FROM TELE-LABORATORY TO E-LEARNING IN AUTOMATION CURRICULA AT THE UNIVERSITY OF PISA

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Abstract: The design and development of computational infrastructures supporting existing tele-laboratory experiences in the field of automation and robotics are described. The goal of the activity is to provide a proper e-learning environment in which remote laboratory experiences are integrated in a coherent way. The addition of e-learning features, as self-assessment and progress monitoring tools, asynchronous tutor interaction, authentication, evaluation and follow-up features, has led also to the modification of the original tele-laboratory set-up.

Keywords: Education, Educational aids, Laboratory education,.

1. INTRODUCTION

Experiences with web-based, remotely accessible, laboratory in the robotics and automation courses for mechanical and electrical engineers at the University of Pisa dates back from the late '90s (Bicchi et al, 2001). The development of these tools has been originally driven by the student demographic pressure and the increasing budget limitations in infrastructure spending. In order to guarantee to the students some basic laboratory experience, experimental set-ups, remotely accessible through the internet via a web browser, have been made available (Bicchi et al., 2004). A similar path has been followed independently by many other groups worldwide, as for instance (Casini et al., 2003; Bonivento et al., 2002; Delgado et al., 2004), just to name a few recent experiences. More recently, these tele-laboratory experiences have started to be integrated into environments for web-based remote learning - see for instance (Leleve et al., 2003). The requirements of an e-learning environment pose additional constraints on the tele-laboratories setting, that may ultimately lead to substantial modification of the experimental set-up itself (Balestrino et al., 2004). In this paper we describe the current evolution of the automatic control tele-labs at the University of Pisa toward e-learning objects. This effort is part of a nationally funded project that has the final goal of developing a nation-wide distributed e-learning environment in the field of robotics and automation. (Valenti et al., 2002) The project teams together italian institutions with previous tele-laboratory experiences, so that each original experimental set-up may evolve into a single instructional unit of a common educational project.

The paper is organized as follows: in the next section the common system requirements of the new e-learning environment are reported. In section 3 the re-implementation of the system architecture, designed to meet the needs of the e-learning environment, is described. The newly implemented learning tools are described in section 4, and the steps for the evaluation of the overall learning projects are reported in section 5. Finally some conclusions are given.

2. SYSTEM REQUIREMENTS

The original tele-laboratory set-ups available at the University of Pisa consisted in a magnetic levitator and in a 5-degrees of freedom robotic manipulator. The levitator has to become the experimental part of a learning unit focused on control of open-loop unstable linear plants, and directed to students in basic automation courses. The manipulator has been selected as part of a learning unit devoted to robot motion planning, for students of more specialized automation and robotic courses. In both cases there are some general requirements that the learning environment has to satisfy. We report here those that have greater impact on the modification of the original tele-laboratory system:

- identification of a clear experimental goal, on which the student will be evaluated at the end of the training period;
- presence of self-assessment tools coherent with the experimental goal;
- traceability of the student, i.e., possibility for the student and for the instructor to review the history of the student experimental activities during the training period. A corollary of this requirement is the need of authentication tools, and of a controlled access;
- definition of interacting tools between the instructor and the students;
- definition of a software management structure to allow the access of students, instructors and system administrators at the proper priority level;
- implementation of a procedure for learning object evaluation;
- immersivity of the experimental experience, through the availability of sensorial (visual, tactile, audio, …) feedback to the student in perceived real time.

We would like to underline an interesting, and sometime overlooked aspect of the evolution of the tele-laboratory into an e-learning unit, i.e., in order to fullfill e-learning environment requirements, some of the appealing aspects of the original design may be lost. In particular, the need of authentication prevents free access to the experiment: only authorized users may access the e-learning environment.

