

Active learning in control education

Perfecto Reguera¹, Juan José Fuertes¹, Manuel Domínguez¹, and Bernardo A. León de la Barra²

Abstract— The continuing development of the Information and Communication Technologies (ICT) is bringing about deep changes in the way we work and live, as the widespread application of ICT is accompanied by organizational, commercial, social and legal innovations. These changes have made new tools available for education and training. In particular, Internet Based Education has been growing continuously and several teaching applications make remote connections to physical systems over the net. This paper illustrates how undergraduate students have implemented a remote motor position control. Some of the teaching and learning benefits of such an experience are also identified.

I. INTRODUCTION

THE huge expansion experienced by the Information and Communication Technologies has determined a strong growth of the Internet as a medium for transmission and diffusion of information. This expansion has evolved from a unidirectional transmission of information, i.e., users/clients only receive information, to a bi-directional exchange of information between users/clients and physical systems. This type of development has determined that different tasks including supervision, maintenance, and systems/processes' operation have started to use the Internet as a physical and logical support layer to implement their actions. This has opened new research areas such as remote supervision and robot's programming and tele-operation via the Internet [1]-[2].

The field of teaching and learning deserves special attention. For many years now there have been technological platforms which have enabled the sharing of remote devices over the Internet therefore allowing distant participation in hands-on sessions using real equipment located at geographically dispersed locations. This sort of experimentation environment is called remote laboratory,

Manuscript received March 2, 2005. This work was supported in part by the AAC-IAF-León-Spain and Consejería de Educación de la Junta de Castilla y León (Agencia de Calidad) under Grant ULP-01/04.

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telelaboratory, or on-line laboratory [4]-[7], [16]-[18].

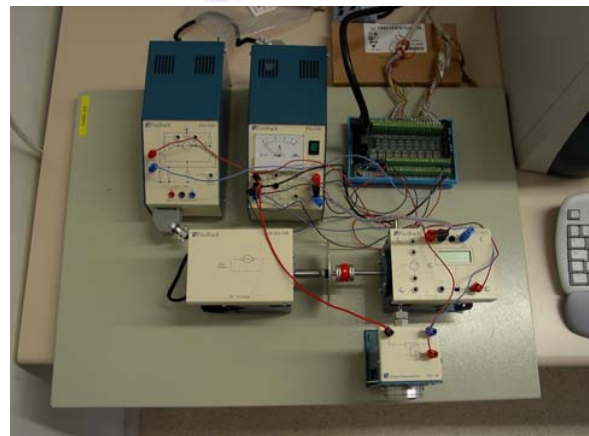
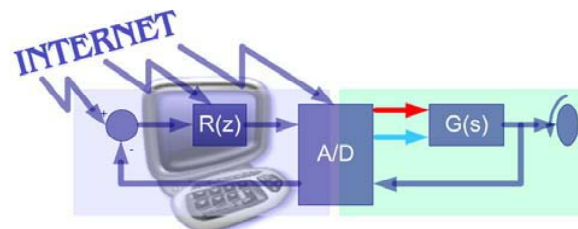


Figure 1. Remotely operated motor position control system.

A number of social, political, economic and cultural changes have taken place in Europe in the last few years determining that the higher education sector is also in a period of great transformation. There are several important EU agreements that seek to implement a European Higher Education Area (EHEA) by 2010 [15]. These agreements show a resolute will to promote a Europe of knowledge. The main ideas in these agreements can be summarised as follows:

1) Students are the central element in any education process. This means that educators should focus on developing and implementing student centred teaching and learning models as opposed to the more traditional instructor centred models.

2) Education influences the cultural, economic, business, intellectual and technical dimensions of a society and because of this, education must be adapted to suit the requirements demanded by a society of knowledge.

Education will help to achieve a dynamic and competitive European economy, and this economy will be based on knowledge.

3) Higher education must be substantially improved to address challenges linked to the need for innovation in the methods of generation and transmission of knowledge.

4) Global information networks should influence the way higher education institutions provide education opportunities. Universities' essential nature and objectives should be reinforced by the use of ICT. These technologies will actively encourage knowledge "mobility" providing a thrust to European cooperation.

5) Lifelong learning opportunities should be easily available to all members of the society.

6) Students are the professionals of the future and, because of this education, must be reformed using input from key stakeholders.

