An architecture for virtual and remote laboratories to support distance learning

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Abstract: This work describes the experience of the authors regarding the design, development, analysis, and exploitation of Web-based technologies for creating an online experimentation framework with distance education purposes. This framework is specially design for scientific and technical courses that require a quite important presence of experimentation. Every component belonging to the proposed structure for these kind of portals is integrated into a free modern Learning Management System (LMS) that enhances collaborative work. The features, use, and integration of this LMS (Moodle) along with the other required tools are detailed. The proposed framework was used to implement a network of remote and virtual laboratories for control engineering education (AutomatLabs) that is presented here too as an example of its application.

Introduction

Many universities, such as the Spanish University for Distance Education (UNED), offer to thousands of students all over the world the possibility of following graduate and post graduate studies at distance (e.g. Harry, 1999). In order to provide a high quality education with these conditions, these institutions need to use modern distance education resources, methods, and technologies.

The research on the development, improvement, and exploitation of these issues has produced important results in the last years such as the Web-based laboratories. These online labs are already quite well established in several scientific and technical disciplines because they help to illustrate scientific phenomena that require costly or difficult-to-assemble equipment (e.g. Chang et al., 2005). Other tools appeared due to the need of distance education resources are the LMSs, used for the administration, documentation, tracking, and reporting of training programs, classroom and online events (e.g. Ellis, 2009). In open universities, the introduction of these kind of teaching methodologies is a key piece to cover needs from students who must conjugate work and study and it is commonly accepted that digital media (such as simulations, videos, interactive screen experiments or web laboratories) can positively impact students knowledge, skills and attitudes (e.g. Kozma, 1994).

Web-based laboratories can consist of two different parts: the simulated experiment and its real (remotely controlled) counterpart. In particular, Gratch et al. (2007), state that simulations have evolved into interactive graphical user interfaces (GUIs) for student exploration (e.g.). Virtual Laboratories (VLs) are a particular approach to hands-on laboratories by means of these computer based simulations which focus on presenting both similar views and similar ways of work to their traditional counterparts. Thanks to these tools, students are able not only to observe the behaviour and evolution of the simulated systems but also to manipulate their parameters. In engineering, remote real experimentation has been widely available for more than a decade (e.g. Salzmann and Gillet, 2007) and the importance and benefits of remote laboratories (RLs) in this discipline education has been widely studied. Unlike VLs, in which the actions applied to the virtual system and its reactions are simulated, RLs use real plants teleoperated.

All these experiences have been possible thanks to the advent of the Web, which has promoted a wider adoption of remote experimentation since Web browsers are the ideal tool to ubiquitously execute the client application. However, developers face extra work when transforming an existing local system

into a Web-based environment as, even though they are used to manage hardware and software in a local control system, new problems arise when making it accessible via the Internet. This work offers a complete and well tested solution to this problem: a general framework for developing VLs and RLs that are deployed via the Internet by means of a free LMS.

Most works on virtual and remote laboratories are mainly focused on solving the technical issues related to the building of web-based lab solutions and not providing specific software tools designed to meet these goals and some basic guidelines on how to use them. In general, they do not take into account the programming issues that hinder control engineering teaching staff when designing and developing VLs and RLs (e.g. Casini et al., 2009). Park et al. (2005) found that the developments proposed in the literature to create remote experimentation systems are usually custom made solutions and hence, their conception, selection of software tools, and global architecture are not simple tasks due to the high offer in the existing software tools. This paper provides a conceptual framework that is general and simple enough to be applicable to any technical or scientific course that needs to provide experimentation as a complement to the theory lessons. Moreover, when provided, the web environments of the previous works and many others (e.g. Gurkan et al., 2008) do not consider the social context of interaction and collaboration among students (and between teachers and students) in traditional hands-on laboratories. The framework presented in this work is based on three software tools: Moodle to create collaborative Web learning environments, Easy Java Simulations (EJS) to easily create the Java applets that serve as GUIs in both VLs and RLs, and LabView for the computer programs to control the remote hardware in the RLs.

