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Remote Fuzzy Control of a DC Motor

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Abstract: This paper presents a simple and economical approach for the development of a fuzzy control remote laboratory using Matlab. The objective of the laboratory is to offer students and professionals a valuable tool for improving their fuzzy design abilities, and to test the performance of fuzzy controllers in a real DC motor. Advantages in regular educational process are related to an increase in time and space flexibility in the use of limited resources. For the industry, the advantages on using this approach are related to a decrease in the costs of industrial operators training in new techniques.

1. INTRODUCTION

Fuzzy controllers can be considered for controlling those processes whose mathematical model does not exist or it is very difficult to calculate ((Zadeh, 1965), (Zadeh, 1973)). Another advantage of fuzzy controllers is that they can be easily tuned by users which are not experts in control theory (Wang, 1997). These controllers can include heuristics and common sense rules that are easily understood by the experts on the application of interest but not on control theory; this fact partially explains the success of this control approach (Bonivento *et al.*, 1998) in different areas as, for example, the applications in power electronics and motor drives (Special Section, 2007).

Therefore, it would be worthwhile to develop a practical focused course on Fuzzy Control for non specialist but needing control for their work or research. A valuable option is to use Information Technology (IT) resources in this educational process (Poindexter and Heck, 1999) because it leads to an increase in time and space flexibility. Distance education takes more advantage of the new technologies than standard education, but when the latter makes appropriate use of IT as an effective learning support resource then “blended learning” appears, and it seems to be the future educational trend ((Bersin, 2003), (Valiathan, 2002), (Smith, 2001), (Troha, 2002)). The extended use of these resources has been possible provided the increasing number of computers at home connected to Internet, and it could decrease the actual teaching hours at University in undergraduate programs ((Overstreet and Tzes, 1999), (Kapila and Tzes, 2003), (Shor and Bhandari 1998)).

Nowadays, relation between Internet and Process Control is far from an experimental phase but in a mature state (Gomes and Bogosyan, 2007), providing practical applications at those companies that offers online courses (ISA Training Institute, 2003), (Siemens Energy & Automation, 2003). Internet-based learning is also interesting for companies in which employees training plays a role (Badersten and Avasjö, 1997), (SAE International, 2003). Far from educational applications, remote industrial process monitoring and control through the Internet provide different advantages (i.e., optimization of infrastructures performance, preventive maintenance managing, decrease personnel costs, etc.) and it also represents a step ahead for tele-working (López, 1999), (Crossan and Burton,. 1993), (Norman, 1993) in the area. Some relevant applications can be found in medicine (Katsura *et al.*, 2007), chemical plants (Cushing, 2000) or robotics ((Rösch *et al.*, 2002), (Luo and Chen,. 2000), (Marin *et al.*, 2005), (Birk and Kenn, 2002), (Safaric *et al,*.2001)).

Two different operating options are available for remote labs: batch and on-line. On-line operation considers control algorithms at the remote computer, the control actions and sensors being the information transmitted through Internet. The reference and parameters can be changed while the experiment is being carried out, but variable delays appear as a consequence of Internet traffic. Batch operation avoids Internet delays because the reference and controller parameters are sent to the server before the experiment starts and, once finished, the process output is sent to the remote computer. In this case, it is needed to add some interaction to the system to show the dynamic evolution of the controlled plant. It can de done with a camera, a scope that shows the time evolution of the process variables (usually decimation and packing of the sample data should be used to reduce traffic overload) or both. Nevertheless, in addition to current Internet delays ((Yang *et al.*,2003), (Sala *et al.*, 2006)), complexity and expensiveness usually arise when trying to implement plant remote control. Some insight in the solution of these problems is given in this work, especially for those institutions where Matlab is the standard tool. The proposed solutions complement Matlab for remote control and aims to two premises: simple (for server provider) and economical (for remote user).

After outlining configuration needs for virtual (simulated) and remote (real) Matlab-based process control approaches, this paper presents in section 3 a remote laboratory on DC-motor fuzzy control. Section 4 introduces the set-up of this laboratory in the framework of a control repository.

2. MATLAB-BASED CONFIGURATION FOR REMOTE PROCESS CONTROL

Based on Internet, two different options can be found for setting up laboratories in learning environments: virtual laboratories and remote laboratories. A virtual laboratory allows, for example, continuous access to a simulated process in a computer. Under this structure, a remote interaction between the student/operator and the virtual laboratory is possible.