This paper argues that Internet-based remote laboratories used in undergraduate control teaching may contribute to address some of the challenges outlined above. It is also argued that this type of laboratory also contributes to active learning. Note that "learning by doing" [19] has been previously identified as one of the seven principles of good practice in education [8]-[9]:

1) *Contact between students and faculty*: this should be a two-way communication process between student and instructor.

2) *Reciprocity and cooperation among students*: good learning is a collaborative and social effort, not a competitive and isolated one [9]-[10].

3) *Active learning*: students must take ownership for what they learn. In general, we remember only 20 [%] of what we hear, and 90 [%] of what we say and do ourselves [11]. It is in this area where remote laboratories may contribute to students' learning by doing.

4) *Prompt feedback*: students have to recognise what they know and don't know in order to focus on their learning. Students need ways of regularly knowing their current performance and level of knowledge.

5) *Time on task*: students need help in learning effective time management techniques.

6) *High expectations*: teachers have to expect the best from students. This idea becomes a self-fulfilling prophecy when teachers and institutions hold high expectations for themselves and make extra efforts to support students reach their full potential.

7) *Respecting diverse talents and learning styles*: students need opportunities to show their talents and learn in ways that work for them; this means that it is necessary to offer different ways: collaborative learning and work, self-evaluation, remote hands-on sessions, simulations, etc.

II. REMOTE LABORATORY STRUCTURE

Using remote laboratories to encourage students' active learning has at least two potential benefits: what the students learn when they use the laboratories and, if possible, what the students learn when they actually build the laboratories themselves. In other words, being able to build a remote laboratory may increase students' interest in the subject. The remote laboratory may become a platform through which students with basic knowledge of programming strengthen and integrate their theoretical knowledge with practical skills. In these circumstances, active student learning intensifies enormously.

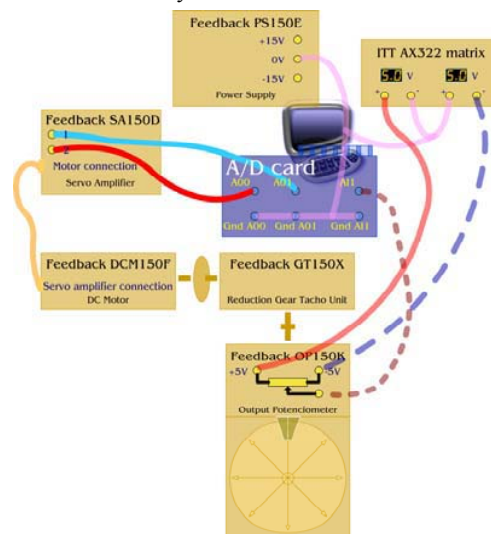


Figure 2. Connection layout for the motor position control system.

Using the Internet Server Application Programming Interface (ISAPI) architecture we developed a motor position control scheme which could be remotely operated. This module is part of a larger initiative which is described elsewhere [12]. The actual system is a Feedback MS150 servo unit connected to a PC using an Advantech 1711 A/D card. Figures 1 and 2 provide further details on the system.

To allow the connection over the Internet, without security or traffic problems, a common structure based on a three-tier or three-layer model is used, i.e., there are client, intermediate, and server layers, respectively. Clients are always Java applets, the server layer is the union of the physical system, the A/D card and the PC running the control program. The intermediate layer is a Windows service using an ISAPI interface [12]-[14]. Figure 3 illustrates the three layers and their interconnections.

The ISAPI interface is a Microsoft's programming interface between applications and their Internet server. ISAPI is used for the same sort of functions as Common Gateway Interface (CGI) but uses Microsoft Windows dynamic link libraries (DLL) for greater efficiency.

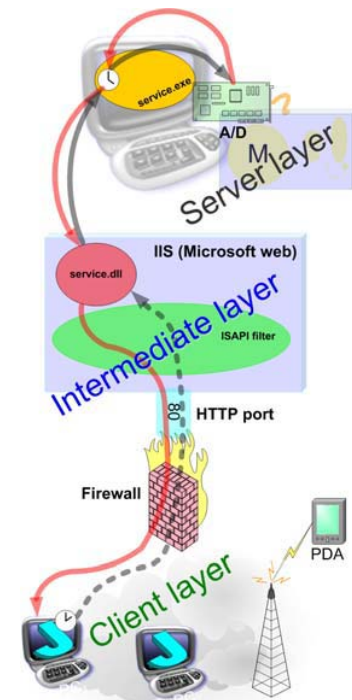


Figure 3. ISAPI structure.