The paper is organized as follows: Section 2 gives a global vision of the framework proposed in this paper to Web experimentation portals, its structure, and the use and features of the tools it requires. Section 3 presents an instantiation example of this framework applied to a control engineering course (AutomatLabs). Finally, in Section 4 some conclusions and future work lines are given.

E-learning platform framework

This section presents a general framework based on a systematic approach using two types of resources. It can be used to develop Web experimentation portals with educational purposes, especially for technical and scientific courses. Figure 1 shows the structure of an e-learning platform to publish remote and virtual laboratories on the Internet.
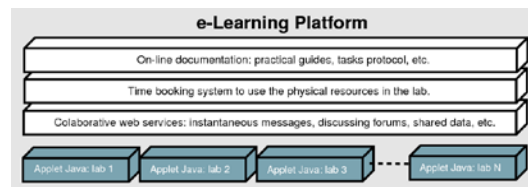

Figure 1: E-learning platform architecture

The Web environment, based on Moodle, provides students with all the theoretical documentation, protocol tasks, and complementary information they may need as well as communication channels between students and professors (e-learning resources). The Java applets of the virtual and remote laboratories used for the experimentation part of the course (experimentation resources) are also contained in this system and integrated into the LMS. Moreover, during the -virtual or remote-experimental sessions, they can save the obtained data in the server. These files are placed in a file repository within their personal account of Moodle and so, students can access them from any computer with an Internet connection and use them to write the laboratory reports which are finally sent to the instructors by means of a submission application of this LMS.

Experimentation Resources (Virtual and Remote Labs) Implementation

This stage of implementation is divided into two steps and involves the methodology to design and build: 1) the GUI, which serves for both the VL and the RL, and 2) the server application which acts as a gateway with the real plant in the laboratory (only used by the RL). Both tasks must be done for each of the VL and RL that would be provided in the online experimentation portal.

1. Client GUI: The GUI applications are distributed as Java applets (developed with EJS) to Web browsers. By means of the applet GUI, students can observe the effect in the dynamic behavior of the processes during their virtual or remote manipulation. They can also save data registers (parameters and measurements) or images (graphs with plotted data) of the experiments for later analysis. These files are saved in the server, sent from the applet via FTP using the Linlyn class4 and get stored in the personal folder corresponding to the students Moodle account. Communication between these client applications and the server ones is described in the next section.

2. Server Application: The development process of the second step is addressed by means of the well-known client and server architecture. Figure 2 shows the basic structure of these applications, where a remote client manipulates a process located in the laboratory through a server computer working as a middleware communication layer. Visual feedback of the distant equipment is usually provided by a webcam that points to the real equipment.

TCP/UDP links are commonly used for exchanging data and commands between both sides based on a design pattern known as command-based architecture. The server side executes three tasks concurrently: the Command Parser, the Sender, and the Acquisition and Control-Loop. The command parser receives commands from the client, interprets them, and executes the requested actions. When no request is received, the command stays idle, leaving the processor free for other duties. Similarly, the sender "sends" to the client the measurements acquired by the control loop when a command requires it. The acquisition and control-loop thread performs the data acquisition and closed-loop control of the process. On the other side, the client application also implements the transmission layer needed to exchange data with the server (Sender and Receiver threads). A third task is the rendering of the information to the final users.
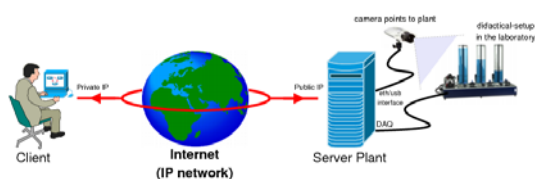

Figure 2: Remote control of a physical device through the Internet

This framework uses a novelty approach to make the creation process of the experimentation resources in an easier way, which relies on the use of two software tools especially adequated for developing these experimentation resources: LabView and EJS. The approach is based on the creation of generic communication modules both in the client and the server sides. On the client-side, a Java library called jil.jar with a generic communication interface has been created. By this class the TCP protocol is hidden to users and simple Java classes/methods are provided to set up the connections. This library can be easily integrated into EJS programs to dialog with the server. Similarly, on the server-side, a LabVIEW executable program called JiL Server operates as a middleware communication layer between the client and the plant. Thus, developers are only required to create a local control Virtual Instrument (VI) in LabView that performs the acquisition and the closed-loop control of the plant. More information about this approach can be found in the literature (e.g. Vargas et al., 2009).