Halfway between traditional and virtual laboratories are the remote laboratories that offer a real experiment to remote users. The incorporation of Webcams allows observing the evolution of real systems in addition to variables of interest. Most of the equipment needed for setting up a virtual/remote laboratory is available in traditional laboratories. The only additional element required is an interface between the local application and the Web server.

A complete "Systems Engineering and Control Web-based Laboratory" will include different components (organized as guided steps for a student and in an increasing order of complexity): theoretical laboratory works where design techniques are explained (based on virtual laboratories), process simulation frameworks to test user control developed abilities (also based on virtual laboratories), and remote industrial process control where tests on real systems can be observed (based on remote laboratories).

If Matlab is used as a control design tool, then Matlab Web Server (MWS) is a very powerful and very straightforward tool that helps to develop virtual laboratories (Valera *et al.*, 2005), (Valera *et al.**b***, 2005). Other alternatives could be to use the Matlab Builder for Java or .NET tools [ref]; through Matlab COM automation interface [ref]; use common gateway interface (CGI) or other methods and tools that allows to connect the Matlab kernel machine to a web server, like JMatlink or EasyJava (Sanchez *et al.*, 2004). In brief, the developer must design a web page to allow the user to introduce the experiment parameters (controller type, controller parameters, reference signal, sample time, etc.), send this data to the Matlab application (a set of m-functions must perform the experiment) and return the results to the user using another web page or applet.

When MWS is used, direct remote process control is not possible if this software is used alone. Then MWS must be complemented with some software functions (as those presented in this work). This section shows simple and economical approaches for hardware and software configuration requirements in remote simulation and real processes control using Internet platforms and MWS.

2.1 Matlab Web Server Configuration

Matlab Web Server is a integrated software that enables Matlab programmers to create applications that use the capabilities of the World Wide Web to send data to Matlab for computation and to display the results in a Web browser. A set of programs enables remote Web access to Matlab applications (The MathWorks Inc., 2003). For an extensive explanation of the main features of MWS and commands used in the development of basic applications see (Vallés *et al.*, 2001), where the configuration for authors' equipment is explained and examples of virtual/remote laboratories are presented. Required file structure and interaction between applications is shown in Figure 1.

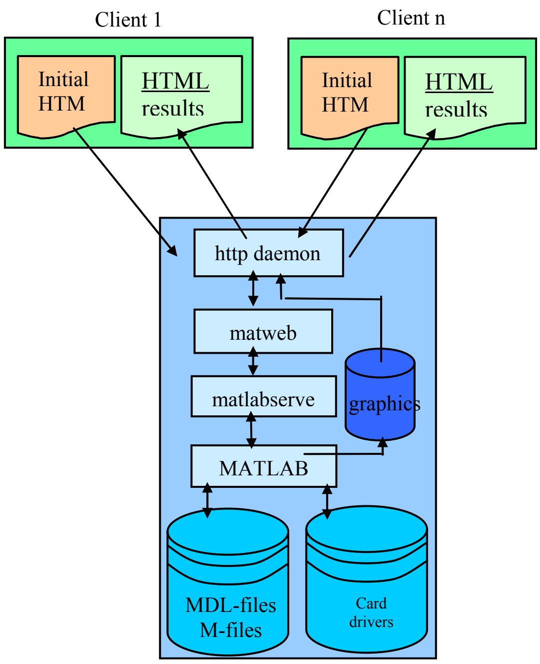


Fig. 1. Remote laboratory file structure. Three files are needed for executing Matlab applications through the Internet: an HTML file for data submission to Matlab, a M-file for processing data input and calculate results, and a HTML output document to return results to the user.

However, MWS does not allow on-line access to the low level hardware. Therefore, to allow remote laboratories and remote control of real systems using MWS, an additional configuration with several data acquisition cards has to be used and a set of routines have been programmed to access these cards from the Matlab environment and the web server..

The routines that have been programmed to access these cards from the Matlab environment allow A/D conversion, D/A conversion, Encoder signal management, Digital input/output access and timer programming. All these functions have been programmed using C++ language. The Matlab executable functions are obtained as DLL files with the mex command, using Visual C++ v6.0 compiler.