3. SYSTEM ARCHITECTURE

From a student user point of view, there should be no major difference in accessing the e-learning environment from a Java-supporting web browser with respect to the previous access to the laboratory system. However, while the modality has to be perceived as the same, the actions offered to the student include now access to educational material, to interaction tools with the instructors, to past experimental results. This clearly indicates that now the system has to include different users classes (not only students, but also instructors and administrators)

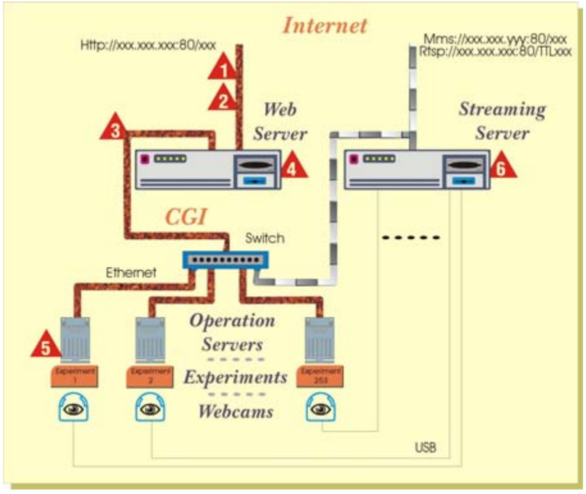

Fig. 1. System hardware configuration and connectivity. #1 in figure: web-server with fixed public IP address and HTTP service; #2: HTTP and other services on port 80 to guarantee compatibility with other proxies; #3: routing system on NAT subnetwork; #4: access to experimental functionalities through CGI; #5: NAT subnetwork of control dedicated servers; #6: streaming servers for real time video broadcasting.

a data base with different access rights, DB-management procedures administrative tools. All these tools must be made available on the system server, which was originally the only communication channel between users (clients) and the experimental set-up. Since the system has to guarantee also the immersivity of the learning experience (in our case through video streaming from web-cam) it has been decided to set up two servers, one (the web server) dedicated to system access and connection with the data base and/or the experimental set up, the other (streaming server) solely dedicated to video transmission. The main features of the system as depicted in Fig. 1 can be summarized as follows:

- presence of two distinct servers, each one with its own fixed, public, IP address, offering different services: one dedicated to video streaming, the other dedicated to user access to the experiment and system management;
- both servers use the port 80 for compatibility with proxy systems;
- the system is modular, with routing on a NAT (Network Address Translation) subnetwork; the NAT subnetwork comprises the operation servers, each one dedicated to a single experiment (two for the moment);
- the web server allows access to the experimental activities through CGI (Common Gateway Interface)

Both servers are Pentium 4 machines, with the Windows 2000 Professional operating system, which allows a simple management while guaranteeing stability to a certain degree. For the operational servers, the requirements may be dictated by the experiment itself; as for the interface toward the web servers, the availability of IP protocol and ethernet is a sufficient requirement. Presently, the magnetic levitator is running under control of an RTAI Linux machine, while the manipulator planning and control system is running under Windows 2000.

In the architecture of Fig. 1, the web server has still the critical role of interfacing the whole system with the remote users. This has been accomplished by developing JEHUTY (Java wEb Hyper modUlar inTerface sYstem), based on the use of Java servlets to build dynamic web pages on the fly in response to the user information and data base data. The interaction between JEHUTY and a client requesting access to the system is depicted in Fig. 2. After authentication, the client can access the experiment, or can access the data base in order to retrieve material or to perform some management operations, as explained later on in the section. The different communication paths and software actions taken by JEHUTY are illustrated in Fig. 3. One simplifying aspect of this design is that all user classes access the system in the same way, independently from the kind of operation they have to perform. In particular, system management operations are accessible home page of the telelaboratory (see Fig. 4). Overall, four user classes are defined, of which only three have management rights.

