SyTroN: virtual desk for collaborative, tele-operated and tele-learning system with real devices

R. Chellali[1] and N. Mollet[2] and C. Dumas[3] and G. Subileau[4]

[1] IIT Genova, Italy. ryad.chellali@iit.it
[2] IIT Genova, Italy. nicolas.mollet@gmail.com
[3] IRCCyN Nantes, France. cedric.dumas@emn.fr
[4] Virtools/Dassault systems Paris, France. geoffroy.subileau@virtools.com

Abstract. Tele-training is a main issue nowadays and it is strongly motivated by the increased mobility of people. This mobility shouldn't be a limit for a good training: pertinence and efficiency have to be the core of distant training environments. In this paper, we introduce SyTroN, a tele-learning system using virtual reality and tele-operation techniques. The first aim is to propose intuitive virtual classrooms/desks supervised by a real teacher for collaborative or individual distant learning, using Internet. The second goal is to go from virtual to real: SyTroN supports the connection to real devices, potentially rare and expensive, allowing distant experimentation's abstracted by virtual tools. After 5 years of development, our work has been validated with psychologic tests, which highlight the efficiency of our global system on one year of use within an engineering school.

1 Introduction

The use of virtual reality has been strongly facilitated during the last ten years: techniques are mature, costs have been reduced and computers and devices are enough powerful for real-time interactions with realistic environments. Industrialists have also validated huge prototyping, simulating and training systems: we can cite the VTT project, which aims to train on technical gestures while manipulating a virtual milling machine[1]. We can also cite the GVT project[2], with individual and collaborative [3] learning for industrial maintenance procedure on military equipment. The use of virtual reality for large public is more recent, but already pertinent: interactive 3D video-games using VR devices, such as the Nintendo Wii, is a good example of this success. On another hand, many works have been already done in the field of distant/e-learning, illustrated for example by the notion of virtual classrooms/courses proposed by some universities[4] with pertinent results[5]. Those distant learning are now very useful in a world where people are travelling a lot, and where jobs opportunities conducted them to move several times. This context makes (distant and mobile) training as one of the most active domain in the field of Virtual Reality. Now, techniques could go from expensive training environments in dedicated rooms to personal computers or even laptops, while large-band networks allow easy access to distant and heavy information.

Concerning Tele-operated systems, virtual reality techniques are very interesting and used since the begins. Indeed it provide a good abstraction for real devices operators have to operate with. VR allows simulations, but also interesting augmented representations of real devices and this is very useful in executing tele-operated tasks. Obviously, one can take advantage of these rich environments for pedagogical purposes. We can cite the work of Bicchi[6], who applied e-learning techniques in the field of automatic control, in order to learn the usage of a robotic arm for example[7]. Dongsik[8] was focused on simulating electronic circuits in distant virtual laboratory, with the ability to apply the models on real equipment with webcams, in order to validate the theoretical simulations.

SyTroN project is born in this context. Fundamental research and innovative solutions have been developed in order to success in mixing VR techniques, mobile and distant learning, and tele-operation applications. With those techniques, the fundamental goal of our project is to increase the learning efficiency in a two steps process: first, students learn and simulate, and then they manipulate real devices. To do so, SyTroN provide virtual classrooms supervised by a teacher, where distant students, with standard supports such as distant reference books or media contents, have to train by acquiring theoritical skills and learn more about processes and devices models. Once an acceptable level reached, students can move to teleoperation of the real devices to face and solve real problems. SyTroN system is a complete and functional solution allowing for the moment simulation and training on 3 different tele-operated devices. The system also takes advantage of VR for pedagogical add-ons not available in the real world, in particular with dynamical and contextual information in the 3D environment to help the training process.

The first part of this paper deals with the presentation of our models and its implementation. The next section gives an overview of the system usage. Finally, the last section presents the field validation of SyTroN, based on a comparison of training sessions with traditional techniques versus training sessions using SyTroN.

2 Contribution: SyTroN

We present in this section the models and the implementation of SyTroN.

2.1 Global vision

The figure1 illustrate the global vision of SyTroN. The proposed architecture allow multiple distant connections of all the elements of the system. We can identify three logical sub-systems, distributed on the Internet network:

- The users, which include the teacher and the students.

