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INTERACTIVE PLATFORMS FOR VIRTUAL AND REMOTE EXPERIMENTATION: CONTROL AND ROBOTICS APPLICATIONS

Phd Thesis Abstract

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Department	Informática y Automática E.T.S. de Ingeniería Informática
Title	Interactive Platforms for Virtual and Remote Experimentation: Applications of Control and Robotics
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Summary

Introduction

Distance education is a mode of education in which students and teacher are not present in the same classroom. This method was already used a long time ago in United States in 1728. When teacher Caleb Phillips was trying to find interested people to send them the course: "*The Short Hand*" by correspondence weekely [1, 2]. This method was called correspondence education and was formalised in 1840 in Great Britain where professor Isaac Pitman taught shorthand by correspondence through the "*Phonografic Corresponding Society*" [3, 4]. From then until 1950 several universities decided to integrate the correspondence education in their programs. This period is known as the first generation of distance education.

After 1950, correspondence education began to be replaced for technological advances (radio, television and telephone communication). For example, in 1965 the University of Wisconsin taught courses based on telephone communication. In 1968 University of Stanford created an educational television network, and in 1969 the Open University of London started to broadcast signals radio and television to teach. The Open University of London inspired the creation of Spain's National University of Distance Education (UNED) in 1972 [5]. Since the 1990s, the networks communications and the Internet has had a revolutionary impact on the distance education. From this period, many universities have incorporated ICT into their teaching method in many disciplines.

In Control Engineering in particular, students need to acquire knowledge and skills of control systems modeling in order to develop and test experiments. This requirement represents a serious drawback for the distance learning process [6–8]. In this context, the experiments must be adapted to be operated through the Internet [9–11]. At the same time, the remote experiments can be complemented with a simulation of the process. This kind of applications are known as virtual and remote laboratories. A virtual laboratory simulates a model of the physical process, while a remote laboratory provides access to the real physical process over the Internet. Simulation is a very appropriate way of complementing control education, but, generally, it cannot replace experimentation with the real plants. A simulation is only as good as the model is, and a model is just an approximation which cannot reproduce every aspect of the process, such as, for instance, unexpected non-linearities. In a remote laboratory, students can gain access to the laboratory from a remote location that allows them to interact with real experiments. They can change control parameters, run experiments and observe the results. Furthermore, interactive experimentation on real-world plants is highly motivating for students and also develops an engineering approach to solve realistic problems.

In recent years, several research groups from different universities have implemented platforms to develop virtual and remote laboratories [11–13]. Some of these platforms combined very well known tools in Control Engineering (*MATLAB/Simulink* or *LabVIEW*). For example: *MeRLab* from the University of Leicester [14] and *Telelabs* from the University of Western Australia [15]. While the University of Chattanooga developed some simulations for study the dynamic of the systems combining *LabVIEW* with *MATLAB/Simulink* [16]. Another example is *Automatic Control Telelab (ACT)* from the University of Siena [17], which uses mobile robots to develop experiments with multi-agents systems. In Spain there are several research groups that are dedicated to development of these kind of tools. For example in the University of Almería, they developed a platform with LEGO robots to teach robotics [18, 19]. In the University of Alicante they developed the platform *RobUALab* [20, 21] for industrial robotics experiments.

Our institution, the Spanish National University of Distance Education (UNED) offers distance education courses on Automation Control for as many as 300 students every year. In our Department (DIA) several virtual and remote laboratories have been developed to support the distance learning process [22–25]. This laboratories have been joined to the platform *AutomatL@bs* [26], which is a network to share resources by 7 universities of Spain.

Objectives

The general objective of this research work is to design and to implement interactive platforms to develop virtual and remote experimentation in the context of Automatic Control and mobile robotics. To reach that, a virtual environment will be implemented. This environment is a simulation and a remote control of each process that allow to develop experiments in an interactive and easy way. The following are the specific objectives of this thesis:

- To implement and develop a virtual laboratory to perform automatic control experiments with the ball and hoop system.
- To implement and develop a control application to perform experiments with the ball and hoop prototype.
- To integrate in an experimental platform the virtual and remote laboratories with the ball and hoop system.
- To implement and develop a virtual laboratory to perform automatic control experiments with the ball and plate system.
- To integrate the virtual and remote laboratories with the ball and plate system in an interactive platform.
- To implement and develop a virtual laboratory to perform simulations of formation control of mobile robotics with obstacles avoidance.
- To implement and develop an experimental environment to perform experiments of formation control of mobile robotics with obstacles avoidance.
- To implement and integrate the virtual and remote laboratories with mobile robots in an interactive platform.

