



American Control Conference 2000
Chicago, Illinois, USA
June 28-30, 2000

WEB-BASED REMOTE EXPERIMENTATION USING A LABORATORY-SCALE OPTICAL TRACKER

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Keywords: Education, Remote laboratory experimentation, Web, Virtual reality

Abstract

This contribution presents a remote laboratory approach for experimentation with real plants, which uses the communication techniques of the World Wide Web. The aim of this kind of distance learning environment is to facilitate the access to these plants for students and professionals in the area of control engineering. Furthermore, resource sharing among the involved universities reduces money and time for maintenance or development of new experiments. The new approach for remote experimentation incorporates software that uses the powerful computational engine of MATLAB/SIMULINK together with the Quanser's WinCon real-time system to perform the experiments. Web-based components are used to support the user interface by animation of plant models in virtual reality. A laboratory-scale optical tracker will be used in order to demonstrate the advantages of the realisation of this remote laboratory approach.

1. Introduction

Laboratory experiments play an important role in engineering education, since a student can apply and verify in practice the theoretical knowledge acquired during lectures. One of the aims in control engineering education, therefore, is to teach the techniques and possible pitfalls of theoretically based design methods when applied in practice. The control system design process involving practical experiments and observing the dynamics of a real plant gives a valuable insight. Simulations may also be a suitable complement in achieving this aim (e.g. [Sch98], [VCL00]), however, in many cases they cannot replace a real experiment. Simulations give only approximations of the real behaviour. A control engineering student should be able to design a controller that matches a given performance requirement within a real plant environment. For this reason, laboratory courses are of crucial importance to gain practical experience.

A good practical education shows a well-equipped laboratory that provides different experiments. This involves a considerable investment. On the other hand, there is a re-

stricted access to an experiment due to organisational purposes (e.g. laboratory course is not being offered, tutors are not available, etc.) which imply rigid time schedules. Furthermore, the students can normally only use experiments offered by one university.

As a result of the availability of digital computers and the technical progress of communication and information sciences, one can make use of this innovative potential to establish remote laboratory courses. The wide spread World Wide Web successfully demonstrates how current technology can support sharing information among large dispersed groups. The significant functionality in transmitting information and the effective mechanism for integrating tools into a single interface are the main reasons for using the Web for educational purposes. The advantages in having a Web-based remote laboratory are mainly:

- *different experiments:* access to experiments located at different universities,
- *flexible time-schedules:* experiments can be accessed 24 hours a day,
- *saving travel time and cost:* student's presence at the experiment location is not necessary,
- *saving tutors:* virtual education leads simultaneously from the lecturer-oriented to the student-oriented type of teaching,
- *saving equipment costs:* expensive experiments are shared among universities.

Although the lack of a direct physical contact to the experiment may lead to a loss of 'practical feeling', it can be compensated by enhanced multimedia components (e.g. virtual reality or VRML models). In the following section a new remote laboratory approach will be described, which tries to obtain the necessary "closeness" to the experiment.

2. The Web-Based Remote Lab

One important aspect when designing a remote lab is to keep all hardware components as simple as possible to guarantee fast and effective maintenance. The same criteria apply to the utilisation of commercial available software

packages. The modular structure of the remote lab proposed is shown in Fig. 1. The main components are:

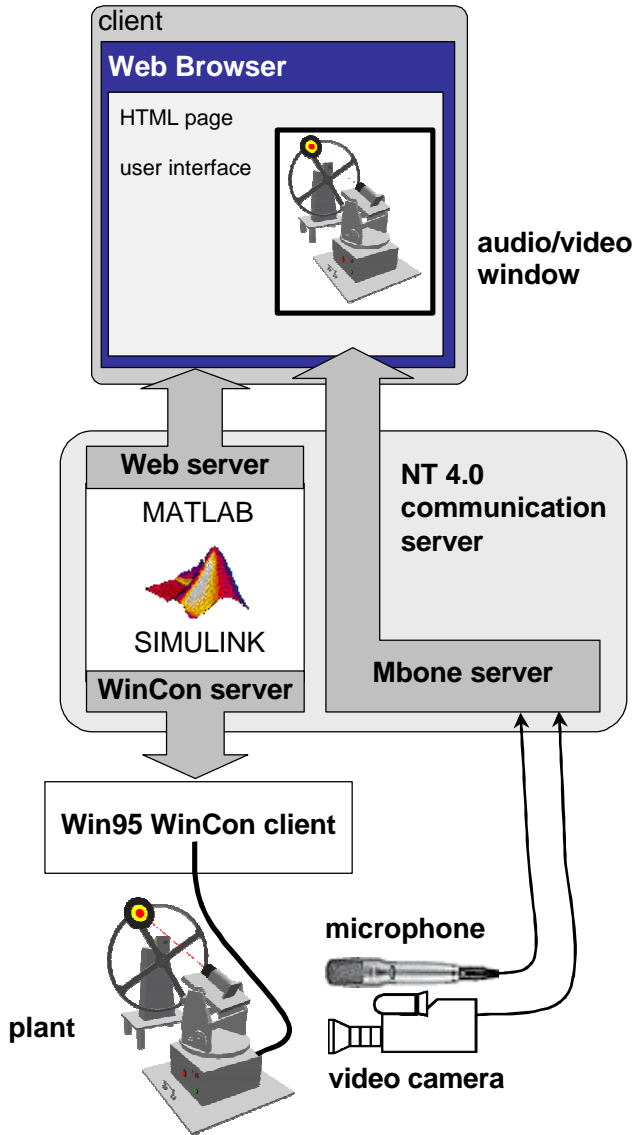


Fig. 1. Schematic diagram of the remote laboratory structure.

- *communication server*: runs on a PC with MSWindows NT 4.0 as operating system. This server runs MATLAB/SIMULINK combined with the WinCon server to communicate with the WinCon client (real-time client). The communication between the Web server and MATLAB is performed through the MATLAB's engine interface. Thus, MATLAB commands are sent to SIMULINK through a DLL attached to the Web server, to get or set parameters of the SIMULINK model and to operate the experiment via WinCon. The advantage of this configuration is that new experiments with different physical structures can be easily set up, since one can directly write new MATLAB commands embedded

in the JavaScript language. On the communication server only the SIMULINK model and the corresponding M-files have to be rebuilt.

- *real-time client*: runs on a PC with MSWindows 95 as the operating system. This client is called the "WinCon client" since it runs the real-time code corresponding to the implemented SIMULINK model [QCI98b]. Therefore, the WinCon client contains a multi-I/O card [QCI98a], which is the hardware connection to the plant via digital and analog I/O-ports.
- *external hardware*: corresponds to a microphone and a video camera, which are connected to an audio and a video capture interface, respectively. This interface is included in the communication server performing live audio and video transmission for having the "closeness" to the experiment. The audio/video transmission and receiving used here is based on the concept given in [RJ99]. The Mbone server is installed on the communication server machine and it consists of the Mbone RAT audio and VIC video transmitter. They produce an audio and video stream, which use RTP UDP/IP channels. On the user side the Java Media Framework tool [Sun00] is for displaying the video through an applet in a browser window. Fig. 2 shows this window, denominated as "Real-time video connection" including the "Real-time audio pane" for audio tuning. A resolution of 288×252 pixels, a frame rate of 10 frames per second and encoding in h.261 format is a good practical choice for transmission [RFC00]. This set-up guarantees a good animation property, since the time constants of the plant used in our experiment are in the order of 0.1 seconds. It is also acceptable for students, who are using the remote lab from home via ISDN lines.
- *client*: is a Netscape browser, which runs on the student's computer to access and operate the remote experiment. The Web page necessary to control the experiment is organised in form of a control panel, Fig. 2. The Hyper Text Markup Language (HTML) and JavaScript have been used to organise all actions. The main operating actions (e.g. start/stop an experiment session, or reset the plant to a predefined initial state) are located in the general control panel frame, since these actions do not depend on the type of experiment. The specific commands to operate the plant as well as parameters to modify the characteristics of the reference signal and of the implemented controller are found in the user console panel. Sliders are used for entering continuous data and to facilitate operating the plant. A Java slider applet and an internal scanning mechanism written in JavaScript provide means of pushing the values from the sliders directly to the communication server. An interactive plant user interface enables the user to operate the real plant manually by mouse ac-

