous behavior of the process has to be avoided following communication interruptions or bad user manipulations. This is more important in open-loop than in closed-loop mode of operation, where a local controller keeps the plant around its operating point. In order to carry out successive experiments, it is necessary to be able to reinstate the experiment.

Three different **client-server architectures** can be considered, independently of the applications:

- ① A unique client communicates with the server. Only simple communication features have to be implemented.
- ② A few clients communicate with the server which handles the real-time control, video, data sharing, communication and users management tasks.
- ③ Many clients communicate with a reflector which handles video, data sharing, communication and users management tasks. The reflector is the only computer which has access to a server of type ①. The server performance is therefore not affected by the number of clients.

In the multiple-clients cases (②, ③), two options for handling the accesses can be considered depending on whether individual or collaborative work is expected:

- A unique client, called the master, experiments on-line, while other clients, which have requested an access, wait off-line.
- A unique client, called the master, experiments on-line, while other clients, which are authorized members of a team, watch the actions of the master on their passive cockpit.

Secured or even pay accesses may be necessary in particular cases, but usually the need of owning the client software and knowing the server IP address can be a sufficient precaution.

Applications of the remote experimentation principle and some of the proposed refinements are described in the next two sections.

5 Application Scenarios

Different remote experimentation scenarios can be considered according to the bandwidth of the available network. At the current development stage, and due to the saturation of the Internet, remote experimentation can mainly be performed inside an institution equipped with an efficient Intranet. In this case, the first option to consider is a use in the classroom for live demonstrations conducted by the teacher. Hence, equipment needs not be moved, and the students' questions can be handled in an interactive manner. The second option consist in offering the students a remote access to the laboratory from a computer room. This way, practice time is unrestricted and no supervision is necessary.

If an access from outside the Intranet is requested, limitations on the user-interface quality and responsiveness can be necessary. For example, video images may need to be dropped or the refresh rate reduced. This is particularly the case with international connections over the Internet or in local connections from a student's home over an ISDN phone line. Hopefully, sooner or later, fast Internet protocol and ATM links will let the user take full advantage of remote experimentation capabilities between academic institutions.



Fig. 7. Field added to the PID controller cockpit for remote use.

6 Application Example

This application considers performing remote control experiments on a servo drive.

The system (Figure 6) is simple and exhibits an almost-linear behavior [12]. It consists of a 14 W DC motor equipped with a built-in tachometer (❶). The motor drives a load which is a steel disk (❷). An adjustable magnetic brake (❸) introduces a viscous-friction term, allowing thereby a modification of the time constant during operation. Either axle angular position or speed can be controlled by adjusting the motor voltage. The angular position is measured by a potentiometer (❹) connected to the motor axle through a reduction device. The reference value can be generated manually by a similar potentiometer (❺). Both potentiometers are equipped with enlarged disks which permit easy visualization of the motion, either locally or remotely.

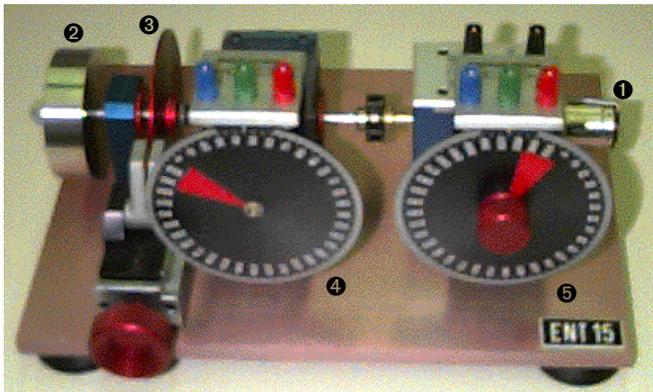


Fig. 6. The real servo drive.

Before connecting for remote experimentation, students can obtain full description of the process and suggested experiments through the WWW. Original documents are provided in Adobe PDF format. Students can read these documents on-line or transfer them for further reading or printing. The client software and information on how to establish the connection to the real process are available through the same channel.

The local PID controller (described in Section 2) was only slightly modified to make remote access to the servo drive possible. A point-to-point architecture ❶ (see Section 4) was implemented. Fields added to the cockpit user-interface are represented in Figure 7. Built-in real-time simulation of the servo drive is possible once the time constant and the static gain are introduced into the appropriate field. Virtual experimentation by simulation or real experimentation on the remote process can be selected in the “Mode” field. The IP number of the server has to be provided. While operating (indicated by the

text “On-line”), the refresh time is indicated (number of milliseconds between two successive updates of the user interface).

An additional window is displayed (Figure 8) providing a reconstructed virtual representation of the dynamic evolution (actual position of the rotating disk) driven either by the simulated data obtained locally or by the real measurements obtained remotely.

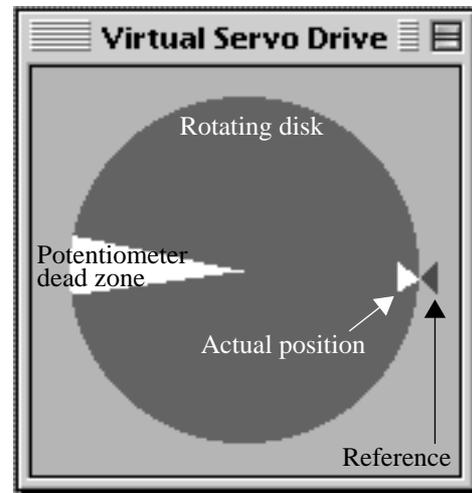


Fig. 8. Virtual representation of the rotating disk position.

The QuickTime™ Conferencing software [15] provides the real view of the process (Figure 9) as well as the sound.



Fig. 9. Real representation of the rotating disk position.

An additional actuator allowing to remotely adjust the magnetic brake will be the next addition to this application. The possible selection of the controlled variable (position or speed) will also be added.

7 Conclusions

The proposed remote access to real equipment can considerably reduce the number of experimental setups necessary for practical work, i.e., also the maintenance effort that an academic institution has to provide. As a matter of fact, it is obvious that all students will not want to experiment simultaneously if flexible access is given. As a consequence, fewer setups will be necessary. Remote experimentation also turns the traditional way of studying into a more flexible and personalized learning, with reduced presence on campus and more active and creative work. In-time experimentation can thus be carried out by students whenever they feel the need to compare their knowledge to reality as part of their learning process. Finally, it allows teachers to easily present real (but remote) installations in the classroom.

Partial or full replacement of local experimentation with physical processes by remote experimentation will depend on the network development and the users' expectations. Whatever the evolution will be, the cognitive impact of remote experimentation has to be evaluated carefully before being generalized.

Compared to experimentation in virtual reality, remote experimentation on real processes is easier to implement and more versatile. In fact, adding or selecting another real process does not involve the elaboration of complex mathematical models and graphical representations.

Finally, remote experimentation is not limited to education. In research and industry, remote accesses also represent an interesting opportunity to meet the growing need of scientists and engineers who wish to share unique or expensive equipments.

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