INTERNET BASED REMOTE LABORATORY: THE LEVEL CONTROL OF THREE COUPLED WATER RESERVOIRS

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Abstract: This paper presents a remote laboratory for long-distance education: the level control of three coupled reservoirs. This process is non-linear and multivariable so that different control problems and strategies can be tested. The user can control and visualize the experiment in real-time using a standard Web browser; no additional software is required. A client/server architecture was implemented using Java and C++. HTML, PHP and *JavaScript* were used to compose the Web page. The modular architecture allows easy expansion to accommodate other experiments. A PID control experiment for sinusoidal path tracking using a dial-up connection (worst case) is presented.

Keywords: Long Distance Education, Level Control, Teleoperation, Educational aids.

1. INTRODUCTION

Long distance education is becoming reality for students, teachers and researchers in many places, allowing them to interact remotely using the resources already available (Di Stefano, *et al.*, 1997; Apkarian and Dawes, 2000; Vicinio, 2002).

A **remote laboratory** means the remote experimentation on real processes. In opposition, a **virtual laboratory** is based strictly on software simulations. It is well known that a simulation is quite often far from the reality; it depicts "only" the underlying mathematical model. For a good education it is necessary to be faced with real signals: noisy and reflecting lots of non-linear effects that are neglected in under-graduated control courses. The use of remote laboratories allows the sharing of expensive experiments between different educational institutions.

The presented architecture for remote labs goes beyond the universe of long distance education. Many other applications can use this technology, as in the industry, medical, commercial and entertaining fields. In the long distance education context, remote laboratories are known as very efficient, due to the high level of interaction with the user. The main idea of the proposed remote lab is to use the *World Wide Web* as supporting communication platform and a *Web Browser* as its interface (Röring and Jochheim, 1999). The client software required to run the experiment is the everywhere available *Web Browser*. The Web server implements the interface between the remote client and the physical experiment in the laboratory.

The developed remote lab allows the teleoperation of the level control of a three-coupled reservoirs process at the University of Brasília (Luna Filho, *et al.*, 2002). In real-time the user can adjust controller parameters, reference signals and see them on a dynamically updated plot of chosen signals and on a 2-D visualization of the water levels.

2. THE THREE COUPLED RESERVOIRS

In the technical literature level control has been often used for educational purposes due to easiness of construction and the visualization appeal for students. Each process aims to show a slight different control theory concept. For example, Grega and Maciejczyk (1994) describe a system with two reservoirs, one in a higher level feeding a lower with variable cross-section. Johansson (2000) shows a four-tank system in two levels that can be configured to be minimum- or non-minimum phase.

In the following a technical summary of the three coupled reservoirs process at University of Brasilia will be presented. It was build to show simple concepts as PID control at different operation points, fuzzy logic control (Luna Filho *et al.*, 2002) and also to verify more complex algorithms as non-linear decoupling and exact linearization of multivariable systems (Gosmann, 2002).

2.1 Dynamic model of the reservoirs

Three interconnected water reservoirs and two pumps compose the process, as illustrated in figure 1. The two inputs signals are the water flow at the two pumps. The outputs are the water levels in the three reservoirs. The dynamics of the process is clearly non-linear, due to the square root of the level dependence of the flow. Two levels can be controlled in this configuration, the third level will be considered as an intermediate variable.

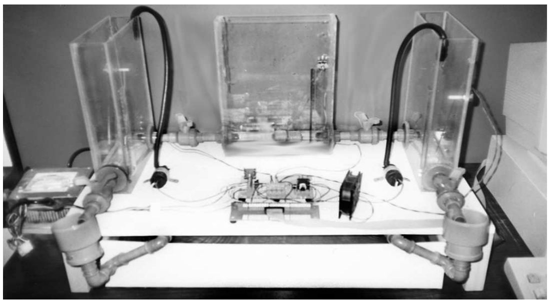

Fig. 1. The three coupled reservoirs process.

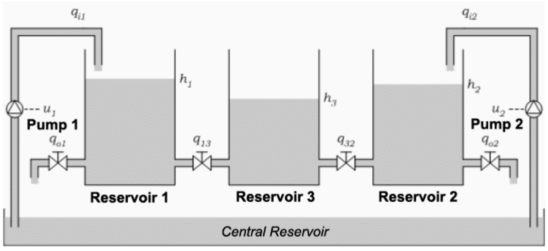

Fig. 2. Schematic representation of the process.