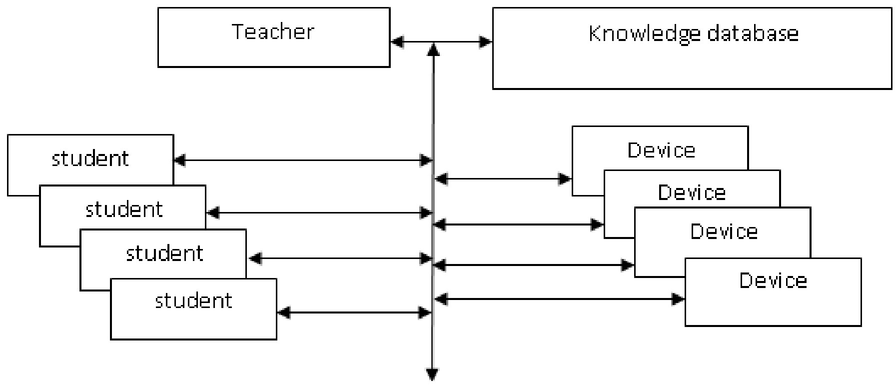

Fig. 1. Global vision of SyTroN

- The devices
- The manager and the knowledge database

Figure 1 : Architecture of SyTroN

The teacher and the student sub-systems are user-oriented, i.e. the interfaces are designed to ease the use and to perform the learning process. The devices entities are control oriented, i.e., each entity achieves mainly the functions of enabling the remote control of any device of the platform. A device is composed itself of two parts: the device and the device server. The manager is the core of the system. It contains all the information describing the system (users, devices and network), like status, configurations and history for instance. It is database oriented.

Here's an overview of the standard *usage* of the system:

- *Teacher connection*: a teacher requests a connection. Verifying his rights from the knowledge database does this. Thus, the teacher is given the list of actions he is able to do. These actions are of two types: time-critical or asynchronous.
- *Student connection*: the student can connect using the same protocol as teachers. Obviously his rights are different. Once connected, the student can work alone or within an existing virtual classroom. For both modes, the student accesses the following services.
- *Getting or uploading a document*: before beginning the lecture, the student will download the contents of the course to study the basics. Notice that this is possible if the teacher has already uploaded the needed material.
- *Discussing with the teacher*: during a learning session or off-line the session, a student can contact a teacher or the other students to have a chat, a videoconference or just by sending an email. Here also, two categories of functions are available, synchronous or asynchronous.
- *Using a device*: a user can interact with a physical device in real time. This is the main sensitive action a user can perform. Following the availability of

the device and the user rights, a device is allowed to one user (except when the device is shared between the teacher and the student). The interaction here is mainly synchronous and time critical. Indeed, the control loop is not local but it is geographically distributed over the network.

2.2 Functions

In the following points, we are now introducing the set of functions attached to each logical entity, according to the needs of usage.

Users functions Except for some specific functions, students and teachers are considered as end-users and both are clients. The corresponding functions enable to access the SyTroN services, namely, the device servers and the knowledge database. Two main sets of functions are available: Communications, and Remote controls.

The *communications* functions enables the users to access to the contents and to people within the SyTroN system. Namely, the students can:

- Access to lectures, tests and evaluations ;
- Contact teachers and other students ;
- Get the devices status and gateways ;
- Simulate devices;

Some specific functions are reserved to teachers : adding devices, adding lectures, and setting tests and evaluations.

The *remote control* functions link users to physical devices. Users are enabled to achieve remote physical interactions: they may send controls and receive measurments in return, i.e. the device status as well as some information about the remote environment.

The previous functions are implemented for the most used OSs: Windows, Unix and Linux. Users terminals are designed for WEB-based interface as well as proprietary interface. The communication blocks of each function are TCP-IP based.

Device functions are separated between a server and a controller.

Device server is the gateway between users and the remote world. It is composed of two parts: the device gateway and the device controller. The device gateway connects the users and the knowledge database to the device. The device controller pilots the actuators and gets the sensors information. The device gateway is just a translator. Depending on the considered device, the gateway formats the users commands and passes the parameters to the controller. The concerned actuators execute the command and respond to the device controller by giving the new position of the mobile. The functions of the gateway are mainly dedicated to synchronous communication. TCP protocol is used to guaranty the exchanges synchronicity and integrity.

