14th International Conference on Optimization of Electrical and Electronic Equipment OPTIM 2014
May 22-24, 2014, Brasov, Romania

Remote Laboratory as a novel tool for control engineering studies: a feedback study

Amélie Chevalier[1], **Cosmin Copot**[1], **Andra Hegedus**[2] and **Robin De Keyser**[1]
[1]Ghent University, Belgium, [2]Technical University of Cluj-Napoca, Romania

Abstract

Remote Laboratories use Internet to connect remotely to real-life plants to teach theoretical concepts to students [1]. Experience dictates that engineering students are more motivated to learn these new concepts when they have the opportunity of doing real-life experiments where projects and team work play an important role [2]. However, in present times of limited time and financial resources at the universities, providing practical experiments for the booming amount of students is challenging.

A Remote Laboratory for control engineering students with two distinct applications is developed: a Ball and Plate system and a Quadruple Water Tank system (Figure 1). The combination of both applications allows us to provide examples from all areas of interest. The main difference between the presented Remote Lab and previous labs is the possibility to give to a diverse group of students a wide range of control applications. The novelty of our Remote Lab is the high flexibility in terms of control strategies.

1) Ball and Plate: The goal of the Ball and Plate system is to control the position of a ball on the plate by controlling the voltages sent to the servo motors. Basic controllers, such as Proportional-Integral-Differential (PID) controllers, as well as more advanced controllers are implemented for this system. The students can design a suitable controller for the system and implement this designed controller to the system.

2) Quadruple Water Tank system: The Quadruple Water Tank system is a Multiple-Input-Multiple-Output (MIMO) system. Control of MIMO systems is a subject of the master course on control. The developed application of the Quadruple Water Tanks presents to the students a challenging problem where coupling between inputs and outputs is important. The students can apply the theoretical concepts of relative gain array (RGA) and decoupling control to this challenging system. In the Remote Lab application, the students can perform two tasks: identification and control design.

To be able to evaluate the developed Remote Lab as an educational tool, two types of exercises (bachelor and master level) have been developed and presented to a bench of 20 master students. After performing both exercises, evaluation of the Remote Lab is obtained via a survey which uses a 5 point Likert-type scale (1 = very dissatisfied, 2 = dissatisfied, 3 = neutral, 4 = satisfied and 5 = very satisfied). The 23 questions in the survey were divided into four main sections: Interest for remote control of devices, Prerequirements and technical documentation, Application performance and GUI interactivity and Quality of education. The results show that there is a general interest for remote control of devices using a Remote Lab but also that we still have the possibility to improve the performance of the application and the technical documentation.

The Remote Lab can be a useful tool in the education of control engineers as it gives the opportunity for practical experiments in an university environment where time and financial resources for practical applications become scarce. A first survey showed that there is a big interest for these remote applications amongst the students and they accept it as a viable teaching tool in control engineering. This first evaluation of the developed Remote Lab, gives reason to extend it in the future. Future work includes the development of an automatic scheduling in order to give each student a time slot as the system only works with one user at the time.

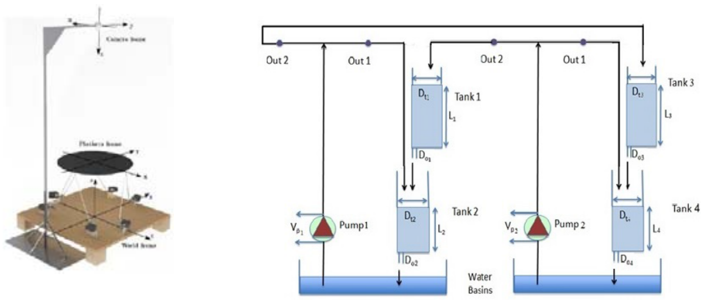


Fig. 1 Ball and Plate system (left), Quadruple Water tanks (right)

References

[1] A. Barrios, S. Panche, M. Duque, V. Grisales, F. Prieto, J. Villa, P. Chevrel and M. Canu, "A multiuser remote academic laboratory system", Computers & Education, vol 62, pp. 111-122, 2013.

[2] C. Ionescu, E. Fabragas, S. Cristescu, S. Dormido and R. De Keyser, "A remote laboratory as an innovative educational tool for practicing control engineering concepts", IEEE Trans. Educ., pp. 436-442, 2013.