Process model. Each of the three reservoirs has a volume of 4500 cm^3, and is coupled by means of valves, as shown if figure 2. The reservoirs 1 and 2, located outer, are supplied by water pumps. These pumps are driven by power transistors commanded by a 0-10V signal that came from a D/A card in the Personal Computer (PC). Each reservoir is equipped with a potentiometer-floater based level sensor.

Considering the process in figure 2, the following variables can be defined:

q_{i1}, q_{i2} = input flow [cm^3/s] in reservoir 1 and 2;
q_{13}, q_{32} =flow[cm^3/s] between reservoir 1-3 and 3-2;
q_{o1}, q_{o2} = output flow [cm^3/s] of reservoirs 1 e 2;
h_1, h_2 e h_3 = water level [cm] in reservoirs 1, 2 e 3.

Applying the mass balance in each reservoir, we have:

$$\begin{aligned} A\,dh_1/dt &= q_{i1} + signal(h_3-h_1)q_{13} - q_{o1}, \\ A\,dh_2/dt &= q_{i2} + signal(h_3-h_2)q_{32} - q_{o2}, \\ A\,dh_3/dt &= - signal(h_3-h_1)q_{13} - signal(h_3-h_2)q_{32}, \end{aligned} \qquad (1)$$

where A is the cross section of the reservoirs and *signal*(·) is the function that returns –1 if the signal of the argument is negative, 0 if it is zero and 1 if it is positive.

The valve characteristics, considering turbulent flow, were obtained experimentally, k = 8.2094:

$$\begin{aligned} q_{o1} &= k\sqrt{h_1}, \\ q_{o2} &= k\sqrt{h_2}, \\ q_{13} &= k\sqrt{|h_3 - h_1|}, \text{ and} \\ q_{32} &= k\sqrt{|h_3 - h_2|}. \end{aligned} \qquad (2)$$

Substituting equations (2) in (1) we get the following non-linear state space representation of the reservoirs system:

$$A\frac{dh_1}{dt} = q_{i1} + signal(h_3 - h_1)k\sqrt{|h_3 - h_1|} - k\sqrt{h_1},$$
$$A\frac{dh_2}{dt} = q_{i2} + signal(h_3 - h_2)k\sqrt{|h_3 - h_2|} - k\sqrt{h_2},$$
$$A\frac{dh_3}{dt} = -signal(h_3 - h_1)k\sqrt{|h_3 - h_1|} - signal(h_3 - h_2)k\sqrt{|h_3 - h_2|}. \quad (3)$$

The student to design a PID controller can linearize these equations. In that case the coupling can be considered a perturbation signal. The student can also design a state-space controller for the multivariable system. And it is also possible to use the non-linear equations to design exact-linearizing controllers (Gosmann, 2002).

As a multivariable process the remote lab should provide the user with independent choices for the controller parameters associated to reservoir levels 1 and 2. It is also expected that the experiment could be on-line monitored by their associated references, control and measured variables.

Level Sensors. The level sensors installed in the three reservoirs have been build using 4.7kΩ linear potentiometers connected by a metal rig to a floating element, as shown in figure 3.

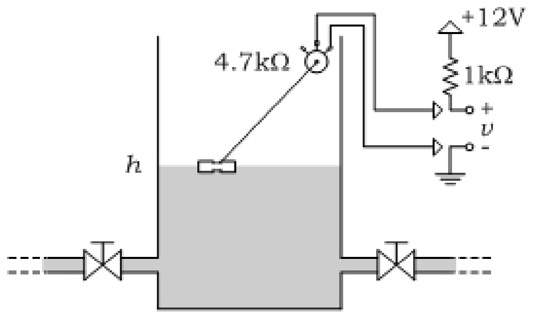

Fig. 3. Schematics of the level sensor.

The potentiometers are connected in series with a 1kΩ resistor, as a voltage divider, driven by +12V. The voltage of each potentiometer is connected to an A/D channel of the acquisition board in the PC. The operation range of this sensor is 0 to 28 cm.

Pumps. The actuators of the system are two pumps driven by a voltage in the range 0-10V.

The pump control is implemented by a power electronic circuit commanded by D/A channels of the PC acquisition board, as shown in figure 4.