The server loads the DLL the first time a request is received and the DLL then stays in memory, ready to service other requests until the server decides it is no longer needed. This minimizes the overhead associated with executing such applications many times. This means remote users are able to run external programs using a world wide web Hyper Text Transfer Protocol (HTTP).

An HTTP server can unload ISAPI application DLLs to free memory or preload them to speed up the first access. Thus, DLLs are faster than CGIs, as they don't need to create a new process to run the external program. Applications can also be enhanced by ISAPI filters.

The ISAPI structure is a robust, simple and easy maintenance solution, because only two software components are needed: a web server and a DLL application. Non-desktop PC clients like PDAs (Personal Digital Assistants) or Handheld PCs are also accepted. If this structure is used, these latter clients only need a web browser and don't need Java virtual machine. Note also that it is possible to build a specific DLL to answer to this type of clients. Windows for Pocket PC needs commercial software to run Java programs, so the ISAPI option solves this problem. This means that both Java and non-Java clients are supported with no changes in the structure.

A. Important features

The operation of the proposed structure is based on a service program which runs on a PC. This program, called

service.exe, consists of two threads that are executed independently: one thread is dedicated to reading the output channels of the A/D card and the other thread is dedicated to writing to the input channels of the card. This program is indispensable for two fundamental reasons:

1) The server which executes the Internet Information Server (IIS: intermediate layer), Web server, is located in a "demilitarised zone" (DMZ), with access to the outside world while the PC is within the corporate virtual private network (VPN). Note that the network administrators don't allow connection requests originated in the outside world (IIS). In fact, the PC itself is the one which initiates the transmission of data to the IIS. The program service.exe is dedicated to establish output connections with the Web server, to send the values read on the card, and to determine if writing requests exist on the Web server for the card.

2) The program service.exe enables us to separate the A/D card hardware from the software since it includes the DLL's of the card currently in use. If the A/D card was to be replaced, it would be enough to rebuild the program including the DLL's of the new card.

The server executing the IIS has one port open to the Internet, i.e., the HTTP port. This port is used to receive reading and writing requests from the clients. As this server cannot make input connections to the corporate VPN, external attacks will not compromise network security.

The structure proposed here is a natural evolution of earlier structures [14] and is one that doesn't create problems to corporate VPN administrators. In other words, if a remote laboratory is to be operated within a corporate VPN, it is necessary to consider the proposed structure or others that don't allow input connections from the outside world.

III. STUDENTS' WORK

The students of the Computer Science degree at the University of León have programming skills. This is why remote laboratories allow us to encourage active learning in our students in two different ways, namely, through the use of a remote laboratory to conduct web-based control engineering experiments, and through group work efforts to connect a physical system to the Internet on which they will later conduct further experiments. The latter approach is always very attractive to them, and this is why they show a lot of interest and dedication to this sort of tasks. In addition, the depth of knowledge that they reach in areas like regulation, programming languages, concurrent programming, network applications, Web servers and database managers makes this a "success story". We want our students to grow and develop to meet the needs of the modern workplace. This is why all of the subjects in our curriculum are highly integrated, with a number of them focusing on the connection of the physical world to the

virtual world.

Preliminary work conducted at the University of León, during the period October 2004–February 2005, was considered very positive by the students and has achieved the connection of a Feedback MS150 system to the Internet. We initially worked with a group of fifteen students. We presented our students with three different options when it came to the actual laboratory work. They could choose to work in traditional instructor-guided individual practical sessions, in 2-3 student group work sessions, or they could go for a more ambitious project whose main goal was the Internet sharing of a Feedback MS150 system with the subsequent execution of two remote experiments on it. The decision was to be taken by the students on the basis of the advantages and disadvantages of each option. The instructors were not going to decide for them. Once the students had made up their mind (they usually chose the last option because of the challenges that it involved), students would stick to their decision primarily because they had gone through an active thought process to reach their decision. This means that they took an active role in their own learning right from the start, deciding what they wanted to learn. The instructor’s job was to serve as a guide so that they achieved some minimum requirements. The instructor also motivated them to reach their full potential.

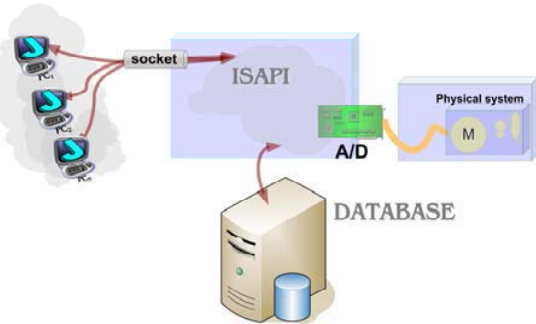


Figure 4. Target structure.