Remote Laboratory as a novel tool for control engineering studies: a feedback study

Amélie Chevalier[1], Cosmin Copot[1], Andra Hegedus[2] and Robin De Keyser[1]
[1]Ghent University, Belgium
[2]Technical University of Cluj-Napoca, Romania
email:{amelie.chevalier, cosmin.copot, robain.dekeyser}@ugent.be, andra.hegedus@gmail.com

***Abstract*—This paper discusses the main structure, architecture and applications of a newly developed Remote Laboratory for control engineering students at Ghent University. The applications are twofold: a Ball and Plate system and a Quadruple Water Tank system. Combination of both applications gives a broad spectrum of possible practical examples, featuring challenging control aspects such as multiple-input-multiple-output control, decoupling, non-minimum phase systems, open loop unstable systems and PID control design. The feedback of the students shows that improvements are possible in the performance of the system and in the technical documentation. A major conclusion of the survey is that there is a keen interest in the Remote Lab to provide practical experience in the training of a control engineer.**

I. INTRODUCTION

The concept of Remote Laboratories where Internet is used to connect remotely to real-life plants has been first introduced almost 15 years ago [1]. Since then, state-of-the-art Remote Laboratories for teaching theoretical concepts on electronics [2], mechatronics [3] and control engineering [4], [5] have been developed. These currently existing Remote Labs give possibilities to give basic examples in their fields of specialty. More recently, research on authentication and authorization for Remote Labs has been performed [6].

For difficult theoretical concepts, experience dictates that engineering students are more motivated to learn these new concepts when they have the opportunity of doing real-life experiments where projects and team work play an important role. This type of learning is called active learning [7]. However, in present times of limited time and financial resources at the universities, providing practical experiments for the booming amount of students is challenging. These problems can be resolved by implementing a Remote Laboratory for the practical experiments which is nowadays a 'must-have' to provide cutting edge possibilities in educations [8].

Every year, more and more students enroll in bachelor or master programs at Universities. At Ghent University, almost 900 students started their engineering studies in September 2013 [9]. Almost half of these students choose an education in the field of mechanical, electrical, chemical or physics engineering. All these disciplines have the compulsory bachelor course 'Modeling and Control of Dynamical Systems' for basic control engineering concepts. Master students that specialize in control engineering also have the course 'Computer Control of Industrial Processes' where advanced control techniques are taught. For control engineering, real-life laboratory experiments can provide a better understanding of the theoretical background of the course [10]. However, the possibilities to do laboratory experiments are restricted due to:

- the increasing amount of enrolled students every year,
- the insufficient financial resources to provide the necessary laboratory equipment for the large number of students,
- and the limited work time of the academic staff that has to find a balance between time for research and time for educational purposes.

A functional Remote Lab can provide a viable solution to the stated problem of the laboratory experiments. The idea behind the current version of our Remote Lab is to provide short experiments on a bachelor level and more advanced experiments on master level. As 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 concepts.

The developed Remote Lab consists of two distinct applications: a Ball and Plate system and a Quadruple Water Tank system. The combination of both applications allows us to provide examples from all areas of interest present in the entire group of students. The Ball and Plate system is a combination of both mechanical and electrical engineering while the Quadruple Water Tank is an important example in chemical engineering. The general structure of the Remote Lab and both applications will be discussed in subsequent sections.

This paper presents a newly developed Remote Laboratory with two main applications for both master and bachelor engineering students. It discusses the architecture of the Remote Lab and feedback is provided by presenting example exercises to a group of students and afterwards having the students fill in a survey.

This paper is structured as follows: The next section presents the developed Remote Laboratory with a discussion of the basic concept followed by the explanation of both developed applications: the Ball and Plate system and the Quadruple Water Tank system. Section three presents the Remote Lab as an educational tool with an explanation of possible exercises and an evaluation of the Remote Lab based on a survey amongst students. A conclusion section summarizes the main outcome of the study and discusses the future work.

II. REMOTE LABORATORY

Via the Remote Laboratory, students can gain access to physical applications in the university lab using an Internet connection [11]. The main difference between the presented Remote Lab and previous labs is the possibility to give to a diverse group of students a wide range of control applications. State-of-the-art control Remote Labs lack the possibility to give system identification examples or to use advanced control techniques (e.g. Internal Model Control, Fractional Control, ...) combined with a user-friendly interface [8], [5]. The novelty of our Remote Lab is the high flexibility in terms of control strategies.

To be able to give a general access without the need of specialized software, only open standard technologies have been used. The main application of the Remote Lab has been developed in Java, making it easy accessible through a Web browser [12].

