Remote Laboratory - Towards an integrated training system

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***Abstract* – Remote laboratories are essential to e-learning platforms in scientific and technical disciplines. However they present a delay in their development in comparison with other (less complex) e-learning contexts such as virtual classrooms, e-projects, … We are focusing on this particular training activity with the aim of giving means to instructors to build generic remote laboratory environments, homogeneously melt into standardized e-learning environments, in the most effective way. This paper outlines our current research and presents our experimentation platform.**

I. INTRODUCTION

Remote Laboratories compose a section of e-learning which one finds too little explored in actual scientific researches, in comparison with more theoretical vectors such as on-line courses, virtual classrooms, educational intranets, self-training, e-projects, role playing, ... Yet this kind of training is essential in scientific and technical disciplines and answers to real need : heavy and costly industrial systems can neither be moved nor be duplicated whereas every learner has to be confronted with their use in a real (at least in a realistic) situation during training period. Under present conditions, how to give learners access to such systems in a remote configuration with, at the same time, the realism of local environment representation and system security ?

As we will develop in § II, we observe deep research works in teleoperated systems [1,2] and in "more classical" *e-learning* interfaces [3,4] but we find (in our opinion) too few works on a remote laboratory platform integrated in a global Learning Management System (LMS) [5]. Is this because such a study particularly requires interdisciplinarity and appears to be more complex than other learning contexts ?

Considering this particular need and the skills of our research team, specialist in e-learning, we have recently started a project whose main goal is to provide means for instructors to build complete remote laboratory systems bound to be integrated in a global homogeneous educational environment (providing other training activities). These means consist in :

- A generic environment providing tools to teleoperate a system (with appropriate commandability and observability), to let learners follow a remote laboratory scenario, to allow instructors to observe and evaluate their learners, and to enable communication between learners and instructor(s),
- A method helping to develop a remote lab. platform based on this generic environment and in its adaptation to particular systems, considering common points noticed in classical local laboratories, according to disciplines.
- An environment for authors to create easily and efficiently remote laboratory scenarios (authors don't have to be experts in web programming to create scenarios; technicians building and maintaining a remote lab. platform have !)

We will discuss in detail about these developments in § III after having laid out this research context in § II. Eventually, in § IV, we will present our experimentation platform and a first experiment which we have developed in order to point out technical difficulties inherent to remote laboratories in automation discipline.

II. REMOTE LABORATORIES

E-learning technology standardization process represents the first research activities in computer-based education field. A lot of committees have been created by institutions and organisations such as IEEE, US Department of Defence and the European Commission to deliver recommendations and standards in order to support the interoperation between heterogeneous LMS. Below we list the most relevant initiatives that play a major role in the standardization process.

IMS [6] (Instructional Management System) : Global Learning Consortium, Inc. has been developing and promoting open specifications for facilitating on-line distributed learning activities such as locating and using educational content, tracking learner progress, reporting learner performance, and exchanging student records between administrative systems.

ARIADNE [7] (Alliance of Remote Instructional Authoring and Distribution Networks for Europe) aims at creating tools and methodologies to produce, manage and reuse computer-based pedagogical elements and telematics supported training curricula.

LTSA [8] (Learning Technology Systems Architecture) is a set of specifications proposed by IEEE 1484 LTSC (Learning Technology Systems Committee). It covers a wide range of systems, known as learning technology, CBT (Computer-Based Training), electronic performance support systems, computer assisted instruction, intelligent tutoring, education and training technology, metadata, etc..

AICC [9] (The Aviation Industry CBT Committee) is an international association of technology-based training professionals. The AICC develops guidelines for aviation industry in the development, delivery and evaluation of CBT and related training technologies.

At present, several on-line laboratories have been developed. One can distinguish two categories out of them [5] :

- **virtual laboratories,** which use software simulation of physical devices such as Matlab+Simulink [11] or LabView [10,12],
- **remote laboratories,** which offer remote access to real laboratory equipment and instruments. In this paper we use "remote lab." term to design this last kind of laboratory.

The common principle of remote lab. experimentations is that learners can change system parameters through Internet, then a special interface converts those parameters to comprehensible and acceptable data for the local computer attached to the physical set-up, as shown in Fig. 1.