Due to the number of students involved, three sub-projects were identified and allocated to different groups of students. These sub-projects were (see Figure 4): “clients” (allocated to three people), “access to the physical system” (allocated to seven people), and “database” (allocated to five people), respectively. The students could also choose the group they wished to belong to, where a minimum of three people were needed to make up a group. The job of the instructor was then to tailor the specific requirements that students were expected to meet to the actual number of students in each group and to their previous technical knowledge.

The client layer takes care of the graphical representation of the data, together with the collection of real-time video data of the operation of the physical system. Note that the video data are served by a TCP/IP SNC-RZ30P web-cam

and students must use the DLLs provided by the manufacturer. The ISAPI layer makes sure that the physical system can be shared over the Internet, incorporates different types of regulators in a position control problem, and offers remote configuration services of the A/D card. The database layer is the one which safeguards the experiments’ data, sends e-mail messages with these data, makes backups, and offers remote services for graphical representation of the data.

A. ISAPI-Layer

This layer has been built with a DLL and the following services have been implemented (Figure 5):

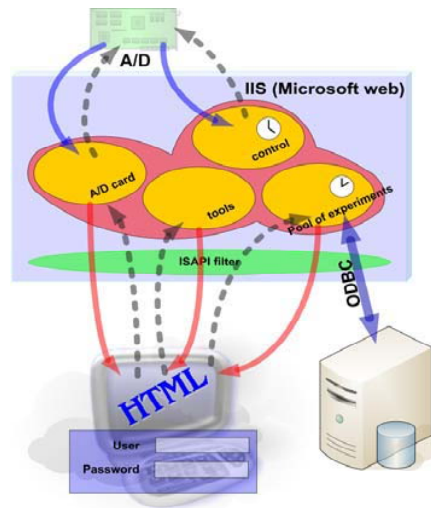


Figure 5. ISAPI-layer structure.

1) *Queue of experiments manager*: this manager executes the experiments in the order determined by the queue. A user’s request of the execution of an experiment always prevails over the queue although a user who wishes to connect to the physical system will not be able to do so until the currently active experiment is finished. The queue of experiments is stored in the database, and there is a dedicated thread to manage it. Registered users can issue requests to this manager using a Web interface. The manager will answer with HTML pages showing how many experiments are waiting on the queue and if there is an experiment running.

2) *A/D card manager*: this manager handles Web-based requests on the status of the card. It will answer with HTML pages showing the status of each input channel for both analog and digital inputs. The manager can also write to the output channels, making it possible to set the output channels to any convenient value. This option is very handy when an instructor wishes to simulate specific disturbances (see Figure 6).

3) *Physical system control manager*: this manager

executes a particular controller when specified. This controller is the one that implements real time control of the physical system, i.e., the one that reads variables and “writes” control actions on to the A/D card channels using the proprietary DLL’s. As the controller is defined via a difference equation, it is possible to implement many types of controllers. There is a dedicated thread to manage it.

4) *Testing and configuration tools*: it is a set of functions that make it possible to change some parameters of the A/D card, e.g., the sampling time, the span of the channels, etc. It is also possible to monitor the controller status as reflected in the control output, the error signal, or in internal values of the control algorithm, among many other possibilities.

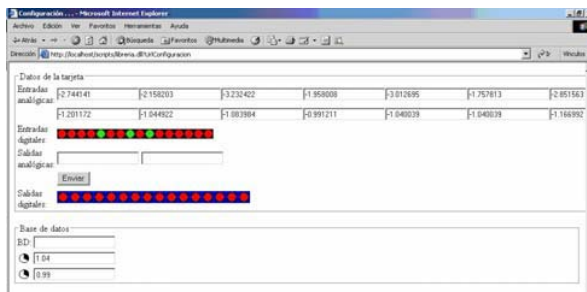


Figure 6. A/D status interface.

The testing and configuration tools are very important to verify the right operation of the DLL built by the students. In particular, they can observe how the sampling time influences CPU’s usage or how it may affect the closed-loop stability of the physical system.