E-learning Resources (Complementary Web Facilities) Implementation

Urban-Woldron (2009) found that, in spite of the advances in computer based simulations (and in remote real experimentation), few works have been made to study the impact of different implementation methods of digital distance learning objects, which is a fundamental topic that teachers have to confront. VLs and RLs do not provide by themselves all the convenient resources for distance teaching/learning of students with all the implications that this methodology involves. Specifically, students must carry out their practical activities in an autonomous way and therefore, complementary Web based resources to the virtual and remote labs should be included. For this reason, all the VLs and RLs in this framework should not only present a description of the phenomena under study and of the didactical setup of the experiment for remote experimentation but also the tasks protocol they must follow to achieve the proposed goals. Moreover, a laboratory report the instructors would correct must be prepared by the students with the data collected during the simulated and real

experimentation. Thus, a second key aspect to be addressed is the development of a Web platform that offers to students a personal online workspace and supports their learning process with the previous (and others) resources.

This e-learning platform organizes the access of users to available experimentation modules and simplifies the organization of user groups. It should also be able to offer notification services by email, instant messaging inside the online portal, news, forums, etc. allowing the interaction and the collaboration among students (and teachers/students).

This framework contains within the web portal all the necessary theoretical documentation like practical guides, tasks protocols, instructions manuals or any other kind of information needed to satisfactorily perform a remote experimentation session in an autonomous way.

The LMS could also suggest or impose a sequence of tasks or activities that students must carry out during an experimental session. The tasks can be of two types: Firstly, the tasks which students must carry out before performing the experiments in the real plant. This work should be done with a GUI that allows students to work in simulation mode. The aim of this first step is to get an adequate previous insight about the process. This way, students will reduce the time spent in the activities that work over the real plant. The access in remote mode should not be allowed until the student has completed the tasks in simulation mode. Once the student's work in simulation mode has been evaluated by the teaching staff, the access in remote mode can be granted.

Another important task that must be taken into account is the management of students and their assessments as well as the uploading of reports and the tracking of them. Also, a personal online file repository for students where the data collected during their experimentation sessions is stored.

Finally, an automatic booking system must be included in the e-learning platform to schedule the access to the physical resources of the laboratory for the RLs can only be used by one person at the same time. Therefore, a special application must be created to take care about the scheduling of these hardware resources. Some LMS also include booking systems that can be adapted and used for this purpose.

At the end of the development process, both kinds of resources are integrated to produce the Web environment. Moodle, a free LMS e-learning platform that offers all the necessary tools to cover the implementation requirements mentioned above as well as some additional interesting features, is used in this framework.

A framework instantiation example: Automatlabs

This section presents an example of application of the framework previously detailed to a university course about automatic and control.

The Department of Computer Science and Automatic Control of the UNED has been using VLs and RLs in the last years to give response to the demand from students who have difficulties to attend the classes in the academic centres. By means of these tools students have the possibility to have a first direct contact with the available systems: coupled three-tanks system, a temperature control system

and a direct current servo-motor. The previous virtual and remote control laboratories can be appreciated in the left part of Figure 3. The upper picture shows the three-tanks system, a MIMO system where liquid level control experiences can be carried out. Multivariable control concepts can be studied and put into practice using this laboratory. The one in the middle shows the DC Motor, a SISO system that allows studying the dynamic behavior in speed and position of a motor fed by a direct current source. Finally, the bottom one depicts the Heat-flow system that allows performing practical experiences on systems with transport delays.