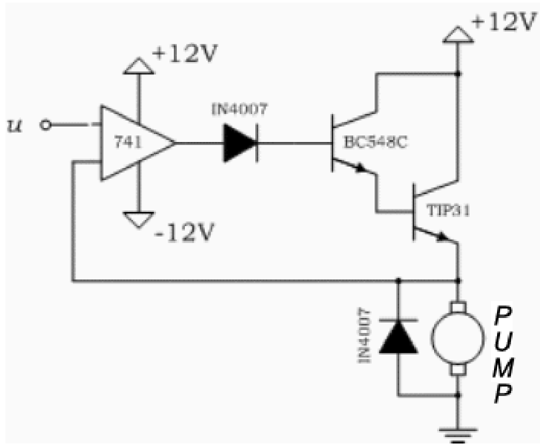

Fig. 4. The pump driver circuit.

3. REMOTE LAB ARCHITECTURE

Remote laboratories can support one or more on-line experiments (Belousov, *et al.*, 2001). Figure 5 shows a possible solution for a remote lab with an arbitrary number of experiments, based on a unique Web server.

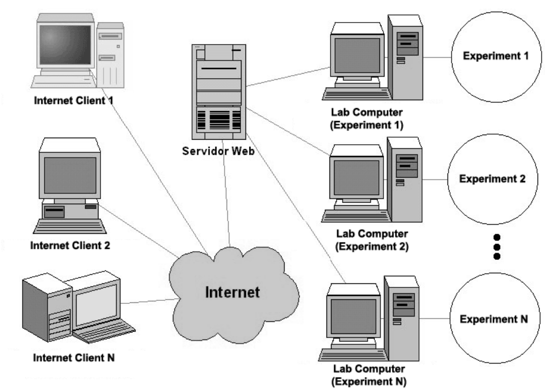

Fig. 5. Generic architecture of a remote laboratory with different experiments and one Web server.

The different client stations shown in fig. 5 reveal the necessity for user hardware independence, so that the remote lab can be widespread accepted.

3.1 Requirements analysis

A remote laboratory requires some features to guarantee quality and effectiveness to the learning process. So, from the communications architecture point of view, the following characteristics should be given/maximized:

- ✓ High portability: Allow highest compatibility using the minimum remote user resources.
- ✓ System updating: self-sufficient architecture, that is, the updating of the system should not depend on the user and every modification should be immediately available.
- ✓ Robustness: Computational tools to protect against any physical damage or system integrity threat. Restart capacity, if necessary.
- ✓ Low cost: Students, in general, are not willing to install specific software to experiment remotely. They also don't want to pay for additional software. So, the remote lab should be based on freeware and conventional Web browsers.
- ✓ User identification/usage limitation: Remote lab through Internet demands user control/registration when accessing the experiments. Once experimenting, other connected users should not have capacity to adjust the controller parameters. The time limitation is also important to let other users gather access.
- ✓ Educational efficiency: Provide high interactivity, technical information about the experiment, modular learning, etc. It is also very important that the experiment data are made available to the user after a run. So the signals should be stored on the server during the experiment run and the user can request the download afterward.

3.2. Communication structure

Three computers, at least, are involved in the remote lab, figure 6: Client (remote user), process controller and Web server. So, two communication paths are necessary and run in parallel during the experiment execution. The first is between the process control and the Web server, through a LAN. The second is between the Web server and the client, through the Internet.

Figure 7 shows the communication structure of the system. This structure is based on client/server architecture and uses essentially *Java*. The Web server is the only interface with the experiment. First, a HTML page arrives at the user. Asking for an experiment start, a HTML form in conjunction with one *JavaScript* and PHP register the identification data. If valid, the *Java Applets* in charge of the experiment control are downloaded from the Web server to the user.

Fig. 6. Remote level control experiment: The three computers involved. From left to right: client, process controller and Web server. In this case the client is in the laboratory, but accessing the experiment like would any other Internet connected user.

The proposed communication structure, figure 7, is generic, supporting different experiments.