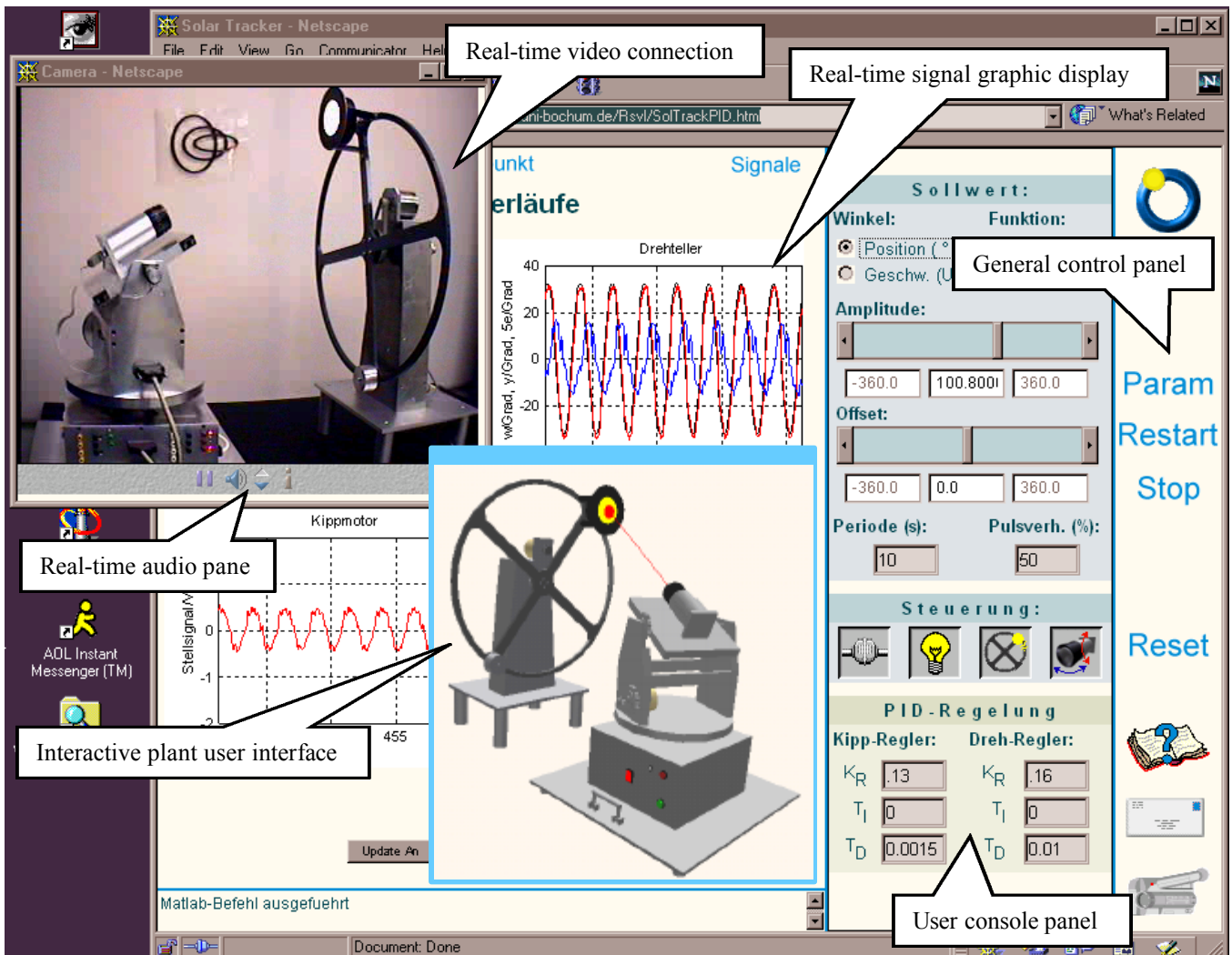


Fig. 2. Screen shot of the client main Web page including video and user interface windows.

tions in the virtual reality scene of the 3-D model. This 3-D plant model is written in the Virtual Reality Modelling Language (VRML). Although the user can inspect the plant by the video camera, a graphical representation of measured signals is needed to show small variations. The diagrams are generated remotely on the communication server by using MATLAB graphical routines. In order to get fast and best results, these diagrams are directly transferred and embedded on the Web page using the Extended Metafile Format (EMF).

3. The Laboratory-Scale Optical Tracker

A short description of the optical tracker is given in this section. The plant is composed of two units, Fig. 3:

- *reference unit*: includes a light source fixed on a wheel. A DC motor moving the light spot on a circular trajectory drives this wheel. The user can select the angle (i.e. position of the light spot) or the angular velocity

of the wheel (i.e. speed of the light spot). It is also possible to change the properties of the signal generator (e.g. shape, amplitude, offset, period) attained to the angle or to the angular velocity.