A. Basic concept

The Remote Laboratory has been based on a client-server structure using a TCP/IP connection. This structure is presented in figure 1 and consists of 3 main parts: the client, the server and the plant setup.

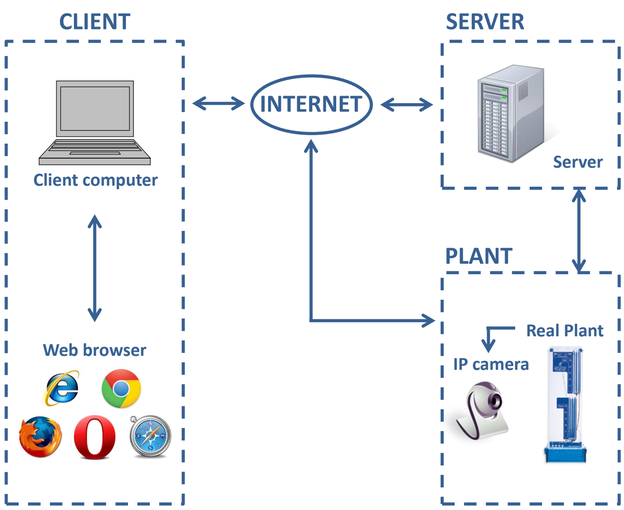


Fig. 1: Basic structure of a Remote Laboratory.

On the side of the *Client*, which is the student for the case of the Remote Lab, the personal computer of the student is present. To establish a connection with the Remote Lab, the student only needs a Web browser, a Java Runtime Environment and a VPN Internet connection to the university network.

The *Server* consists of different parts: a Filezilla server to perform the necessary file transfer, an Apache HTTP server to host all HTML files and the programs to communicate with both applications (i.e. C# for the Ball and Plate system and MATLAB for the Quadruple Water Tank system). A detailed description of the Remote Lab architecture can be found in [13], [14].

The third part is the *Plant* setup which includes the actual plant and an IP camera to give the students opportunity to see the effect of their manipulations to the plant.

The software used on both server side and client side is depicted in figure 2. Connection between the different main parts are also shown in this figure.

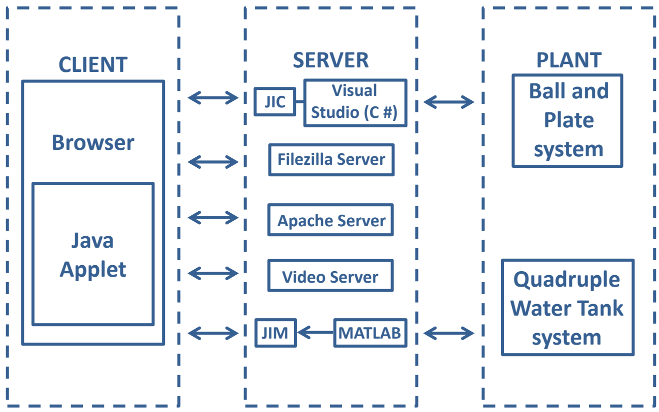


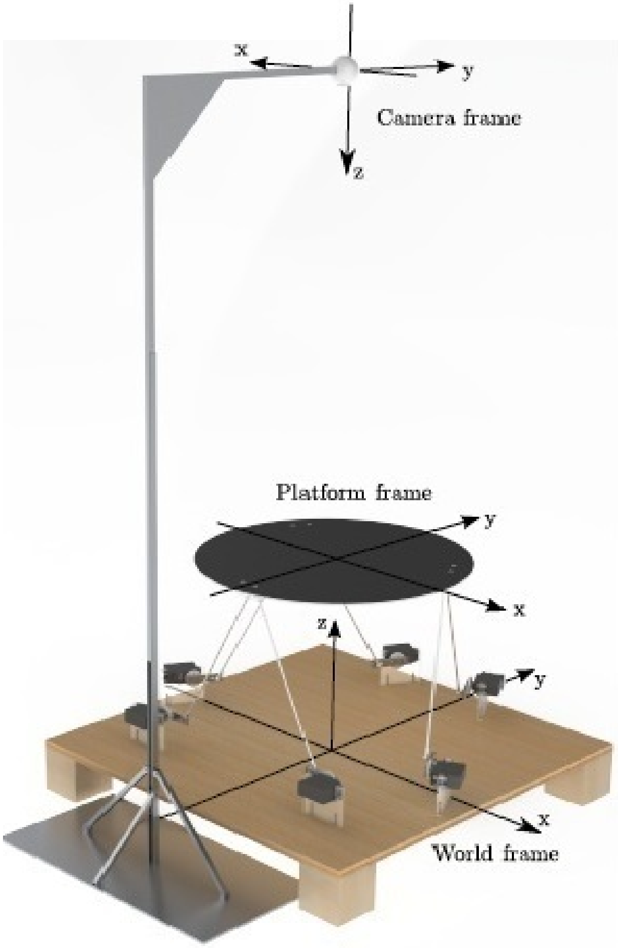
Fig. 2: A schematic overview of a software architecture on both client and server side.