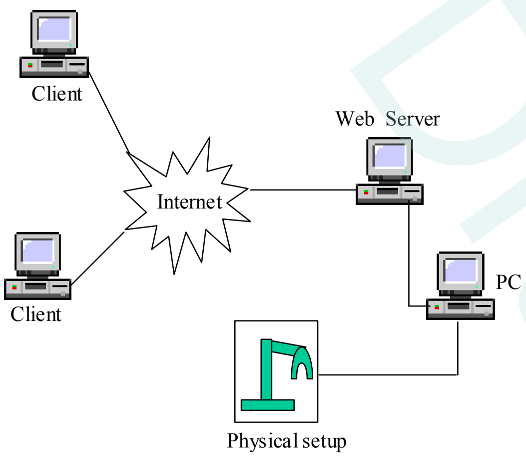

Fig. 1. Basic architecture of a remote laboratory

One can find remote laboratory experiments in various scientific and technical disciplines : automatic control [13, 14], electronic [15,16a], mechanical [16a], robotic [17,18] and chemical fields [16a].

Most of remote laboratory developments focus on the technical aspect and more specially on manipulation parts rather than on pedagogical, economic and security aspects. Some of them have more precisely studied requirements and issues specific to remote laboratories [10, 13, 17].

Next, we present different topics related to remote lab. conception, considered as important in research literature :

- Security : it consists in the protection of the equipment from wrong orders and of the server from network attacks [13]. High level security precautions have to be handled in the development of GUI, in order to avoid users from selecting physically unrealisable parameters [10].

- Pedagogy : remote lab. conceivers generally present their educational approach for their own labs but no generalization is proposed. However we think, as LICEF team in [19], that common points exist; the architecture of web-based remote laboratories would be improved by being based on a generic (discipline and system independent) and scalable basis [16b]. Furthermore remote laboratories must be interactive and support collaborative learning. We notice in [14] a particular effort in this way, with the contribution of a virtual assistant to help instructor in tutoring.

- Financial aspect : globally, every remote lab is based on web browsers so that learners do not have to buy or install specific software (JAVA applets automatically download themselves from servers such as in [17]). Server-side, conceivers have the choice between :
  - professional scientific software (Mathworks Matlab server / Simulink, National Instruments Labview [15], … besides, [13] presents a comparison between them), which provide, in one hand, tools to create web interfaces (poor in LMS integration) and, in the other hand, a very rich toolbox of scientific functionalities (curves, block diagrams, PID control, …)
  - or developing their own Human-Machine-Interface (HMI) with common tools (CGI/Perl [16b], JAVA [17], …).

  According to remote systems, each solution has its advantages : developing its own application could be more expensive than buying scientific software but the latter sometimes lacks specific remote lab. functionalities (evaluation, communication, … and interaction with other LMS parts).

- Human Machine Interface : literature shows various implementations of HMI, generally specific to each remote system and only specifying technical teleoperation part. A few (such as [5, 12, 13, 14, 15]) integrate pedagogical content in their HMI. We have not found any paper presenting a complete HMI featuring administrative, pedagogical, communication and teleoperation dimensions (see § III). Let notice some interesting developments in remote system representation, in [18] : a 3D simulation allows learners to test their algorithms before running them on a real robot, filmed by a webcam.

III. REMOTE LABORATORY ENVIRONMENT

In this part, we will expose different aspects to be taken into account in the conception of a remote lab environment.

Real systems versus educational models

In classical lab. training, one can distinguish 3 system categories, according to their closeness with real life situations, cited here from the most customized to the most real one :

1. educational specific (simplified and/or adapted) systems for "zooming" on specific phenomena

(typically physics or chemical experiences),
2. realistic (sometimes at small scale) systems (for example, a replica of an industrial system such as a conveyor or our vertical store described in § IV) which can be interpreted as physical simulators of real systems, and
3. real systems (tool machines, industrial robots, …).

The use of a system from one of these categories mostly depends on educational goals but also on economical criteria (heavy industrial equipment is more expensive at purchase and maintenance than a type #1 system).

Simulation versus Laboratory experiment
One uses "simulation" when manipulated system is virtual, based on a model run by a computer. In one hand, simulations return results whose closeness to reality depends on the model complexity and, in the other hand, the way results are presented has not the same impact according to their production (in the meaning of a theater production). For instance, try to learn how to play billiards on a computer screen with a keyboard (such as old 2D billiards games, filmed from the top of the table) or dived in a 3D virtual world with Virtual Reality Equipment and force returns : with the same ball movement modeling behind the scene, better commandability and observability make the training more effective.