Structure of the Thesis

This work have been divided int two main parts: the first part consist in the presentation and description of the platform to perform laboratory practices of Control Engineering. While the second part deals with the details of the platform for the development of laboratory practices with mobile robots. The work is divided in the following chapters:

Chapter 1

This chapter describes a brief history of the distance education and its progressive implementation in the Control Engineering Education field. Also a brief history of the virtual and remote laboratories and the influence in the distance education learning process. Some current examples of virtual and remote experimentation at different universities are presented. The general and specific objectives are described and the structure of the thesis is detailed. Finally, the main contributions of this research work are presented (Journal and Conference Papers).

Chapter 2

This chapter describes the theoretical aspects of the systems used to build the automatic control platforms. Firstly the model and details of its dynamic are presented. Also the experiments that can be performed with this system are described (hoop position control, ball position control, zeros of transmission, nonminimum phase behavior and trajectories following). After that the identification process of the real plant is presented (parameters of the ball inside the hoop). Finally the parameters of the controller used in the control loop are calculated. In the case of the platform for mobile robots, firstly the technical details of the *Moway* and *Surveyor SRV-1* robots are presented. What follows are the details of its dynamic and position control. Also the experiments that can be performed (1.- Master-Slaves formation control with obstacles avoidance; 2.- Leader-Followers formation control). Finally the details of the identification process are presented.

Chapter 3

This chapter describes the details of the virtual and remote laboratories developed for the platforms. The description is based in an architecture (*client-server*) and includes all the analysis of the developed applications for all platforms. Special emphasis is placed on the communication through Internet using the TCP protocol and the wireless communications between the robots. In all cases the source code of the developed applications is described with detail. Finally, an analysis of the results is performed to evaluate and validate the behavior of the platforms.

Chapter 4

In this chapter the obtained results with all platforms are presented and discussed. Firstly the results with virtual application and the results with the remote applications. In all cases the results are based on the experiments that can be performed with each platform. Finally the practical aspects of each platform are discussed.

Chapter 5

In this chapter the general and specific conclusions are presented. Also the future works of this research and finally, the improvements that can be developed to these platforms.

Developed applications

The results of this doctoral thesis are four platforms to perform virtual and remote experiments in an interactive easy use environment. The main purposes are educational and have a great impact on control engineering education. The following platforms have been developed:

- Platform to perform experiments of automatic control: It consists of a fully functional powerful tool that provides a simulation of the systems as well as connection with a real plant that represents its control system through *Internet*.

- Platform for mobile robot experiments: It consists of a virtual and remote laboratory experiments available for formation control of mobile robots with obstacle avoidance and multi-agent systems.

To develop these platforms some software applications have been designed and implemented. These applications interact between them and with the hardware. The components of the platforms are the following:

- Interactive simulation of the ball and hoop system developed with *EJS*. This application is the client for this platform.
- Application to control the prototype of the ball and hoop system developed with *LabVIEW*. This application is the server in this platform.
- Interactive simulation (3D) of the ball and plate system developed in *EJS*. This application is the client for this platform.
- Communication interface between *Java* and *Visual C#* to communicate the client application with the prototype of the ball and plate system.
- Simulator for experimentation with mobile robots formation control. This application is the client of this platform.
- Application *Moway Server* to obtain and send the positions of the robots. This application is the server in this platform.
- Source code that runs inside of each mobile robot. These applications are part of the server in this platform.
- Communication interface between *Java* and *Visual C#* to communicate the simulator with the *Moway Server* application.
- Client application of the platform for the *Surveyor SRV-1* robots developed with *EJS*. This application is the client of this platform.

Publications

Journal Papers

- Fabregas E., Farias G., Dormido-Canto S., Dormido S., Esquembre F. "Developing a remote laboratory for engineering education", *Computers & Education*, vol. 57, no. 2, pp. 1686-1697, 2011, doi: 10.1016/j.compedu.2011.02.015, IF: 2.621.