B. Developed applications

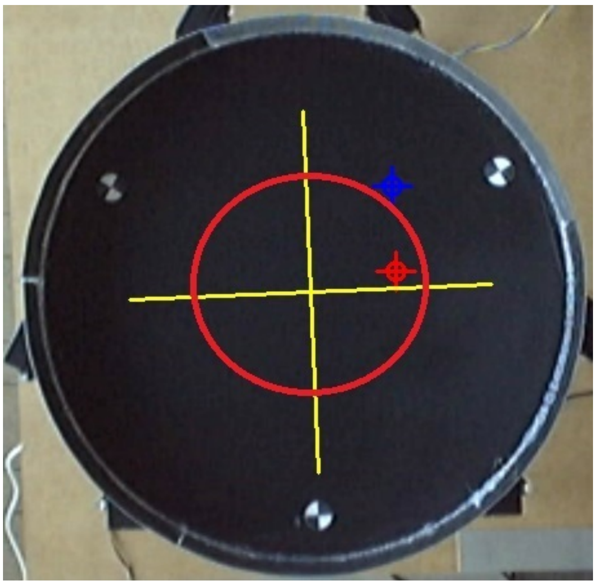
1) Ball and Plate system: The Ball and Plate system consists of a Stewart Platform with 6 degrees-of-freedom, driven by six servo motors, creating 6 possible motions: three linear movements (i.e. longitudinal, lateral and vertical) and three rotational movements (i.e. roll, pitch and jaw) [15]. The goal is to control the position of a ball on the plate by controlling the voltages sent to the servo motors. The second part of the Ball and Plate system is an overhead camera for the feedback in the control loop. Feedback in this system is based on image processing in combination with system like a Hawk Eye, which is used in tennis, to recognize the current position of the ball. The full plant setup can be seen in figure 3. The serial communication between the server and the Ball and Plate system is established by an interface developed in a C# environment.

The necessary software for the vision based feedback in this system was developed by [16]. Calibration of the camera is done by three markers placed on distinct positions on the plate. For feedback, the current position of the ball on the plate is necessary. To obtain this position, the image intercepted by the overhead camera is passed through an edge detection filter. Afterwards, the position of the ball can be calculated with the Hough transformation algorithm. The measured position is then compared with the reference position and the error between the two positions is used in the control algorithm.

One type of implemented controllers for this system are Proportional-Integral-Differential (PID) controllers which are usually used to control physical systems. The students can



(a) Stewart Platform



(b) View from overhead camera

Fig. 3: Full plant setup of the Ball and Plate System.

design a suitable controller for the system and implement this designed controller to the system. The theory of PID controller design is part of basic control course given to the bachelors, therefore this is a good application for bachelor students. Different reference trajectories can be implemented in the system. There are three predefined trajectories implemented in the Remote Lab (i.e. fixed point, circle and square), however, it is also possible to upload a user defined trajectory as a text file.

In the Ball and Plate system it is also possible to do identification of the system dynamics which is part of a master course. As the Ball and Plate system is an unstable system in open loop, identification is challenging, providing an example of advanced system identification. Also fractional-order PID controllers which are advanced controllers can be implemented, allowing the students to select the appropriate control strategy and control parameters.

The graphical user interface (GUI) for the Ball and Plate system is shown in figure 4.

2) Quadruple Water Tank system: The Quadruple Water Tank system consists of the combination of two ”Two Tank Modules” of Quanser to create a system with four tanks. The resulting system is a Multiple-Input-Multiple-Output (MIMO) system with two possible inputs (i.e. the voltages to pumps 1 and 2) and two possible outputs (i.e. the levels in tanks 2 and 4). The plant setup is shown in figure 5.

It can be seen that pump 1 is supplying water to both tank 2 and tank 3, but in different amounts. Similar, pump 2 supplies water to tanks 1 and 4. The resulting system is a non-minimum phase system. Depending on the water flow percentages of each input, the system can also be transformed to a minimum phase system, to have the possibility to show the students different examples.