Every lab has two working modes: virtual (based on a mathematical model of the process) and remote (which access to the real plant). The GUIs are divided into two parts. The left part contains a graphical representation of the plant and a control panel used to define different system parameters. The virtual representation has been developed by copying the actual hardware. Thus, any variation of the system state during the simulation will be automatically represented over the virtual scheme. On the other

and, when a user works in remote mode, this virtual representation is replaced by video images sent from the server. In this working mode, an augmented reality option is offered (Heatflow remote lab in Figure 3) and so the virtual representation of the process can be overlapped with the video image.
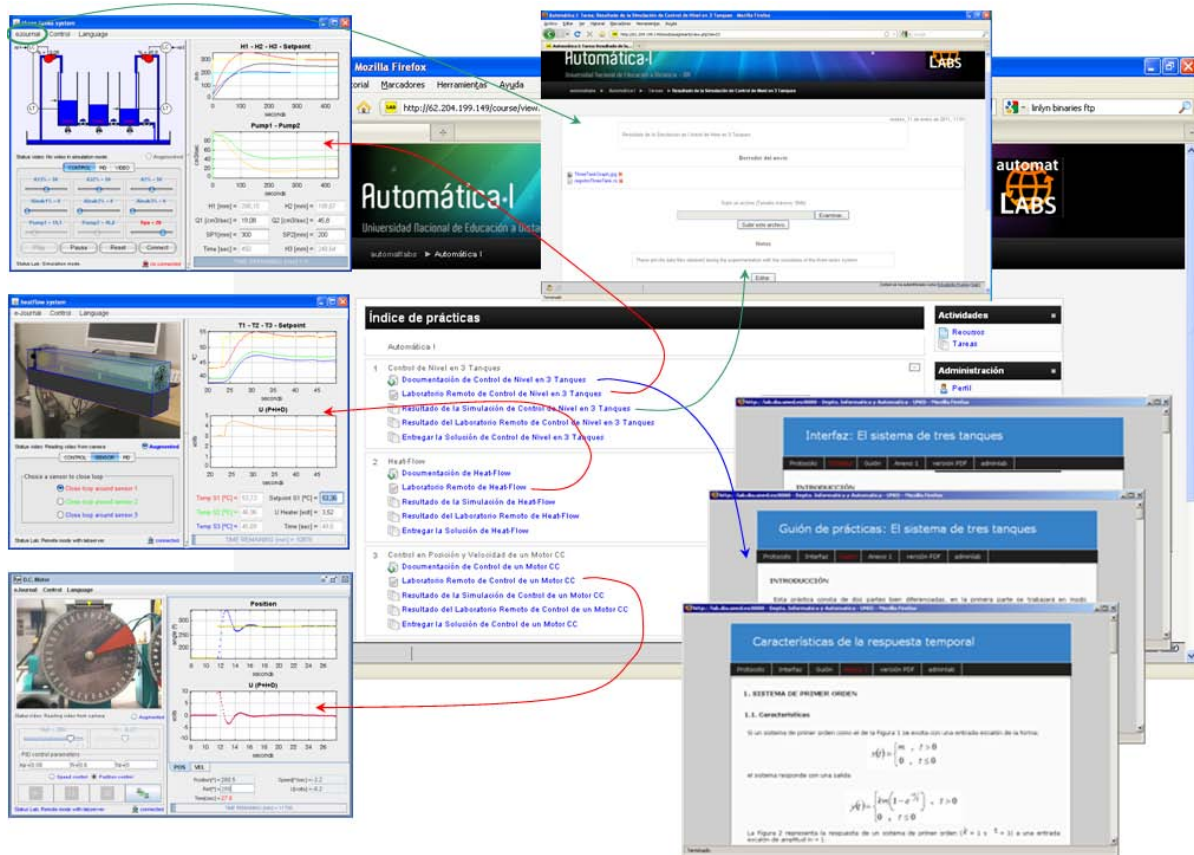

Figure 3: AutomatLabs web page and its online resources.

Figure 3 also shows the main page of the AutomatLabs portal listing all the 3 experimental blocks integrated into the Moodle portal. Each experimental block provides to students all the resources they may need to perform the online experimentation by themselves and they always follow the same structure: first link (blue line) opens the related documentation, protocol tasks, etc.; second link (red lines) opens the corresponding Java applet with the VL and RL (shown at the left of that same figure); third and forth links direct towards the files repositories where the data collected during the virtual and remote experimentation are stored, respectively; and finally, the last link from each experimental block opens the submission application to let students send their laboratory report to the instructors.