Also, a set of Matlab functions have been developed to manage the acquisition card, to implement the controller, to perform the experiment, and to show the results using the MWS services. Figure 2 outlines the data flows between the different modules developed:

- Scheduler: it manages the execution of the controller. Every sample time, that it is signalled by a timer, it captures the input data via the card interface, then it calls to the control algorithm function to obtain the control action that is sent to the D/A converter. Finally, all the data of the experiment is collected and returned.

- Control algorithm: It implements the code of the controller. In this case, code for a fuzzy controller and PID controller has been written in Matlab.
- Experiment setup: In this function the experiment is defined. The reference signal, sampling time, controller type and parameters are fixed. It captures the information that comes from the web page controls, then calls the scheduler, collects the experiment data and it constructs the output web page showing the results

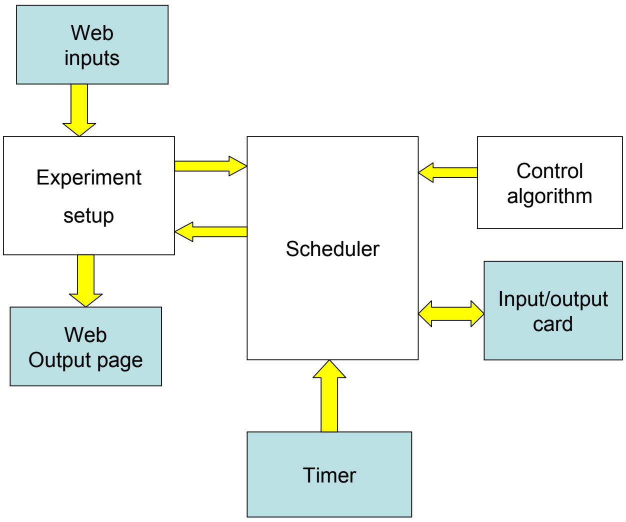


Fig. 2. Controller structure (each box represents an m-file).

With this approach only it is needed to change the experiment m-file and create the html pages for capture the experiment parameters and to show the results. Also, new controllers algorithms can be easily added writing their code as a m-function. This methodology was used to develop a fuzzy controller for a DC motor as it is explained in the next section.

3. REMOTE LABORATORY: A FUZZY DC MOTOR CONTROL

In this work, a batch laboratory based on MWS (and complementary functions) has been implemented because the operation of the lab will be held over internet and on-line operation will produce large and uncertain delays. In this way, any user having a PC connected to Internet and a Web browser can control an industrial process in batch, and no Matlab version is required on the remote user computer (see (Valera *et al.*, 2005), (Valera *et al.****b***, 2005), (Vallés *et al.*, 2001) for details). Additionally, a webcam has been included. This camera allows observing the evolution of real systems.

In spite of some other physical process that have been used and tested (Valera *et al.*, 2004), this work will present examples based on a DC motor. Any other industrial system can be used if the system signals (control actions and process outputs) are available, provided the Advantech™ industrial data acquisition cards PCI-1720 and PCI-1711 used.

DC Motor allows users remotely control the position and the velocity. For the control implementation, some HTML files for data transmission have been programmed to specify all M-file variables and a submit input for transferring data to the program. In this case, the initial Web page submits to Matlab reference values, controller parameters and experiment time. A hyperlink to broadcasting images of the experiment has been added to the main page.

Four different controllers have been implemented in this remote laboratory: a proportional Fuzzy controller, a proportional and derivative Fuzzy controller, a proportional and integral Fuzzy controller and a discrete PID controller. This controller is used as a benchmark controller: first, the students develop the discrete PID controller and then they try to design a fuzzy controller that outperforms its response. This is not for comparison purposes between discrete linear and fuzzy controllers, but it is for introducing a challenge in the design of the controllers.

Fuzzy controllers have a lot of parameters to be adjusted and the users must be trained for an adequate design of these controllers. For those interested in detailed description on fuzzy control advantages, disadvantages and design there exist a huge number of good text books (see, for example, ((Bonivento *et al.*, 1998), (Special Section, 2007)).

In order to help in training fuzzy controller designers, a remote laboratory has been developed focused on this target, and it is going to be shown in the following. In the exposed approach, the user can choose between a fuzzy P, PD or PI controller for the regulation of a DC motor axe position. In the figures 3, 4, and 5 the control loop scheme for each of the used controllers is presented.