From our point of view, simulation is linked to virtual laboratories (where no physical system is used, only computer simulations) and is complementary in this aspect with remote laboratories. As a whole, they are essential when the simulated system is not reachable by students : microscopic or macroscopic phenomena, destructive process, … In fact, we think that, when it is possible, one would be well advised to merge virtual and remote laboratories. Indeed, professional plane pilots have been using simulators made of physical simulators (a real scale cockpit with same equipment as in planes) merged with a computerized simulation of the rest of the plane and the environment. One of the important impact of featuring a simulation facility in a remote lab. is that learners can train on simulator before testing on real system. Therefore they can, on one hand, closely compare reality & theory and, on the other hand, share the real system with other learners in a finer timing granularity, which may allow to make more populated remote lab. sessions than local ones. However, this presupposes an efficiently defined time sharing protocol but results in an increase of productivity of the system (more learners per hour).

Remote Lab. 4 dimensions :
In order to make a complete remote lab experimentation, we have identified 4 strongly linked dimensions whose items have to closely interact between them:

- Remote manipulation dimension

This dimension includes necessary functionalities (from physical devices to programs and HMI) to manipulate the remote system without any educational scenario attached to it, as in research experimentations ([19] proposes remote lab. use by both research and education teams). One can find samples of implementation on teleoperation web sites (such as [20]). The goal of this dimension is to teleoperate the system in best ways, knowing that the distance decreases system commandability (learners can nor directly manipulate the system with their hands) and observability (neither they can directly see in 3D with their own eyes any more).

We distinguish in this dimension, two states for users : active (when they can interact with the remote system) and passive (when they are just observers of an experiment made by another person). The latter state is interesting for trainers to make a demo to every learner or to show to other observers how it works.

Are included in this dimension, every mean for remote controlling (keyboard, mouse, joystick, gloves, …) and feedback displaying (video, 3D, stereovision, VR helmets, force return, …). The HMI for this dimension is specific to the remote control of the system and the conceiver goal is to provide a HMI which allows users to remotely manipulate and observe the system at least with the same results as if they were besides. Teleoperation research literature provides a rich resource to help conceiving this dimension functionalities [1].

- Education dimension

This dimension suits to educational point of view : scenarios built by instructors and run by learners and learner tutoring and evaluation. Laboratory experiment computerization gives more degrees of freedom in conception of scenarios: one can imagine learners acting in a remote lab as in a role playing game in order to give him the maximum of realism, to enforce cognitive appropriation. In this way, we have developed a first approach of a dynamic scenario on our platform (see § IV) and we are studying a generic educational skeleton which could be reused in any discipline. Another interest of computerizing lab. systems lies in the possibility of proposing on-line contextual documentation according to steps in a scenario and studied concepts.

Furthermore, we are concentrating our attention on the standardization aspect in order to permit to efficiently melt down remote labs in e-learning platform and to be able to manage and exchange learners data (profile, remote lab evaluation, …) and educational metadata (prerequisites, tackled concepts, …). These standards have been evoked in § II. This aspect is essential for synchronization with other linked training activities. This enables the automated proposing of different scenarios suited to learners profile and preferences.

- Communication dimension

As in any web-based training system, the quality of the communication between learners and instructor is essential. One has to take account of several ways to implement remote lab sessions considering the location of every participant (as in fig. 2) :

- Where is the instructor ? besides the platform (#I1), besides his learners (#I3) or away from both (#I2) ?

- Where are learners ? together (#L1, with or without their instructor) or alone in front of their own desktop (#L2) ?
- When there is no instructor besides the platform, one may view a technician dedicated to a set of remote lab experiments. His presence may be essential considering security laws.

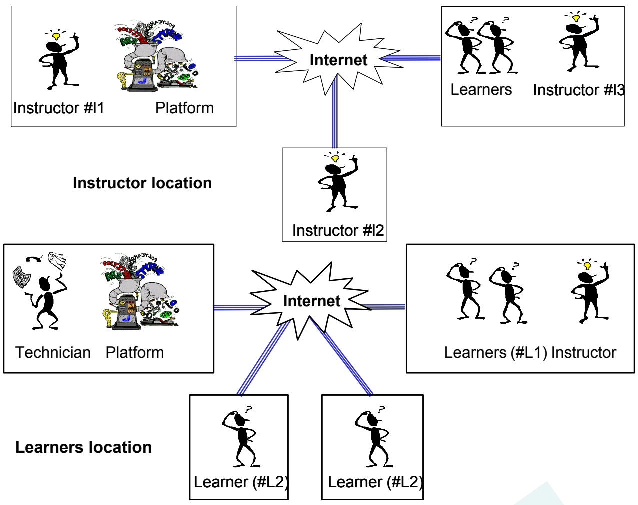

Fig 2: Locations of every participant

- ❑ Administration dimension

This dimension features :

- scheduling remote lab. sessions for trainers and learners, taking account of timetables of every participant.
- Managing security and access control : only registered learners can access certain remote lab. scenarios and interact with remote systems. Trainers must have the ability to deal and take control on the system over learners.