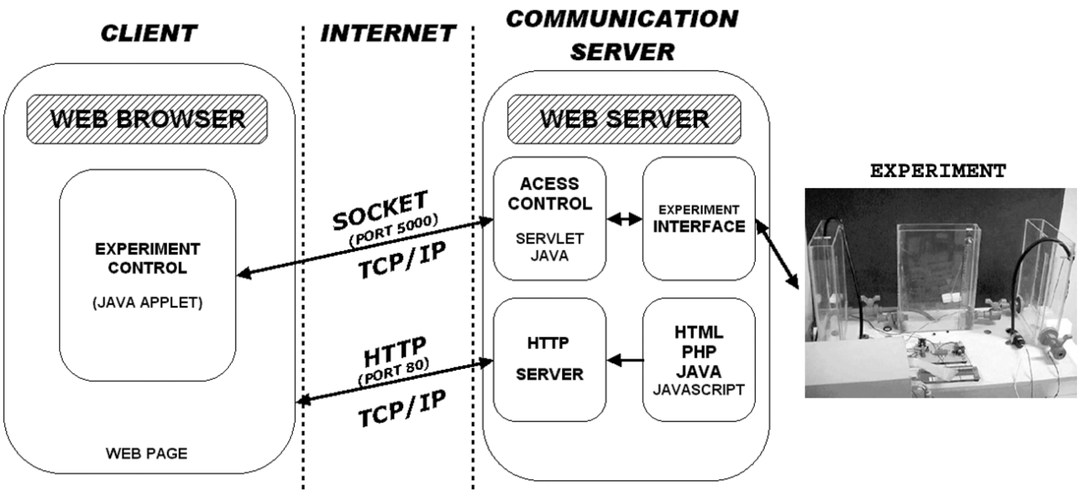

Fig. 7 – Communication architecture adopted in the remote laboratory.