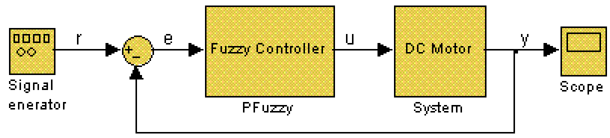


Fig. 3. Fuzzy P Controller Loop.

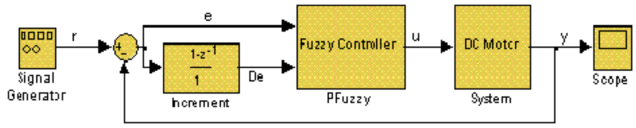


Fig. 4. PD Fuzzy Controller Loop.

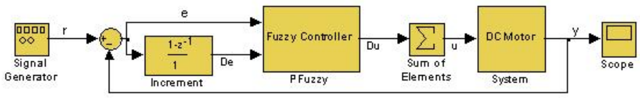


Fig. 5. PI Fuzzy Controller Loop.

It has been used a Mamdani model for the fuzzy controller without normalizing gains in the inputs and output (the input and output domains can be changed). The controller parameters that a designer must chose are:

- Domain of input/output variables
- Number of fuzzy sets for input and output variables
- Linguistic terms for every fuzzy set

- Membership function shape (triangular, trapezoidal ...)
- Membership function parameters: determine the position of every fuzzy set in the domain
- Rule base: Define how to connect the input to the output fuzzy sets and so determine the controller behaviour.
- Functions for fuzzy AND, aggregation and implication operations

It has been shown that the membership function type and fuzzy operators are not determinant in the overall controller behaviour (Bonivento *et al.*, 1998). Therefore, for simplicity purposes, some selections have already been done in the remote lab and could not be changed by users:

- triangular membership functions for input and output variables,
- min functions: for AND and implication operation, and
- max functions: for aggregation function.

Following the same simplification philosophy, some parameters of the fuzzy sets are fixed:

- number and name of fuzzy sets for input and output variables (NB: negative big; N: negative; Z: zero; P: positive; PB: positive big)
- a completely overlap between adjacent membership functions has been used in the input space; in this way only one point for each function is needed (the vertex of the triangular mf),
- the same area is assigned to each fuzzy set in the output space, and then only the centre of the membership functions must be defined by the user.

Additionally to these points, the user must edit and set the remaining fuzzy sets parameters: domain and rules (see figures 6 to 8). Furthermore, other common parameters related to experiments, fuzzy or not, must be selected:

- Input signal. The user can choose between: a step, a sawtooth or a sine signal. The amplitude and frequency are internally fixed.
- Sampling time. The sampling time for the controller execution must be chosen.

3.1 Experiment setup

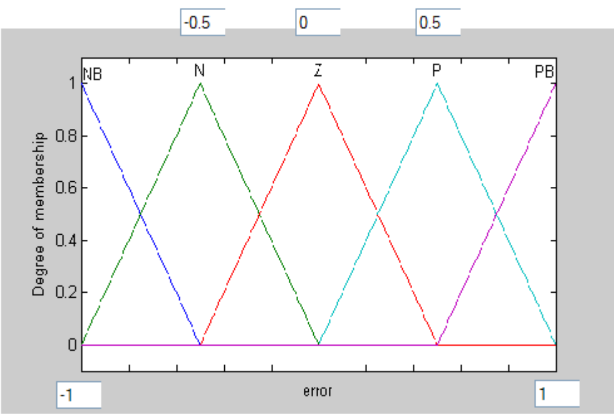


Fig. 6. Input space parameters page.

For every controller type, a web page has been developed to capture the experiment data. The user introduces the controller parameters in text or list controls, depending on the parameter data type. When all it is done, the user presses a button to perform the experiment and all the data is sent to the web server. Figures 6-8 shows how the student can introduce the membership functions parameters and the rule base.

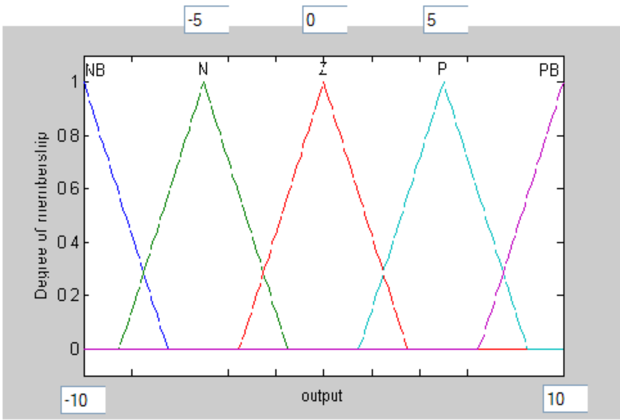


Fig. 7. Output space parameters page.