- M. Guinaldo, G. Farias, E. Fabregas, J. Sánchez, S. Dormido-Canto, S. Dormido. "An Interactive Simulator for Networked Mobile Robots", *IEEE Network Special Issue*, vol. 26, no. 3, pp. 14-20, 2012, doi: 10.1109/MNET.2012.6201211, IF: 2.239.
- Clara M. Ionescu, Ernesto Fabregas, Stefana M. Cristescu, Sebastián Dormido, Robin De Keyser. "A Remote Laboratory as an Innovative Educational Tool for Practicing Control Engineering Concepts", *IEEE Transactions on Education*, vol. PP, no. 99, 2013, doi: 10.1109/TE.2013.2249516, IF: 1.021.
- E. Fabregas, G. Farias, S. Dormido-Canto, M. Guinaldo, J. Sánchez, S. Dormido. "Virtual and real laboratory for teaching mobile robotic", *IEEE Transactions on Industrial Electronics*, 2013, IF: 5.16. (Submitted)
- M. Guinaldo, E. Fabregas, G. Farias, S. Dormido-Canto, D. Chaos, J. Sánchez, S. Dormido. "Mobile robots experimental environment with event-based wireless communications". *Sensors - Open Access Journal*, 2013, IF: 1.739. (Submitted)

Conference Papers

- E. Fabregas, N. Duro, R. Dormido, S. Dormido-Canto, H. Vargas, S. Dormido. "Virtual and remote experimentation with the Ball and Hoop system". *14th International IEEE Conference on Emerging Technologies and Factory Automation.* IEEE Reference MD-003301. Palma de Mallorca. España. September, 2009.
- Daniel V. Neamtu, E. Fabregas, R. Hordea, R. De Keyser. "Remote Laboratory for Leader-Follower Formation Control". *Jornadas de Estudio IUAP/PAI DYSCO.* Ghent. Belgium. May, 2010.
- E. Fabregas, G. Farias, S. Dormido-Canto, S. Dormido, F. Esquembre. "A Practical demonstration of reset control with the ball and hoop system". *9th Portuguese Conference on Automatic Control.* Coimbra, Portugal, September, 2010.
- Daniel V. Neamtu, Ernesto Fabregas, Bart Wyns, Robin De Keyser, Sebastian Dormido, Clara M. Ionescu. "A Remote Laboratory for Mobile Robot Applications". *18th IFAC World Congress.* Milan. Italy, September, 2011.

Conclusions

Students need to acquire concepts and skills of control systems in Control Engineering learning process. Often, these concepts are acquired through experiments performed in a traditional laboratory room. This requirement represents a serious drawback for the distance education learning process. In this context virtual and remote laboratories an important alternative to eliminate this disadvantage. However, the transformation of traditional laboratories in remote laboratories is a complex task, due to the limitations of the communications. This thesis describe the implementation of four interactive platforms to carry out laboratory practices of automatic control and mobile robotics through *Internet*. These platforms are based in a client-server architecture with two operating modes: virtual and remote. The following applications and experiments have been implemented during the development of this thesis:

1. The platform of the ball and hoop system allows performing the following experiments: hoop position control, ball equilibrium point control, zeros of transmission, and nominimum phase behavior. The components of the platform are described as follows:

    - *Cliente BA-S* is an *EJS* interactive simulation of the ball and hoop system. This application can communicate via *Internet* with *Servidor BA-S* application developed in *MATLAB/Simulink*.
    - *Servidor BA-S* is an application developed with *MATLAB/Simulink* to control the prototype of the ball and hoop system through the data acquisition card *PCI-1711L* of *Advantech Corporation*.
    - Communication between these two application is established using the interface *JIM-Server*, developed in the Departamento de Informática y Automática of the UNED.

2. The platform of the ball and plate system allows performing the following experiments: position control of the ball, trajectories tracking (lineal, circular, square, *Lissajous*). The components of the platform are described as follows:

- *Cliente BP-C* is an *EJS* interactive simulation (3D) of the ball and plate system. This application can communicate via *Internet* with *Servidor BP-C* application developed in *Visual C#*.
- *JIC-Server* is an interface developed in *Java* and *Visual C#* to communicate application developed using these two programing languages. This interface is used to communicate *Cliente BP-C* with *Servidor BP-C* via *Internet* using the *TCP/IP* protocol.

3. The platform of *Moway* robots allows performing the following experiments: position control of a robot in a point, obstacles avoidance, Master-Slaves formation control of multi-agents systems. The components of the platform are described as follows:

   - *Cliente MW* is an interactive *EJS* application to simulate experiments with mobile robotics. This application can communicate via *Internet* with *Servidor MW* application using *JIC-Server* interface.
   - *Servidor MW* is an application developed with *Microsoft Visual C#* to send the positions of the camera to the robots.
   - Source code to control the positions of the robots. This programs runs on board in the robots.

4. The platform of the *Surveyor SRV-1* robots allows performing the following experiments: Leader-Followers formation control of mobile robots. The components of the platform are described as follows:

   - *Cliente SRV* is an *EJS* application to control the robots via *Internet* using the *TCP/IP* protocol. This application communicate with the application *Servidor SRV* using the interface *JIM-Server*.
   - *Servidor SRV* is an application that “translate” the commands received from *Cliente SRV* and send them to the robots.