IV. OUR EXPERIMENTATION PLATFORM : TIPY

In order to point out difficulties inherent to remote laboratories in technical disciplines, we have begun to set up our own platform. This platform deals with automation discipline and is based on the replica (at smaller scale) of a vertical automated store (see fig. 3) shipped by Schneider®. This store has been used for several years for local lab. training for industrial engineering students. It is made of a tower enclosing a loop driving nacelles capable of holding small specific pieces. Learners manually put or remove pieces from nacelles through a door on the right side in order to simulate a real stocking use. An industrial Programmable Logical Controller (PLC) controls the loop motor by way of several sensors and a raw HMI.

The educational goals of this (2x4h) work consist in :

- firstly, learning how to program such a system, using the industrial programming environment provided with the PLC,
- in a second time, modeling its functioning in order to efficiently program it,
- and, finally, programming it.

Considering § II, this platform features a realistic small scale system (cat. #2) controlled by a real industrial PLC (cat. #3). We have extended this initial system to be used at distance. It has become an experimentation platform to test our developments while still being used for local laboratory sessions.

Fig 3: Our automation plaform: a vertical store driven by two PLCs.

Our first enhancement of the platform consisted in adding a system to (un)load the store at distance, as learners cannot directly do it any more. This system, driven by a second similar PLC, consists in a robotic arm with 2 degrees of freedom (1 rotation around a vertical axle, 1 translation in horizontal plane).

Our second step has been making both PLCs reachable by any host from Internet. This has been *easily* possible since nowadays every modern PLC features *Ethernet* communication ports. In our case, we have added an Ethernet communication module per PLC; these specific Schneider® modules feature an integrated web server which is initially programmed for remote servicing and able to be customized for other purposes such as remote laboratory. In our case, these servers ship applets to be run to get real time state of both systems and apply orders as if these orders came from the local HMI.

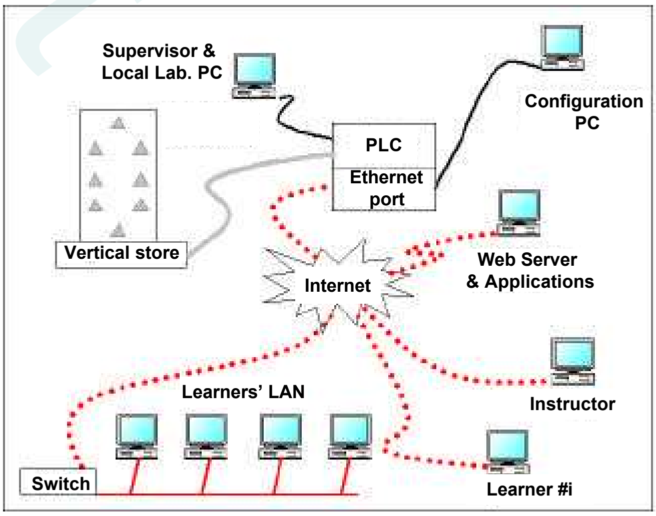

Fig 4: TIPY Architecture

A steady webcam films the platform (a web-motorized one is to be installed) and a VRML 3D reconstruction is available in order to :

- become acquainted with this system (one can move around and into specific parts of it, legends describe each element)
- reproduce the current state of the remote system in real time.

The web interface consists in PHP pages run by APACHE web server and linked to a MySQL database server. The choice of open systems makes it possible to install the platform under Windows or Linux environments. A 3D VRML representation run by the Blaxxon® plugin and linked in realtime with the store PLC by way of a JAVA applet, gives a virtual view which user can orientate as he wishes. Two other applets propose a 2D reconstruction of both loader and store local HMIs. For the moment, no action is available from the 3D VRML reconstruction towards the store but this functionality is programmable.
A remote desktop control is envisaged so that trainers can take control of learners desktop when they are stuck. Professional softwares exist (Symantec PCAnywhere®, Microsoft NetMeeting®, ExpertCity GotoMyPC, AT&T Cambridge Laboratory *Virtual Network Computer* VNC, …) and are the best way to implement this complex functionality.

Our web platform enables to :
- author (currently with a poor design) new remote laboratory dynamic scenarios (learners go from step to step using a pathway depending on its previous results) (see fig 5),
- schedule instructor and learners remote laboratories,
- perform a remote laboratory experiment (PLC remote programming, debugging and controlling of the system).