Control of MIMO systems is a subject of the master course on control. The developed application of the Quadruple Water Tanks presents to the students a challenging problem where coupling between inputs and outputs is important. Each individual output of the system depends on both inputs (i.e. Tank 4 receives water from Pump 2 and from Pump 1 via Tank 3). The students can apply the theoretical concepts of relative gain array (RGA) and decoupling control to this challenging system.

In the Remote Lab application, the students can perform two tasks: identification and control design.

Identification of the system can be done by sending a text file with two columns: a PRBS signal and a constant signal. The first column is used as a reference signal for pump 1, while the second column is used for the second pump. From the measured output signals, the system can than be identified using the methods learned in the control course.

Control design for this system is very flexible. The student needs to give the numerator and denominator coefficients of the transfer function of the controller independent on the fact whether this is a PID controller or a more advanced controller such as Internal Model Control or Model-based Predictive Control.

The graphical user interface (GUI) for the Quadruple Water

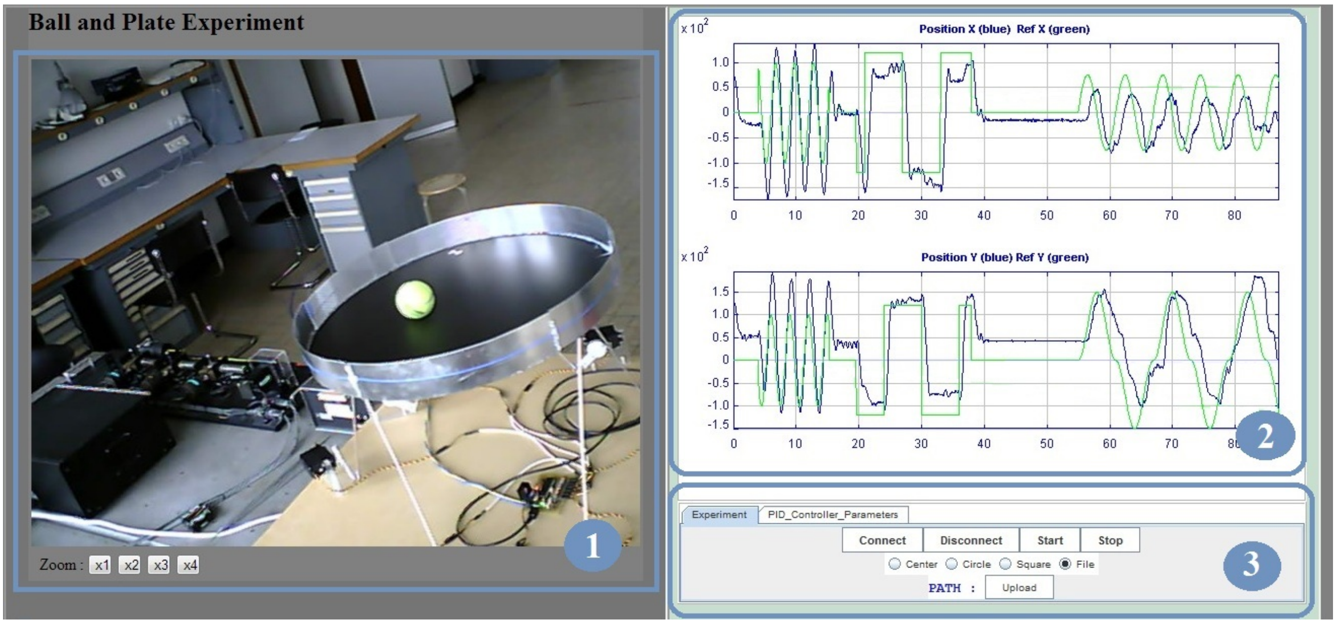


Fig. 4: Graphical user interface for the Ball and Plate system with a video panel (1), graph display panel (2) and two tabbed panels (3) for controlling the plant.

Tank system is shown in figure 6.

III. REMOTE LAB AS EDUCATIONAL TOOL

To be able to evaluate the developed Remote Lab as an educational tool, two types of exercises have been developed on both bachelor and master level. These exercises have been presented to a bench of 20 master students. After performing both exercises, the students had to fill in a survey in order to obtain an evaluation of the quality of the Remote Lab. In order to explain the operation of the Remote Lab, a User Manual was given to the students, which was also included in the evaluation.

