

Development and student evaluation of an Internet-based Control Engineering Laboratory

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Abstract: This paper presents the structure, functionality and application of an improved Remote Laboratory for engineering students hosted at Ghent University. The Remote Laboratory consists of two setups: Ball and Plate system and Quadruple Water Tank system. These setups introduce basic control aspects such as PID control design and non-minimum phase systems. Also more challenging aspects such as multiple-input-multiple-output control, decoupled and decentralized systems and advanced control strategies such as Internal Model Control or Model Predictive Control can be investigated on the setups. Based on a feedback study that targeted the bachelor degree students, the level of effectiveness of this concept has been shown but also possible functional enhancements that can be applied to the systems have been pointed out. The feedback survey data concluded that the Remote Laboratory has attracted the attention of students and had a positive impact in their training.

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1. INTRODUCTION

The Remote Laboratory (RemoteLab) has gained increased popularity as an alternative to on-site laboratory experiments since it was first introduced more than 15 years ago (Overstreet (1999)). This concept was developed by universities as an educational tool providing an option for advanced research and learning for students. Nowadays, due to the facilitated access to the World Wide Web (WWW), it is possible to implement remote laboratories in academic environments. This tool has proven useful in the curriculum of undergraduates who required hands-on experiments on test beds provided by the universities.

In the last decade, more and more attention was focused on implementing and developing platforms that allow students to perform remote experiments with the help of the Internet. The idea behind the RemoteLab implies that the user connects remotely to a real-life plant via the Internet without the constraint of having the same location as the setup. Major universities have brought their contribution to this still-in-development sector of teaching, amongst them we can mention the iLab and European Schoolnet (Gomes and Bogosyan (2009)). This additional teaching resource can be applied to various fields such as mechatronics (Chaos et al. (2013)), control engineering (Jara et al. (2009)) and electronics (Hsu et al. (2000)).

The development of the RemoteLab came as a complement to the theoretical aspect of teaching in order to

satisfy the necessity of applying acquired knowledge to real-life applications. It is considered that besides theoretical background one must also acquire a practical experience for a better enhancement in knowledge. This principle has been applied to undergraduate students who study in the field of science and engineering and require practical experiments to provide better insight into the theoretical aspects.

Academic environments have resorted to implementation of Remote Laboratories due to multiple factors:

- The lack of necessary space or available hardware equipment required to conduct the laboratory experiments for a large group of students
- The reduced number of academic staff required for on-site surveillance of the remotely controlled equipment
- Possibility of sharing remote laboratories between multiple universities in close collaboration
- Increased number of enrolled students on an yearly basis

Due to the expansion and variety of the remotely controlled experiments, a classification can be developed based on the nature of the equipment. On one hand, we can talk about the Remote Simulation which implies that the user controls a virtual system hosted on the server side. On the other hand, the Remote Experiment deals with controlling actual hardware equipment available on a different location than the user. This paper concentrates

only on the concept of Remote Experiment where students connect remotely via the Internet to actual real-life plants.

On a yearly basis, the number of students which enroll in the bachelor and master programs at Ghent University, is in continuous expansion, reaching approximately 1000 students in the academic year 2014-2015 (Ghent University (2014)). A major percentage of these students specialize in the field of mechanical, electrical, chemical or physics engineering. All these disciplines take the course Modeling and Control of Dynamical Systems included in their bachelor curricula to learn about basic control engineering concepts. Advanced control techniques are also taught in the master degree for the control engineering students.

The RemoteLab has proven useful in academic teaching because it offers the possibility for students to conduct multiple experiments, control the input of the systems and analyze the generated output. The idea behind the current version of our RemoteLab is to provide short experiments on a bachelor level and more advanced experiments on a master level. Provided the fact that the bachelor students by far outnumber the master students, short exercises make an introduction to the practical aspects possible for a larger number of students. Master students have the possibility for more extended experiments to test more difficult theoretical concepts.

The two applications that are part of the Remote Lab are the Ball and Plate system and the Quadruple Water Tank system. The Ball and Plate system has proven to be an educational tool for fields like mechanical and electrical engineering while the Quadruple Water Tank is a representative example in the chemical engineering field.

The purpose of this paper is to conduct a feedback study on the bachelor degree students which required conducting experiments on the RemoteLab setups and afterwards having the students fill in a survey.

The structure of this paper is as follows: section two covers the concept which lies behind the RemoteLab. The third section contains a detailed presentation of the two applications: the Ball and Plate system and the Quadruple Water Tank system. In section three, the educational context of the RemoteLab is discussed based on the feedback provided by the students. The final section formulates a conclusion based on the outcome of the study and discusses possible future work.

2. REMOTELAB

The purpose of the RemoteLab is to ensure facilitated access to real-life experiments provided by the university via an Internet connection (Farias et al. (2010)). The current implementation of the RemoteLab hosted by the Electrical energy, Systems and Automation department from Ghent University is the result of significant structure and content improvements. Starting from the old implementation which used Java Applets and Virtual Private Network connection (Hegedus (2013)), new features have been included with the help of open source and up-to-date technologies. A step forward is made using the web hosting framework Django which enables access to the RemoteLab even from portable devices such as mobile phones or tablets. Besides this accessibility feature, also

a wider range of control applications, e.g. Internal Model Control or Model Predictive Control, have been made available to the student.

2.1 Conceptual presentation

The architecture of the RemoteLab cannot be summarized to a standard implementation due to the different requirements and real-life plants. Nonetheless, a general structure can be defined comprising of: the plant itself, a local server (experiment server) which acts as a gateway between the plant and the remote computers controlling the plant and last, a middleware responsible for the exchange of information between the local and remote computer, which is located on the core server. The architecture for the RemoteLab presented in this paper is illustrated in Figure 1. The four components used in the structure of the RemoteLab can be easily differentiated: the clients, the core server, the experiment server and the plant setup.

The **client** is represented by the students that access the remote experiment via an Internet connection. This implies that the client has no constraints regarding his location; the only requirements imply a browser and an Internet connection.

In order for the client to control the plant, a web application is developed. To make this application live and available on the Internet a website hosting server, i.e. the **core server**, is used which acts as a middleware between the client and the experiment server. The core server is used to host the Django website alongside the HTML files and JavaScript files used in the development and is in fact an Ubuntu based virtual server. Due to the fact that the core server is Linux based, Apache is chosen for the software configuration. This server software uses an SSL protocol complemented with the Secure HTTP connection to manage the request received by the user and to ensure proper security. Also for the video stream provided by the cameras, a reverse proxy that protects the output stream of the camera from external malware is configured. The communication between the client and the core server is done using a TCP/ IP protocol. The client application, which is hosted on the core server, is a modular project based on sub-applications which have a specific functionality and are loosely linked in order to avoid influences that may occur in the development of the application's structure. The sub-applications are the accounts module which is responsible for the management of the user accounts, the reservation module which provides an efficient time management system to control the setups, the laboratories module which is responsible for the user interface to control the experiments and the remote.lab module which ensures the integration of all these modules in the Django project.

The **experiment server** establishes the link between the remote personal computer and the plant, the physical setup to control the system and an Internet Protocol camera for visual feedback. This experiment server is configured differently in the two RemoteLab applications. For the Ball and Plate system, an Apache server is used which redirects the user's request to the C# application which controls the actual plant. For the Water Tank system, the experiment server handles the incoming requests with the

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