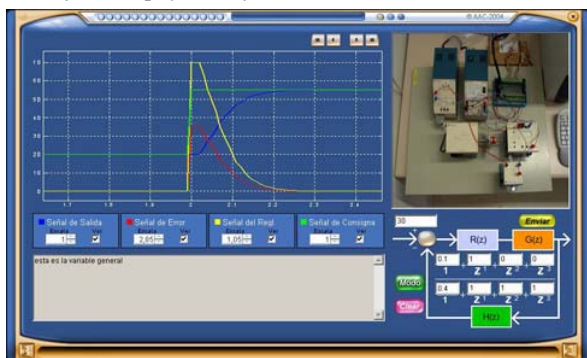


Figure 7. Student’s interface.

B. Client-Layer

This layer is implemented in Java [15] and provides the following services (Figure 7):

1) *Line charts*: they plot real data of the physical system in real time.

2) *A small SCADA system*: it monitors the status of the physical system and students are allowed to operate on specific elements, namely, they can change set-points, they can change the controller and observe, in real time, the impact of these changes.

3) *Online video*: the physical system operation can be observed in real time. The users have control to focus the camera on specific sensors or actuators, and to zoom in/out on a target object. Note that only one user can act on the physical system at any given time.

4) *Information area*: the information displayed in this area provides a text description of the status of sensors and actuators (e.g., when a user acts on any of them this is reported in this area), alarm messages, events, etc. Students can use this zone to download experimental data when the experiment has finalised.

5) *Active regions*: there are several buttons (“balls”) at the top of the user interface. When a user clicks on one of these buttons, a set of online slides becomes available. The slides include a number of topics that may assist the students in completing their experiments (see Figure 8).

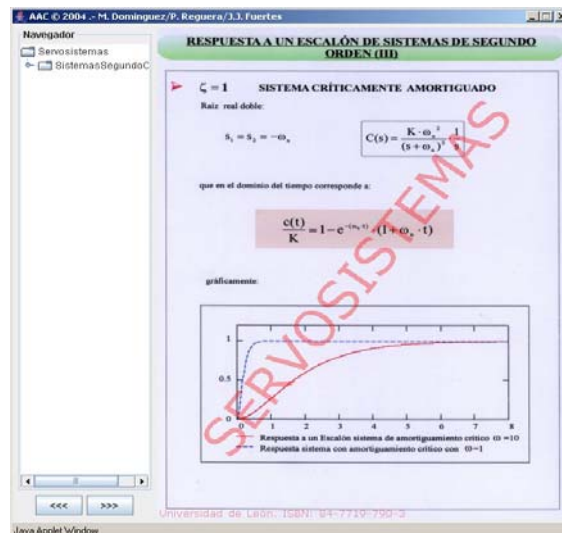


Figure 8. Online documentation.

C. Database-Layer

This layer is really the heart of the multi-user access capabilities. The following services are implemented:

1) *Data warehouse* for the experiments’ data. These data sets are sent by email once the experiments are finished.

2) *Backup management*.

3) *Data initialization*: sampling time of the A/D card, refresh time in the user interfaces, number of simultaneous clients, client using the physical system, etc.

4) A set of ASP pages, only for authorised users, allows the remote management of the system and the graphical representation of data stored in the database.

IV. CONCLUSION

The ISAPI structure is very simple and students with basic programming skills can build it. Laboratory experiments in which students build this sort of structure are

considered more challenging and stimulating than more traditional control laboratory setups. Web-based experiments are visual, didactic, and contribute to teacher-student communication. They also encourage cooperative learning and motivate students because “seeing is believing” and “doing is understanding”.

From an educational point of view it is very useful that the instructor can have full control of the laboratory conditions offered to students. In particular, remote access to a physical resource adds a valuable dimension to the learning process. Instructors can easily enrich their classroom sessions with Web-based demonstrations which remotely access a real physical system. They can illustrate key control engineering aspects, e.g., the effect of the sampling period on the control loop or on data acquisition properties, how the controller gain affects the overshoot or the steady-state error, etc. These features are not simulation-based, and this fact facilitates students’ learning.

The proposed structure is open, modular and flexible in the sense that the same philosophy can be applied to any physical system, the only thing we would have to change is the way we connect to the physical system’s proprietary DLL. The operation is very stable and is not affected by the number of simultaneous users. This fact is mainly due to the simplicity of the structure and the seamless integration of the software tools and the operating system.

A user friendly interface is available where students can watch real time video, plot line charts of the evolution of key variables, have access to the status of the system’s sensors, and act on actuators. Through the same interface they get simple textual information about what is happening in the system and they can access online teaching material to help them with their experiments.

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