AutomatLabs uses a custom made booking system but there are free Moodle blocks such as rmbs5 that can be used instead. Moodle allows interaction among students (and between students and professors) by means of instant messages or forums (as long as the instructors have enabled these resources). Theoretical tests can be defined to evaluate students' knowledge after reading the provided documentation and before allowing his access to the experimentation resources (the EJS Java applets). Instructors can also use Moodle to fix deadlines to perform the previous activities and these events become visible in calendars inside the e-learning platform for all the students.

Conclusions

This work presented a general framework which can be applied to any technical or scientific course that needs to provide experimentation as a complement to the theory lessons and offered an example of its implementation with AutomatLabs, a network of virtual and remote laboratories.

The proposed framework uses Java applets made with EJS, LabView to control the remote hardware, and a free LMS (Moodle) that provides and/or supports all the resources students may need: the virtual and remote laboratories, the documentation, the protocol tasks, the repository to store the files with the

data obtained from the experimentation, an application to submit the laboratory reports prepared by the students, a booking system, and communication channels between students and instructors. The VLs and RLs provide students with the necessary tools to experiment with different systems and put into practice the theoretical lessons learnt from the documentation. This can be easily done in an autonomous way following the tasks protocol prepared by the instructors. Files with the images or numeric data obtained during the experimentation sessions are sent via FTP to the server and get stored separately for the different laboratories in each student's files repositories. A booking system can also be integrated in the e-learning platform to take care about the scheduling of the hardware used by the RLs. Finally, communication channels such as forums and instant messaging are easily added thanks to Moodle. The final result is a framework that allows creating online portals where scientific students can perform their experimentation sessions at distance and in an autonomous way.

AutomatLabs is an example of application of this framework to a university course about automatic control and offers to students three virtual and remote laboratories along with all the other resources and tools described above.

Our current work is focused on two main lines: 1) remove the necessity of the FTP server to send the files with the collected data or images and 2) remove the use of a custom made booking system. The first goal can be achieved creating a Java library in charge of the communication with Moodle's files submission application. The second one could be achieved making some changes to one of the previously mentioned booking system Moodle blocks.

References

Casini, M., Prattichizzo, D., & Vicino, A. (2009). Chapter 6. In *Web-Based Control and Robotics Education* (pp. 127-151), Springer.

Chang, G.W., Yeh, Z.M., Chang, H.M., & Pan S.Y. (2005). Teaching photonics laboratory using remote-control web technologies. *IEEE Transactions on Education*, 48(4), 642 - 651.

Ellis, K. (2009). Field guide to learning management systems. Technical report, ASTD Learning Circuits.

Gratch, J., Kelly, J., & Bradley. C. (2007). Science simulations: What do they contribute to student learning? In *Society for Information Technology and Teacher Education International Conferenc*e, (pp. 3422-3425). Chesapeake, USA.

Gurkan, D., Mickelson, A., & Benhaddou, D. (2008). Remote laboratories for optical circuits. *IEEE Transactions on Education*, 51(1), 53-60.

Harry, K. (1999). Higher education through open and distance learning. Routledge.

Kozma, R. (1994). Will media influence learning? reframing the debate. *Education Technology Research and development*, 42(2), 7-19.

Park, S.T., Lee, H., Yuk, K.C., & Lee, H. (2005). Web–based nuclear physics laboratory. In *Recent Research Developments in Learning Technologies*, (pp.1165-1169).

Salzmann, C. & Gillet, D. (2007). Challenges in remote laboratory sustainability. In *International Conference on Engineering Education*. Coimbra, Portugal.

Urban-Woldron, H. (2009). Innovative teaching and learning scenarios using interactive simulations. In *Multimedia Physics Teaching and Learning*, Udine, Italy.

Vargas, H. Sanchez, J., Salzmann, C., Esquembre, F., Gillet, D., & Dormido, S. (2009). Web-enabled remote scientific environments. *Computing in Science and Engineering*, 11, 34-36.