Students could log into the system from home according to a time schedule, where a time period of 15 minutes was given for each student. Preparation of the exercises (e.g. tuning the controllers and calculating the control parameters) had to be done before hand.

A. Exercises

The exercise for *bachelor* students consisted in designing two PD controllers on the Ball and Plate system, one for the x-position and one for the y-position of the ball. The transfer function of the system is given to the students together with the design specifications of the controllers (i.e. maximum overshoot, minimum robustness and maximum settling time). The students had to implement their designed controllers to the system when the ball is following a circle and then plot the error between the reference position and the measured position of the ball.

The exercise for *master* students consisted in developing decentralized PID control for the Quadruple Water Tank system based on frequency response design tools i.e. FRTool [17]. The transfer function matrix of the system is already given and design specifications such as overshoot and settling time are provided. The students have to apply the designed controllers to the system and show in a plot the coupling effect and the result of using decentralized control.

B. Evaluation of the Remote Lab

Evaluation of the Remote Lab is obtained via a survey which uses a 5 point Likert-type scale (1 = very dissatisfied, 2 = dissatisfied, 3 = neutral, 4 = satisfied and 5 = very satisfied). The 23 questions in the survey were divided into four main sections: Interest for remote control of devices, Prerequirements and technical documentation, Application performance and GUI interactivity and Quality of education. A sample of 5 questions of the questionnaire is given in table I with the average scores underlined. Statistical results, i.e. mean values and standard deviation (SD), of the entire survey are shown in table II for each main section.

From the statistical results, we can see that we still have the possibility to improve the performance of the application and the technical documentation. We can conclude from the survey that there is a general interest for remote control of

TABLE I: Example questions from the questionnaire

How satisfied are you with …					
The accuracy and usability of the User Manual.	5	<u>4</u>	3	2	1
The time-response of the application.	5	<u>4</u>	3	2	1
The live streaming performances during the experiment.	5	<u>4</u>	3	2	1
Using a Remote Lab for practical experience.	5	<u>4</u>	3	2	1
The degree of freedom in the remote control of the camera.	5	4	<u>3</u>	2	1