Future Works

Improvements and suggestion can be implemented in the different platforms from the point of view of the operation and experiments. Some of these improvements are described as follows:

1. The improvements that can be implemented in the platform of the ball and hoop system are the following:
   - The implementation of another kind of control such as *Reset Control* [27]. This kind of control introduces a non-linearity to the system. This non-linearity allows to study the *Limit Cycles* phenomenon using the *Descriptive Function* [28] and *Poincaré Maps* [29, 30].
   - To use another methods to obtain the controller parameters, for example *Genetic Algorithms* and *Fuzzy Logic* [31].
   - To implement the augmented reality for this platform.
2. In the case of the platform of the ball and plate system the improvements that can be implemented are the following:
   - In the application *Cliente BP-C* the simulation can be implemented using *Java 3D*. With this improvement the application can result more interesting for the student from the visual point of view.
   - The performance of the application *Servidor BP-C* can be improved to reduce the delay of the communication via *Internet*. From the source code point of view this may include the use of threats, timers, etc...
3. In the case of the platform of the *Moway* mobile robots, the improvements that can be implemented are the following:
   - The size of the data packet in the wireless communication with the robots can be improved. Because this is a very strong limitation of this robots. Maybe using another kind of wireless communication such as *WIFI*, the size of the data packet can be bigger than the data packet of the *RF* communication.

- To eliminate the acknowledgment (ACK) in wireless communication of the robots. With the default ACK the data traffic is affected.
- To add another camera on the celling of the laboratory to do bigger the working area (arena) of the robots. This can allow another kind of formation experiments that need more space.

4. In the case of the platform of the *Surveyor SRV-1* mobile robots, the improvements that can be implemented are the following:

   - The main limitation in this platform is that robots can not communicate between them with the current firmware. If this limitation could be eliminated, another formation control experiments could be performed.
   - These robots allow other hardware components, for example *GPS*. With this different components, another kind of experiments may be carried out to attracting the interest of the students.

In general for all platforms the controller could be implemented in the client side to study the effects of the network delay in the control loop. Another interesting topic that could be added to the platforms is the implementation of the event based control communication to improve the data traffic of the platforms.

Bibliography

[1] R. W. Battenberg. The Boston Gazette. *Epistolodidaktika*, no. 1, pp. 44–45, 1971.

[2] B. L. Bower and K. P. Hardy. From correspondence to cyberspace: Changes and challenges in distance education. *New Directions for Community Colleges*, no. 128, pp. 5–12, 2004.

[3] J. M. Suárez and D. Anaya Nieto. Educación a distancia y presencial: diferencias en los componentes cognitivo y motivacional de estudiantes universitarios. *Revista Iberoamericana de Educación a Distancia*, vol. 7, pp. 65–75, 2004.

[4] J. E. Padula. Una introducción a la Educación a Distancia. *Fondo de Cultura Económica*, 2003.

[5] Universidad Nacional de Educación a Distancia (UNED). Nuestra historia, 2012. URL: `http://portal.uned.es/portal/page?_pageid=93,499271,93_20500119&_dad=portal&_schema=PORTAL`.

[6] B. S. Heck. Special report: Future directions in control education. *IEEE Control System Magazine*, vol. 19, no. 5, pp. 35–58, 1999.

[7] S. Dormido. Control learning present and future. *IFAC Annual Reviews in Control*, vol. 28, pp. 115–136, 2005.

[8] I. Calvo, E. Zulueta, U. Gangoiti, and J. M. López. Laboratorios remotos y virtuales en enseñanzas técnicas y científicas. *IKASTORRATZA. e-Revista de Didáctica*,

no. 3, 2009. URL: http://www.ehu.es/ikastorratza/3_alea/laboratorios.pdf.

[9] D. Gillet, G. Fakas, Y. Rekik, K. Zeramdini, F. Geoffroy, and S. Ursulet. The Cockpit. An Effective Metaphor for Remote Experimentation in Engineering Education. *International Journal of Engineering Education*, vol. 19, no. 3, pp. 389–397, 2003.

[10] R. Dormido, H. Vargas, N. Duro, J. Sánchez, S. Dormido-Canto, G. Farias, F. Esquembre, and S. Dormido. Development of a web-based control laboratory for automation technicians: The three-tank system. *IEEE Transaction on Education*, vol. 51, no. 1, pp. 35–44, 2008.

[11] J. Andújar and T. Mateo. Diseño de laboratorios virtuales y/o remotos. Un caso práctico. *Revista Iberoamericana de Automática e Informática Industrial*, vol. 7, no. 1, pp. 64–72, 2012.