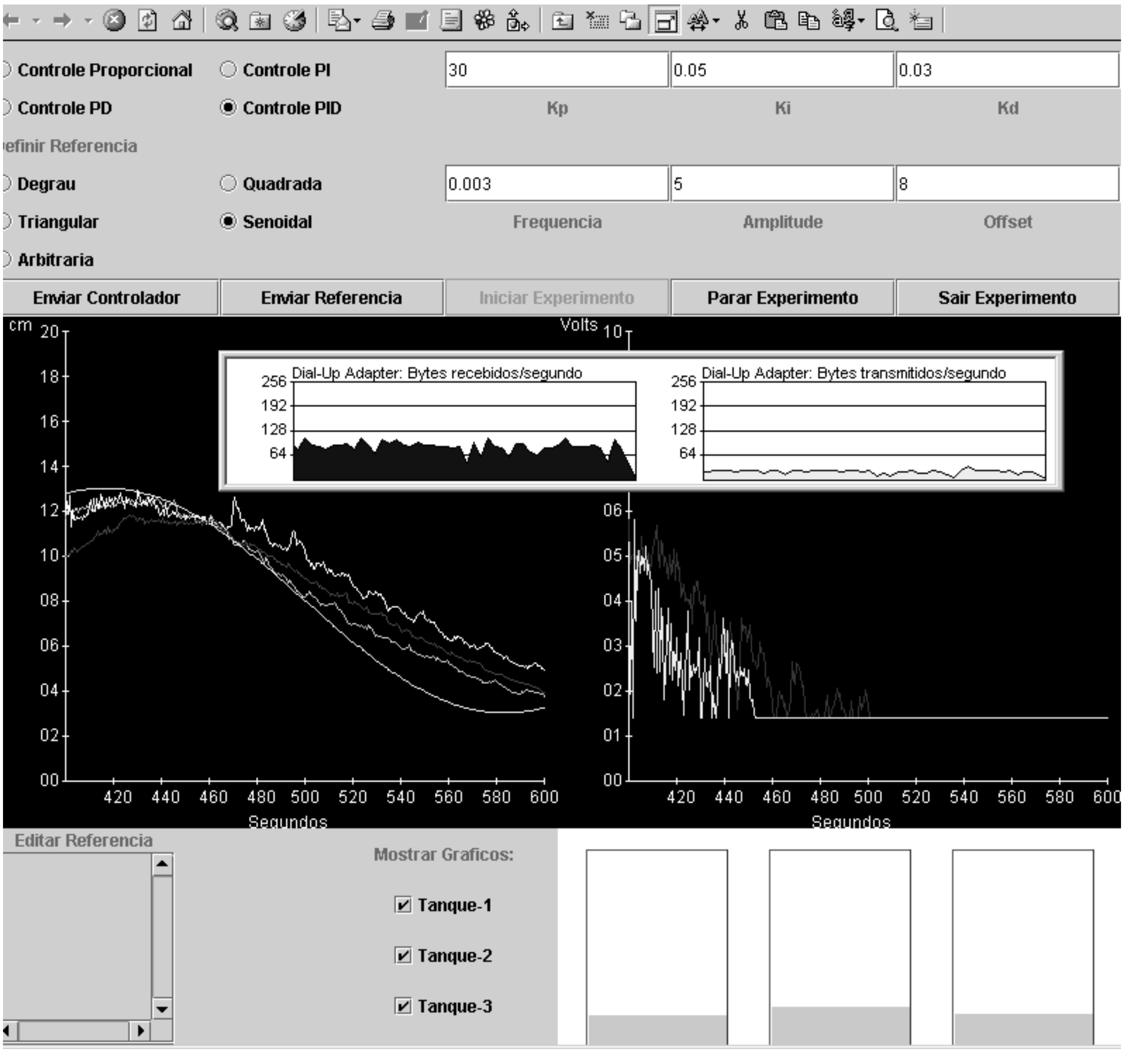

Fig. 8 – Web Browser operating the remote laboratory over a 56 kBps dial-up connection.

After setting the controller parameters and the reference signals (step, sinusoidal, triangular, square or piece-wise) for the reservoirs 1 and 2, the *start* button put all to run. A *Java Applet* opens a TCP/IP connection at port 5000 with the Web server (that runs continuously the *Java Servlet*).

The process control computer runs DOS 6.22, what guarantees real-time, because of its single-task nature. The *Microsoft Lan Manager 2.20* is used to support the LAN connection to the Web server. The controller is implemented in C++. The communication between the Web server and the process control computer is through ASCII files hosted on the Web server. The specific data structure used simplifies the interaction between both communicating tasks.

By the fact that control loops can demand high sampling rates, any cyclic read/write on hard disk is not acceptable (high access latencies of the mechanical hard disk heads). To avoid this, a RAMDRIVE (RAM-based virtual drive) was configured on the Web server to host the ASCII files. High data rates can so be obtained because no disk accesses are needed. Disk access functions are used but in fact RAM operations are carried out.

To start an experiment, a *Java Servlet* writes an ASCII file with the corresponding parameters. Periodic checks of the control and the data files are taken while the experiment is running. The *Java Servlet* also continuously furnishes data through TCP/IP to the remote user, closing so the loop of the remote experimentation.

If the user stops the process or exceeds the time limit the experiment is finished. A PHP *script* provides a copy of the data file that is made ready to be downloaded by the user.

Figure 8 shows a typical result of a PID control for a sinusoidal reference. The left graphics show the levels of reservoirs 1,2 and 3. On the right we have the voltage values applied to actuators 1 and 2.

The result window of a network tool to measure the bandwidth is superimposed on this picture. The result was obtained using a 56 kBps dial-up connection, that is, the worst case (smallest bandwidth). For the client the experiment brought 110 bytes/sec and delivered 56 bytes/sec. It is worth to mention that the experiment sampling-rate is much higher, but to present the result to the user a smaller data rate is quite sufficient.

A “reality-feeling” enhancement for the remote experiment is the use of a graphical representation of the current process state (Belousov, *et al.*, 2001), in our case the water level in each reservoir. Three rectangular bars are drawn using Java to present the three water levels (this information is already available at the Java user interface).

4. CONCLUSION

This paper shows that real experiments in laboratories can be adapted to be shared as long distance education tools. The Internet provides worldwide access.

For the client, only a conventional Web browser and the *Java Run Time Environment* is needed. In the laboratory, the experiment interface and the network structure can be implemented as shown, to allow the remote experimentation. The system as a whole could be implemented using freeware. In particular we point out the *Java* language. It is highly portable and is available without charge.

The implemented three reservoirs level control is a very handsome process because is allows a visual monitoring of the state variables of the process while the experiment is running. Beyond linear PID, state-space, “intelligent” fuzzy and Exact-Linearization have been implemented. They are now being integrated in the remote laboratory.

As future directions we mention the “reality-feeling” enhancement that can be obtained using video *streaming*. A freeware solution offered by Real Player® (*RealProducer Basic* e *RealServer Basic*) could produce and grant the access to only one user a time. The data rates obtained without *streaming* are low enough to allow, even in the worst case, that the remote user could benefit from the real-time experiment monitoring: signal graphics, 2-D level representation and video *streaming*. So the implemented remote laboratory is effectively a promising tool for long distance education.

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