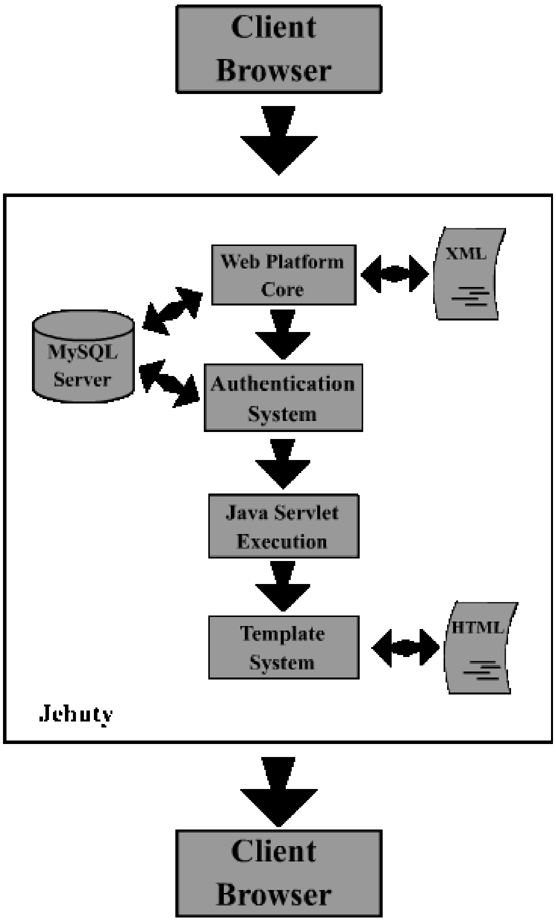

Fig. 2. Example of interaction between a client and JEHUTY: authentication and generation of web pages on the fly.

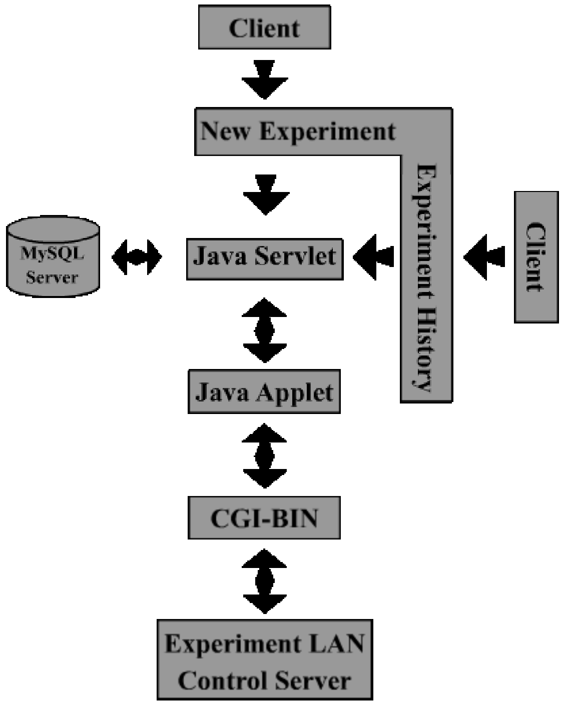

Fig. 3. Communication flow between the remote client and the system data-base (for archival data, instructional material, management operations) and the experiment servers (for tele-laboratory operations).

The first class is that of the system developers, that have the rights to access and change the code of the system and the definition of user classes; the second class is that of the system administrators, that can give/deny authorization access to individuals of all the other classes, insert/delete new learning objects and links between instructors, learning objects and courses, and monitor the overall system log; the third class is that of the instructors (teachers), that may authorize student access, insert instructional material and link it to specific experiments/courses, insert material on the FAQ list, view the history log of the students in their courses; the last class is that of the students. Students do not have management rights; they can access the experiments, documentation, FAQ list and the history log of their own experiments, including the data/results obtained in past experiments, which are stored in system data base.

It is often stated that telelaboratories offer advantages in terms of reduced maintanance requirements and working load of the technical staff. However, at least in the e-learning evolution of the system, there are some additional administrative and technical tasks that have to be taken into account, and that actually *increase* the personnel working load. One of this is the need of a thorough back-up of the system, in order to guarantee the safety of all the users data., possibly on a daily basis. Another one is the availability of technical assistance and back-up assistance. At the present moment in our labs technical assistance is guaranteed only on standard working hours (8.30 to 17.30), while UPS systems provide the only automatic back-up system at night.