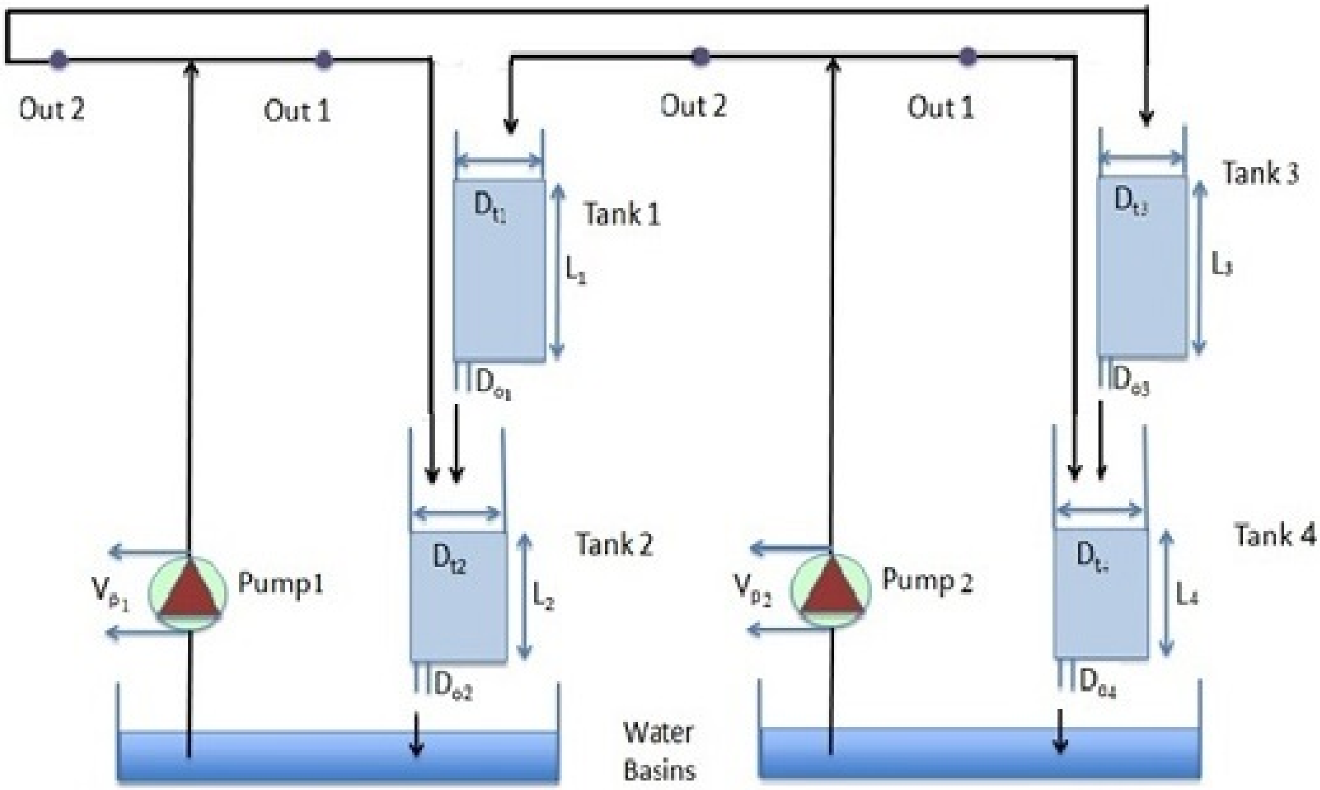


Fig. 5: Plant setup of the Quadruple Water Tank system.

TABLE II: Evaluation results

Main section	Mean	SD
Interest for remote control of devices	4,08	0,87
Prerequirements and technical documentation	3,74	0,97
Application performance and GUI interactivity	3,64	0,84
Quality of education	4,07	1,13

devices using a Remote Lab. The survey shows that the major points of improvement are the flexibility of the user interface to be compatible with different resolutions and the need for a user database simplifying the logging in process. The students gave good feedback for the quality of education, showing that Remote Labs can be a viable form of teaching new control concepts to students.

IV. CONCLUSIONS

The Remote Lab can be a useful tool in the education of control engineers as it gives the opportunity for practical experiments in an university environment where time and financial resources for practical applications become scarce. A first survey on a small bench of 20 master students showed that there is a big interest for these remote applications amongst the students. The survey showed that students show interest in the Remote Lab and accept it as a viable teaching tool in control engineering. It also showed that the performance of the applications and the technical documentation are points were improvements are still possible. This first evaluation of the developed Remote Lab, gives reason to extend it in the future. Therefore, we intend to give a more substantial survey to a larger group of students (both bachelor and master students) to have a better general view on the educational impact of the Remote Lab. Future work includes the development of an automatic scheduling in order to give each student a time slot as the system only works with one user at the time. Thus, a comparative study will be performed between students that use the Remote Lab and those who use only traditional learning techniques in order to evaluate the educational impact such as an increased interest in control engineering and impact on the student's grades.

REFERENCES

[1] Overstreet J. and Tzes A.,An internet-based realtime control engineering laboratory. *IEEE Control System Society*, 19(5):19-34, 1999.
[2] Luthon F., Petre A., Steriu D. and Besleaga A., Laborem: open lab for remote work. *3rd International Conference on Signals, Circuits and Systems (SCS)*, pages 1-6, 2009.
[3] Shyr W., Su T. and Lin C., Development of remote monitoring and a control system based on plc and webaccess for learning mechatronics. *International Journal of advanced robotics systems*, 10(97):1-7, 2013.
[4] Barrios A., Panche S., Duque M., Grisales V., Prieto F., Villa J., Chevrel P., and Canu M., A multiuser remote academic laboratory system. *Computers & Education*, 62:111-122, 2013.
[5] Ionescu C., Fabragas E., Cristescu S., Dormido S. and De Keyser R., A remote laboratory as an innovative educational tool for practicing control engineering concepts. *IEEE Trans. Educ.*, 436-442, 2013.