- *tracking unit*: is composed of a tracking camera mounted on a 2DOF support which can be rotated vertically and laterally, necessary to track the light spot. Two DC motors, each of which is used to control the rotation, drive this support. The camera includes a matrix of 84 phototransistors to detect vertical and horizontal deviations of the light spot from the optical centre. The vertical deviation is fed to a controller for yaw angle control, while the horizontal deviation is fed to a second controller for pitch angle control. Both controllers are used for tracking the light spot.

The maximum angular velocity of the wheel is 2 rad/sec and the corresponding maximum vertical and lateral angle turns of the support for tracking the spot on the circle are

$\pm 36^\circ$. As the tracking camera has a limitation in the view angle of $\pm 12^\circ$, it is a challenge for students to design a controller such that the light spot will not leave the camera's view. The controller set-up shown in the user console panel of Fig. 2 is of PID type. This experimental set-up is therefore especially suited for students enrolled in the course on basic control. The configuration can be simply changed for other type of controllers in advanced courses. The aim of the experiment above is to teach the effects of variations in the parameter of the controllers on the closed-loop behaviour. The possibilities of the configuration can be extended and range from plant modelling, system identification to servo controller design using different kind of approaches.

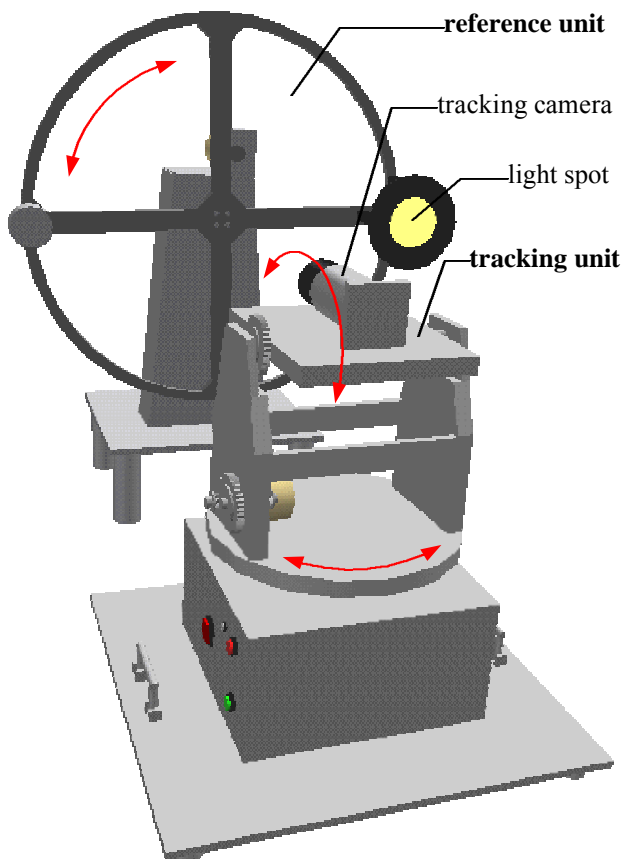


Fig. 3. Optical tracker plant (shown as VRML model)

4. Conclusions

This contribution presents a new Web-based remote laboratory environment for distance education, which addresses students and learners in control engineering. The user can perform experiments using a standard Web browser. The only requirement is to install some browser extensions, which can be downloaded from the Web server and installed simply.

The experiment is controlled using JavaScript statements embedded in the Web page. They contain MATLAB com-

mands, which are sent down to the communication server for execution in the MATLAB environment. This concept simplifies and speeds-up the implementation of new experiments due to its flexibility. For an other laboratory plant only the user console panel in the Web page and the Matlab/Simulink part has to be reprogrammed.

An evaluation form has been elaborated and given to students of control engineering to judge the quality of this remote laboratory experiment. Based on the feedback received, an overall positive resonance could be noticed. The quality of the control panel as well as the graphics has been approved. Controlling a real remote plant through a virtual reality 3-D model caused a surprise among the users.

The remote experiment is now a standard experiment in our basic control lab course. From April 2000 it will be used in the control courses of the German open university Fern Universität Hagen. The experiment is accessible on the Web round the world and round the clock, supposed the user has been granted a login id with password [RSVL00].

Acknowledgement

The support of this project by the *Universitätsverbund MultiMedia des Landes Nordrhein-Westfalen* (Project 9-23-98 *Reale Systeme im Virtuellen Labor*) is gratefully acknowledged.

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