[12] J. L. Guzmán, H. Vargas, J. Sánchez, M. Berenguel, S. Dormido, and F. Rodríguez. Education Research in Engineering Studies: Interactivity, Virtual and Remote Labs. *Distance Educations Research Trends*, 2007.

[13] N. Aliane. Limitaciones Pedagógicas de los Laboratorios Remotos de Control. In *XXIX Jornadas de Automática CEA-IFAC*, 2008.

[14] M. Pipan, T. Arh, and B. J. Blazic. Advanced evocational Education of Mechatronic Professions. *Journal of Education and Information Technologies*, vol. 3, no. 1, pp. 12–19, 2009.

[15] S. Rae. Using telerobotics for remote kinematics laboratories, 2004.

[16] J. Henry and R. Zollars. Experiments and Local Simulations: Student Experiences, Satisfaction and Suggestions. In *Annual Meeting of American Society for Engineering Education*, 2003.

[17] M. Casini, A. Garulli, A. Giannitrapani, and A. Vicino. A MATLAB-based remote lab for Multi-Robot Experiments. In 8^{th} *IFAC Symposium on Advances in Control Education*, 2009.

[18] F. Torres, F. A. Candelas, S. T. Puente, J. Pomares, P. Gil, and F. G. Ortiz. Experiences with Virtual Environment and Remote Laboratory for Teaching and Learning Robotics at the University of Alicante. *International Journal of Engineering Education. Special Issue on Robotics Education*, vol. 22, no. 6, 2006.

[19] F. J. Martínez, R. González, F. Rodríguez, and J. L. Guzmán. Laboratorio Virtual y Remoto para la Enseñanza de Robotica Paralela. *CEA Jornadas de Enseñanza de la Ingeniería de Sistemas y Automática*, 2010. URL: `http://www.ual.es/personal/rgonzalez/papers/eiwisa.pdf`.

[20] C. A. Jara, F. A. Candelas, and F. Torres. Laboratorios Virtuales y Remotos para la enseñanza de Robótica Industrial. In *XXVIII Jornadas de Automática*, 2007.

[21] C. A. Jara, F. A. Candelas, and F. Torres. Robolab.ejs: a new tool for robotics e-learning. In *Remote Engineering and Virtual Instrumentation (REV 2008)*, 2008.

[22] S. Dormido, S. Dormido-Canto, R. Dormido, J. Sánchez, and N. Duro. The Role of Interactivity in Control Learning. *International Journal of Engineering Education*, vol. 21, no. 6, pp. 1122–1133, 2005.

[23] H. Vargas, R. Dormido, N. Duro, and S. Dormido-Canto. Creación de laboratorios virtuales y remotos usando Easy Java Simulations y LabVIEW: El sistema heatflow como un caso de estudio. In *XXVII Jornadas de Automática*, pp. 1182–1188, 2006.

[24] S. Dormido, H. Vargas, J. Sánchez, R. Dormido, N. Duro, S. Dormido-Canto, and F. Morilla. Developing and Implementing Virtual and Remote Labs for Control Education: The UNED pilot experience. *17th IFAC World Congress*, pp. 8159–8164, 2008.

[25] N. Duro, R. Dormido, H. Vargas, S. Dormido-Canto, J. Sánchez, G. Farias, F. Esquembre, and S. Dormido. An Integrated Virtual and Remote Control Lab: The Three-Tank System as a Case Study. *Computing in Science & Engineering*, vol. 10, pp. 50–59, 2008. ISSN 1521-9615.

[26] Universidad Nacional de Educación a Distancia (UNED). Automatl@bs Red de Laboratorios de Automática, 2012. URL: http://lab.dia.uned.es/automatlab/.

[27] J. C. Clegg. A nonlinear integrator for servomechanisms. *Transaction of the American Institute of Electrical Engineers*, vol. 77, pp. 41–42, 1958.

[28] O. Beker, C. V. Hollot, and Y. Chait. Forced oscillations in reset control systems. *Proceedings of the 39th IEEE Conference on Decision and Control*, pp. 41–42, 2000.

[29] S. Seydel. *Practical Bifurcation and Stability Analysis.* Springer, third edition, 1994. ISBN 978-1-4419-1739-3.

[30] J. M. Gonçalves. *Constructive Global Analysis of Hybrid Systems.* PhD thesis, Massachusetts Institute of Technology, Cambridge, MA, 2000.

[31] I. Griffin. On-line PID Controller Tuning using Genetic Algorithms. Master's thesis, Dublin City University, Dublín, 9 Ireland, Aug. 2003.