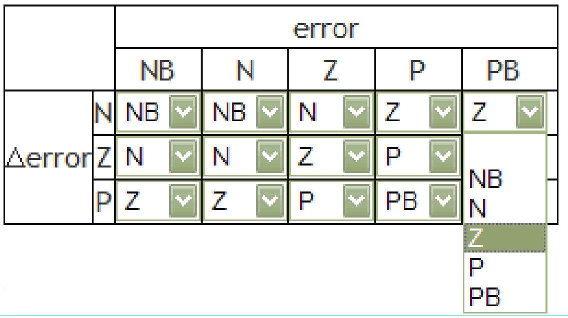


Fig. 8. Rule base editor for a fuzzy PD controller.

3.2 Output results

Two scopes with the reference/output and control signals have been included in the output page (see figures 9 and 10). Also, for the user evaluation of the controller performance, some classic indexes have been included (see figure 11): overshoot, steady state error, IAE, ISE, and settling time.

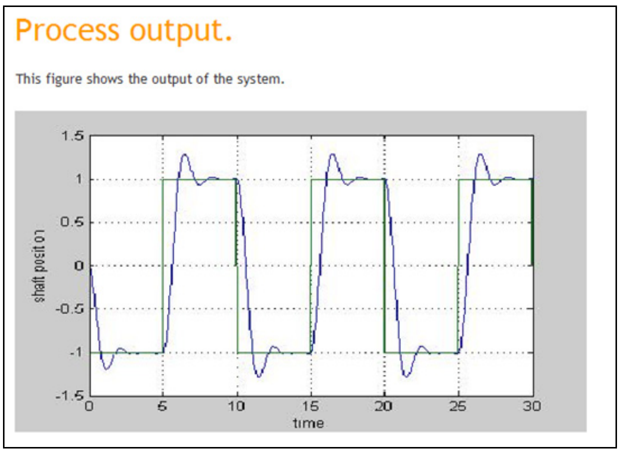


Fig. 9. Scope with the motor velocity and reference signals.

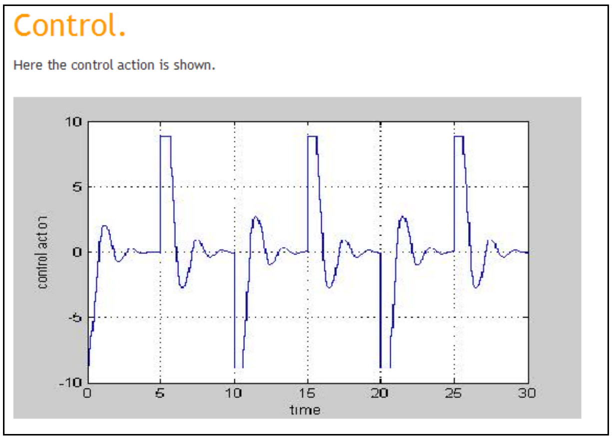


Fig. 10. Scope with the controller output.

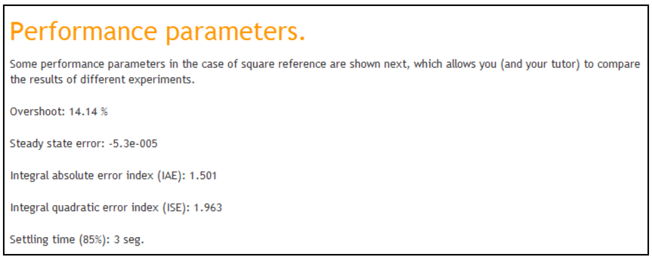
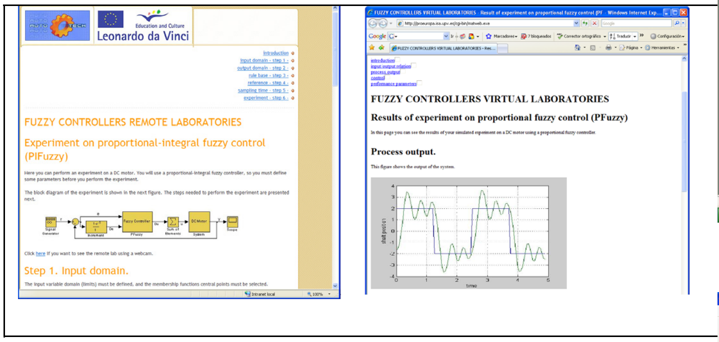


Fig. 11. Performance parameters response page.



a. Input page.

b. Output page.