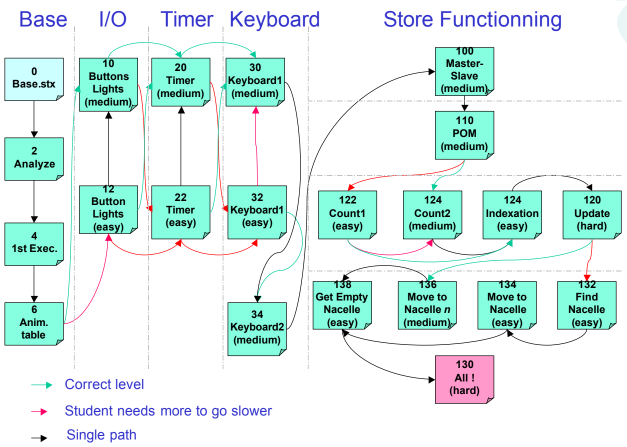

Fig 5: diagram of scenario evolution according to learner current level

The programming of PLCs reveals one of the difficulties in remote laboratory building : making an industrial software (i.e. *Modicon® PL7Pro*) be used by several learners on remote workstations whose configurations are not under our control. In our case, we have set up a Windows TSE (Terminal Server Edition) server which deals PL7Pro to learners and trainer workstations (the software is run on the server and the display is carried to the client); therefore, each client must be on Windows platform and needs just a downloadable small TSE client software to do so.

For the moment, this HMI (a learner HMI screenshot is presented in fig. 6) is not complete, but we are working on it. Among others, it lacks more sophisticated communication tools (videoconference, virtual white board, …) and easy learner tutoring for the instructor, to be used in good use conditions.

First conclusions drawn from this platform building are :
- automated systems are ought to be manipulated at distance, due to recent progress in control technologies which, from now on, feature easy Internet connectivity. JAVA applets (manufacturers propose core applets with their PLCs) and growing industrial distributed system communication (such as Microsoft® OPC) are a good way to interface the controlling of the system with the remote experimentation web IHM.
- Installing a remote-driven camera is not a gadget; the ability to zoom on specific running parts in a debugging process is essential and increases observability level.
- Security is an important aspect : an operator has to remain near the system(s) because of legal statements ; one physical person has to turn on power and be able to push on urgency button in case of main problem.
- Currently, the 3D VRML reconstruction is not used for simulation but it is an interesting idea that learners train on simulation before testing their algorithms on the real system. This would make the system available to several simultaneous groups having access to the real system during shorter durations.
- In our dynamic remote laboratory scenario, conditions used to direct a learner to one or another next step at the end of the previous one, are a little too simply (results from a multiple choice question form combined with time spent on previous step). One can imagine learners having to draw curves or diagrams which require a more powerful validation process. This is another axis of research we focus on.

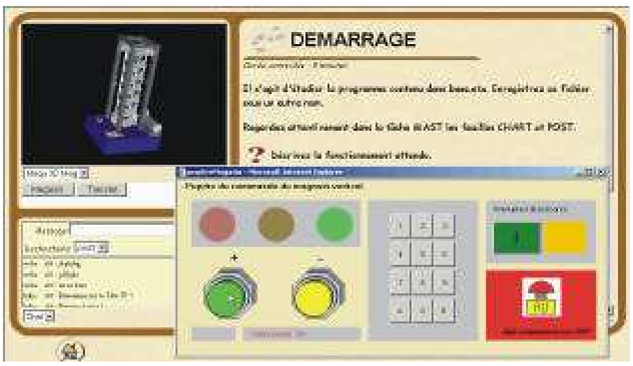

Fig 6: Screenshot of TIPY learner interface

V. CONCLUSION AND PERSPECTIVES

Remote laboratory conception implies additional difficulties, compared to more traditional e-contents (virtual classrooms, e-projects, …). These difficulties are due to system teleoperation requirements, in synchronizing manipulations with e-learning applications, the whole within a standardized platform.

As important research work has proposed standards for traditional e-content in one hand and teleoperation techniques in the other one, the aggregation of the whole requires a certain interdisciplinarity. This paper presented some global aspects of the problem we are currently focusing on. Currently, we are exploring dynamic scenarios and current e-learning standards appropriateness. Our ultimate goal is to provide to learners remote laboratory environments as effective as local ones (why not more?) considering cognitive criteria, and, to instructors, means and tools to improve and facilitate authoring and tutoring.

VI. ACKNOWLEDGMENT

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