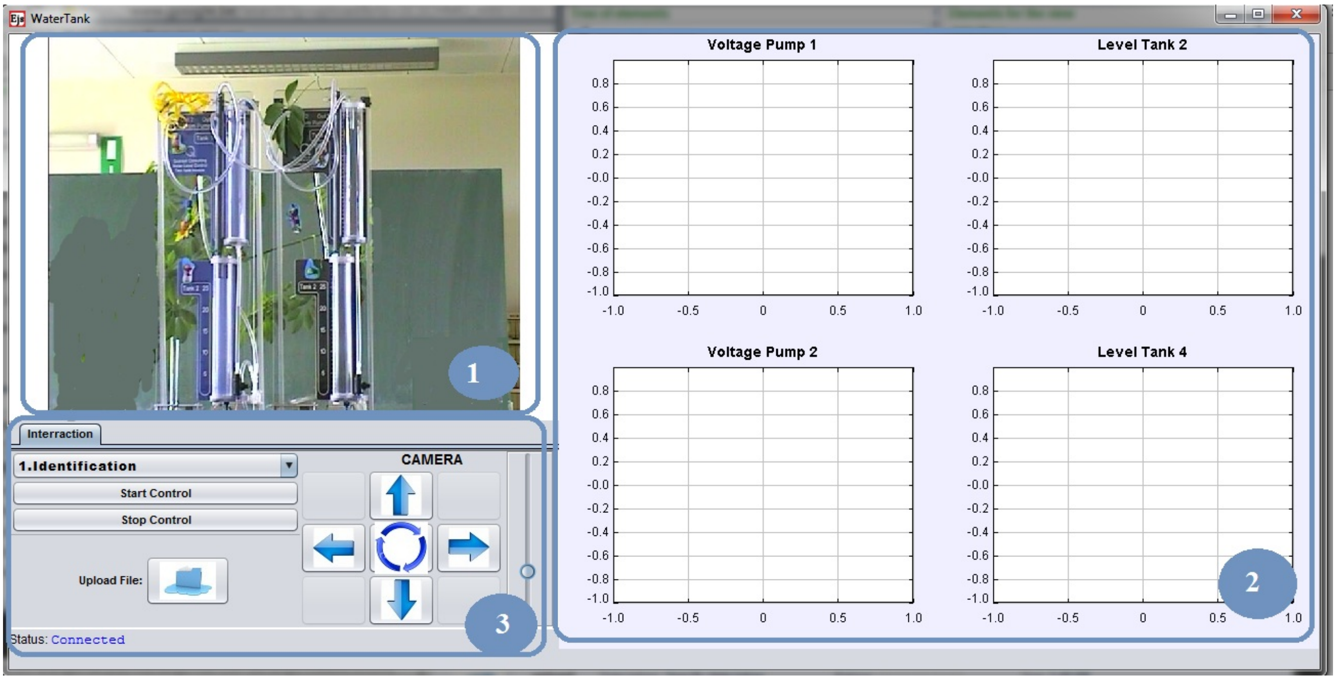


Fig. 6: Graphical user interface for the Quadruple Water Tank with a video panel (1), a graph display panel (2) and a panel for controlling the experiment (3).

[6] Baier A., Bernoulli T., Braun T., Graf C., and Ultes-Nitsche U., Case study of the usage of an authentication and autorization infrastructure (aai) in an e-learning project. *Proceedings of Information Security South Africa (ISSA)*, 2006.

[7] Acevedo P., Martínez J., Gonzáles M., and Valencia R., Cased-based reasoning and system identification for control engineering learning. *IEEE Trans. Educ.*, 51(2):274-281, 2008.

[8] Atanasijevic-Kunc M., Logar V., Karba R., Papiič M., and Kos A., Remote multivariable control design using a competition game. *IEEE Trans. Educ.*, 54(1):97-103, 2011.

[9] Ghent University, Number of newly registered students per faculty, http://www.ugent.be, Sept 2013.

[10] Dormido S., Control learning: present and future. *Annual reviews in Control*, 28(1):115-136, 2004.

[11] Farias G., De Keyser R., Dormido S., and Esquembre F., Developing networked control labs: a matlab and easy java simulations approach. *IEEE Transactions on Industrial Electronics*, 57(10):3266-3275, 2010.

[12] Graba J. *An Introduction to Network Programming with Java*. Springer Science, 2003.

[13] Hegedus A., Copot C., Chevalier A., Nascu I., and De Keyser R., Remote laboratory: a novel tool for control engineering laboratories. *17th International Conference on System Theory, Control and Computing*, 256-261, 2013.

[14] Neamtu D., Fabregas E., Wyns B., De Keyser R., Dormido S. and Ionescu C. (2011). A remote laboratory for mobile robots applications. *18th IFAC World Congress*, pages 7280-7285, 2011.

[15] Stewart D., A platform with six degrees of freedom. *Proceedings of the Institution of Mechanical Engineers*, 180(1):371-386, 1965.

[16] De Paepe M., A ball and plate system with a 6 dof motion platform and vision-based feedback. Ghent University, Master thesis, 2010-2011.

[17] De Keyser R. and Ionescu C. M., Frtool: A frequency response tool for cacsd in matlab. *IEEE International Symposium on Computer Aided Control Systems Design*, Munich, pages 2275-2280, 2006.