Fig. 12. DC-motor Remote Process Batch control.

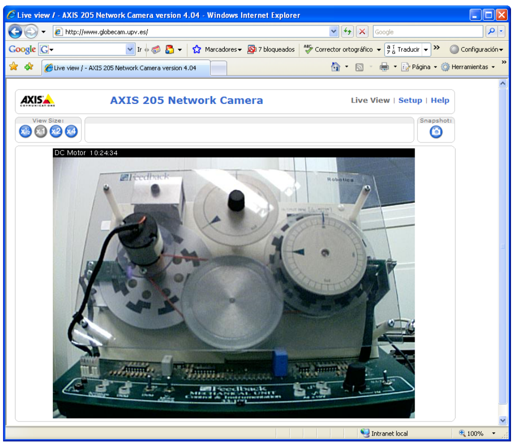


Fig. 13. When visualisation of the experiment is chosen, a new Web page is open and real-time images of the system are visualised.

In addition to previous performance parameters, the user can compare the performance of the fuzzy controller to a discrete PID controller as it has been mentioned above. In the case of the PID controller, the users must specify the control gain, the derivative and integration time constants. Figure 12 shows the input and output HTML pages for one of these controllers, and figure 13 the camera view that displays the real time performance of the experiment.

4. USERS' FRAMEWORK: A REPOSITORY ON CONTROL RESOURCES.

The remote labs presented in the previous section are only a few part of all the innovative material that is being developed in the framework of the AutoTech Project (figure 14). It is a Pilot project funded under the Leonardo da Vinci programme of the European Commission under contract N/04/B/PP 165.011 AutoTech. The project has 9 partners, coming from Norway, Spain, Germany and Romania. In addition, there is one "silent partner" from Switzerland. AutoTech was a 2-year project scheduled ended February 28, 2007 ((Vallés *et al.*, 2001), (Autotech Project webpage)).

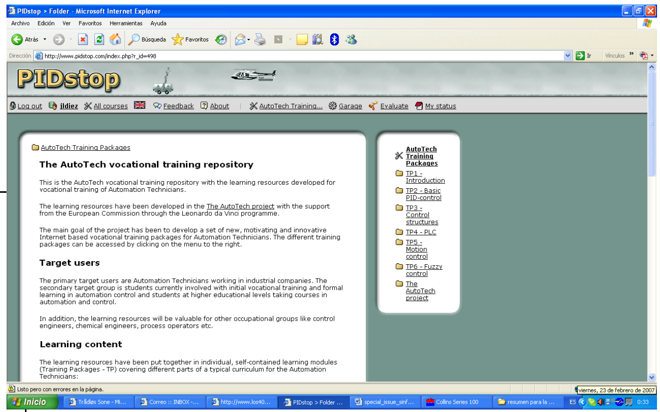


Fig. 14. Autotech project main page.

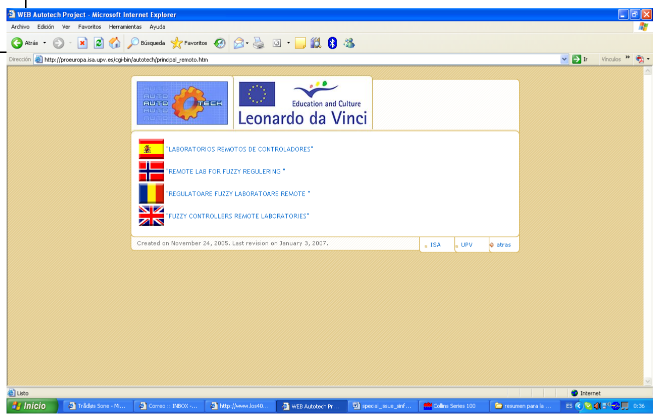


Fig. 15. Main page for fuzzy remote laboratories on the Autotech framework.