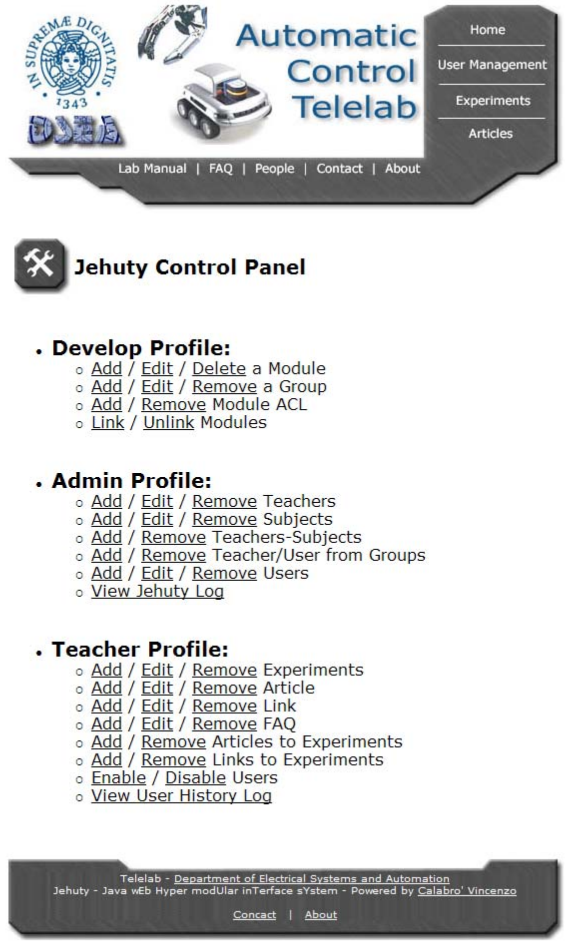

Fig. 4. Web page for remote management of the system, as a function of users classes.

4. LEARNING TOOLS

In response to the system requirements listed in section 2, some specific learning tools have been implemented. As for student/instructor interactions, it has already been mentioned the presence of a FAQ list. This asynchronous interaction scheme has been inserted as the less demanding in terms of instructor workload and implementation requirements. It is envisaged to add in the future also a bulletin board, another asynchronous interaction scheme that has the added feature, with respect to FAQ list, to create direct links within the learning community without the mediation of the instructor. Experiences in web-learning (see for instance (Kukka 2004), to name a very recent report) show that students do take advantage of this feature, progressively increasing the internal exchange of knowledge.

Other critical requirements, partially absent in our previous tele-lab experiments, are the definition of an experiment goal and the introduction of self-assessment tools. The absence of clearly defined goals was not an overlook in design: specific assignements were given in the classroom lessons. However, the students were left relatively free to test with their own chosen objective as a way of encouraging participation in the experimental activity beyond the courses requirements. Since the

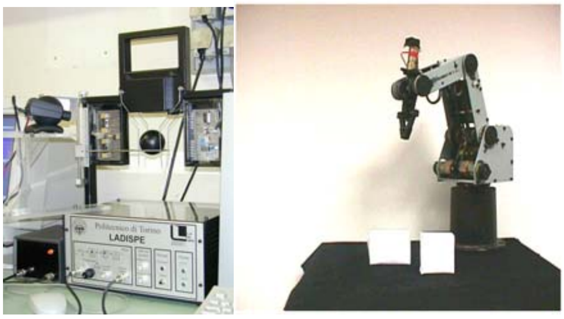

Fig. 5. The two experimental set-up so far integrated into the e-learning environment: the magnetic levitator (left) and the manipulator (right).

integration into the e-learning environment requires a more structured approach, it has been decided to limit the experimentation to a subset of clearly defined and indicated experimental experiences. For the magnetic levitator (see Fig. 5), the experimental experience is the design of linear controllers (PID or through transfer function definition) in order to obtain a given performance in the system step response. The performance is expressed through several standard performance measures , as ITA, ITAE criterions. To succesfully pass the test, the student has to produce a design such that the performance measure indicated by the instructors is above a given threshold. Before the final assessment test, the student has the opportunity to compare the performance of her/his own controllers against the test threshold and the performances obtained, on the same test typology, by the students of the same group. As it can be seen the introduction in the magnetic levitator experiment of specific goals and self-assessment tools has not posed any particular problem, leaving also a rather wide choice of possible experiments, thanks to the fact that this specific experiment is oriented toward a very standard and basic aspect of automatic control. The robotic manipulator planner is however a different case. The manipulator is programmed through the graphic language GeT (see Fig. 6 - (Bicchi et al., 2001)), purposely designed to simplify the task of robot programming. In order to pose the students a convincing instructional challenge, it has been decided to use the experimental set-up as a case of trade-off between program complexity and program efficiency. In particular, the experiment has been modified (both in the mechanics, in the controlling electronics and in the GeT language primitives) into a "pick-and-place" set-up with feedback possibility from a sensorized platform built around the "place" location. The arm movement is artificially disturbed by the system (with a randomly generated perturbation unknown to the user) so that the user has to find a program able to reach the "place" goal even in presence of disturbances, and exploiting the sensor feedback to obtain an estimate of the current end-effector position. A more detailed description of this specific system is given in (Balestrino et al., 2004). The goal is to minimize the following cost function:

$$J = \alpha m + \beta n \qquad (1)$$

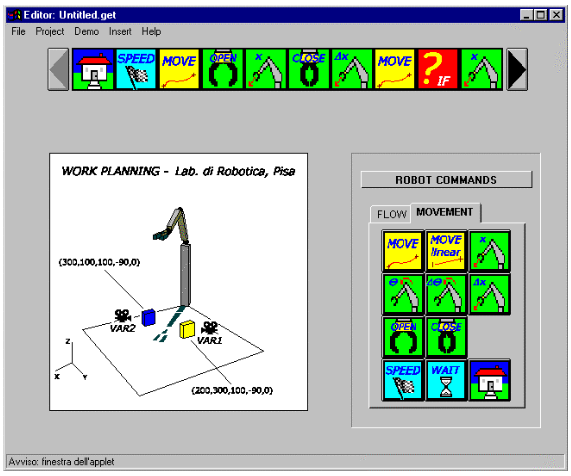

Fig. 6. The programming environment of the GeT graphic language for robot task planning.

where *m* is the number of instructions in the program (a measure of program complexity) and *n* is the number of elementary operations needed to reach the goal, averaged over five successive attempts with the same programming code (a measure of program efficiency). The weighting between complexity and efficiency is fixed by the instructor, though the student is allowed to vary it in the training phase. To successfully complete the test the student program has to obtain a cost value *J* below a given threshold. As self-assessment tool the student can compare its performance in the training phase against the test threshold and against the performance obtained by other student of the same group and with the same identical weighting.

5. EVALUATION OF LEARNING OBJECTS

In the previous sections we have described the evolution of a tele-laboratory system toward an e-learning system, in which the remotely accessible experiments are part of "learning objects". A critical part of any learning object is its evaluation. Therefore, although the system has not yet been tested in its present configuration, so that no evaluation step has been actually implemented, the procedure that will be followed is now described.

Assuming that most of the student users will be university students, the training evaluation is performed accordingly to the first two levels of the Kirkpatrick model (Kirkpatrick, 1998): evaluation of reaction and learning. An experimental follow-up procedure for students seeking professional update to evaluate the learning transfer (the third level of the model) is also in preparation. At the reaction level, the student perception of the learning object is assessed; this is accomplished through a questionnaire in which each student has to indicate her/his subjective evaluation (on a one-to-five scale) regarding difficulties of learning; completeness of the instructional material; difficulties in access and use of the experimental set-up; availability of the experimental set-up; efficacy of the telepresence feedback. As for learning evaluation, the results obtained by the students in the final e-learning course examinations are considered, and histograms are built from the results. The transfer evaluation will consist in a six-months follow-up of those students that have enrolled in the course not as part of their university program, but for professional update. After six months from the end of the course, they will be required to fill a questionnaire in which they have to give a quantitative evaluation (on a one-to-five scale) of: change in job mansions after the training; use of the new knowledge gathered in the training; interaction in the working environment with topics addressed in the training; how much of the topics learned in the training are still maintained. At the present stage, the implementation of a protocol for the evaluation of the fourth level of the Kirkpatrick model (impact and cost/benefit) is considered premature.

6. CONCLUSIONS

In this paper the steps taken to evolve a tele-laboratory system in robotics and automation toward a proper e-learning system have been described. It has been emphasized how this evolution may require a re-design of the experimental set-up and of the overall system architecture, to accomodate in the system in an efficient way the requirements of an e-learning environment. The efficacy of any e-learning environment, hence of the design choices made, can come only from the observation of how the system is used. An evaluation procedure has been established and described. The systematic use of the remote learning facilities as part of University courses is foreseen in the second semester of the academic year 2004/05. From that date, also the first data on evaluation of the "learning objects" will be available.

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