The main goal of the project was to develop a set of new, motivating and innovative Internet based training packages mainly for Automation Technicians, but also useful for students currently involved with initial vocational training and formal learning (e.g. at vocational upper secondary schools), or students at higher educational levels taking introduction courses in automation and control. In addition, the learning resources will valuable for other occupational groups like control engineers, chemical engineers, process operators, etc. The materials developed include:

- on-line interactive remote experimentation on real physical laboratory equipment for level, temperature, neutralization and pressure and position (DC and stepper motors, mobile robots) control and for the control of a railway based on PLC.
- motivating and industrial relevant learning material including innovative and motivating interactive dynamic simulators, games and competitions,
- a flexible web-based training repository in order to facilitate the access to the learning material.

Figure 15 shows the multilingual access to the fuzzy control remote laboratories in the framework of the Autotech project. From students' point of view, they need a login and a password for having access to the experiments and to be able to answer to the questions. If the use of a remote laboratory is required, the student has to book a slot of time for the experiment in order to avoid simultaneous access to it.

The final outcome of the project was 5 fully operational training packages covering important aspects of automation technicians work tasks and training needs. The work presented here corresponds to the laboratory part of Training Package 6 "Introduction to Fuzzy Control". All these learning resources have been tested and evaluated by external and independent users. In the particular case of the remote labs presented here, the evaluators were: vocational students and teachers in a vocational school (Vocational School "Juan Comenuis", Valencia, Spain), university students and university teachers (Technical University "Federico Santa María", Chile), and experts on engineers long-life learning (Industrial Engineers Association of Valencia, Spain).

After two initial "tuning" evaluations done by teachers and experts in spring and fall 2006 (only devoted to detect technical problems), the final evaluation (in which students also participated) was performed in spring 2007. The amount of information collected in this evaluation was huge (questionnaires to students, interviews with teachers and experts, reports, etc.) and can not be reproduced here, but main findings are summarised next.

In general, users found the simulations and remote laboratories very useful and more motivating than traditional exercises. From experts' point of view, the use of technology in Vocational Education had clear advantages in the learning process, because IT resources really improved the understanding of complex concepts and the learning process was much faster. Then, the topics can be explained in (around) half time than in regular lectures and there was more time for describing additional topics, explaining some parts in more detail, doing more exercises, etc. The experiments answer pages were found very well suited for testing the effect on the performance of the changes in design parameters. It was especially relevant for students the use of plots to understand the remote data gathering.

However, some drawbacks were also reported. In the case of industrial training, the Training Package was well suited for the learning objective, but the use of fuzzy in the industry is very limited. In the educational case, the level was high for Vocational Training, and it can be used for demo purposes only. However, the course seemed to be adequate at introductory courses on engineering degrees, and especially as an introduction to the matter for Master students. Regarding the possible mismatch between the level of the proposed courses and the expected level from external users, it was a likely comment given that the syllabus followed does not match any real course but it was, more or less, a list of common contents in the Vocational Training courses for all partners (and countries) involved in the project.

Therefore, the main conclusion on the reported evaluation about whether remote laboratories applied in Vocational Education will be worthwhile or not is that this combination works. This kind of material can be used in continuous education and training, and for handicapped (or not) students in regular university courses. The overall quality reported by users was "good quality" (scored 5, from 1(worst) to 6(best)), and another confirmation of the good experience is that the suggestions usually were: to have more material like this, and to export the technology to other areas in order to share more equipment between students or researchers.

5. CONCLUSIONS

Virtual and remote laboratories provide an innovative experimental tool allowing control lecturers: to optimize laboratory resources (for instance, sharing plants or software), to develop innovative classroom material (making use of advanced pedagogical methodologies), or to reinforce students' knowledge in a time-space flexible framework.

This paper has presented an approach for developing virtual and remote laboratories about fuzzy control, based on commercial technologies (Matlab by Mathworks). The objective of the laboratory is to offer students and professionals a valuable tool for improving their fuzzy design abilities, and to test the performance of fuzzy controllers in a real DC motor. Its integration in a repository on control resources has also been presented. In this way, joining the resources developed by different universities at different countries can offer a set of training packages, covering important aspects of automation and control, for being used by many students not physically at the same place.

The proposed approach provides straightforward methodologies for the developer of the teaching material (control lecturer) and low-cost for the user (student).

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