Device controller is the interface between the real and the logical worlds. Its main function is to close the local control loop. This component is device dependent: for each device, one needs to write a specific driver. For SyTroN implementation, three devices with three different dynamics have been tested. Due to the nature of the considered devices, two control platform are used : the Matlab (from MathWorks) platform and a proprietary platform (C++ based API).

Knowledge database functions The knowledge database contains all the information needed to manage the global system. Three sub-databases describes the three logical units (the teacher, the student and the device) involved in a distant learning session, the cross-relationships between the units, and a history of platform uses.

The main functions of the K-database are the following:

- Managing people by setting and verifying the rights of users such as name, co-ordinates (email, address), list of lectures (etc..). Each field allowing to users to access to SyTroN services.
- Managing contents such as Lectures, Tests and evaluation program, Tests and evaluation results.
- Managing devices by adding, modifying or keeping devices histories.

This database is SQL compliant. The current version is MySQL and specific C++ API is used to interact with users and devices. In addition, we added a gateway module to open partly the system to let administration manage the teaching activities/scheduling within the engineering school.

3 Example of devices and usage

We give in this section a short description of two devices we have integrated in SyTroN, and some views of the running system.

3.1 Devices

The figure 2 presents two of the three devices we have already included in our system.

The heating board is dedicated to the study of heating processes, simulating complex systems with numerous inputs and outputs in the state space (an algebraic approach of automatic control). The heating board is a basic MIMO system (Multiple Inputs Multiple Outputs). The students have here to keep constant the temperature of the board, regardless to the external temperature. The goal of the training session is to learn MIMO control techniques, especially control laws.

The mobile Pekee robot is a classical robot produced by Wany Robotics SA. This robot has two actuators, namely two DC motors enabling the robot to

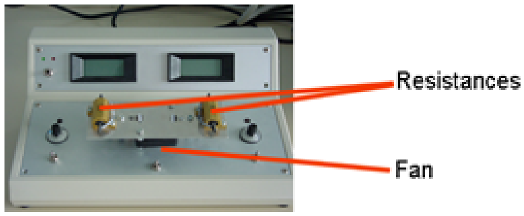

Fig. 2. -*Left*- The heating board. -*Right*- The Pekee robot.

move with 3 degrees of freedom. On the other hand, Pekee has onboard a set of sensors (telemetry, light, gyros, choc detector, et.) enabling to handle the robot environment. Both actuators and sensors are handled by the onboard PC. This last communicate with any other PC using the wireless Ethernet based channel. The communication can concern the state of the robot (sensors information) or robot controls (DC motors or a request for a specific measurement).

3.2 Usage

Starting the session, the student download the documents explaining the lecture, the manipulation protocol and the attended results. Following this, the simulation phase can start on the virtual device (equivalent of the real one). This enables to acquire the theoritical basis. In this virtual classroom(figure 3), students can easily manipulate virtual devices, helped by VR pedagogical metaphors such as avatars, the use of transparency, etc.

The heating board. The student can verify the results of the simulations by comparing resulting curves to theoritical ones. From the derived model, the student can switch to the real device to setup the control parameters, namely the PID constants. These parameters are sent via the asynchronous TCP channel to the device server and the real test can start. The control closed loop is then operating to maintain the temperature to a desired one. The client calculate the inputs of the heating board and send it via the TCP synchronous channel. The device extract the current temperature and return it to the client and so on. This question-response process is done at 1Hz frequency. Indeed, as the response time of the system is greater than 15secondes, 1Hz frequency for the control loop is enough to verify the Shanon theorem and to ensure the stability of the system. To add more impact on the learner, a video feedback was added to this device.

The mobile Pekee robot. For the mobile robot, time constraints are stronger than for the previous device. Indeed, the purpose here is to enable to a distant student to pilot a mobile with a visual and a force feedback. It is obvious that the shorter the system response time is the better is the manipumation. A UDP based protocol is used for this service. As for the heating board, the first stages of the mobile robot manipulations are concerned with the discovery of the device

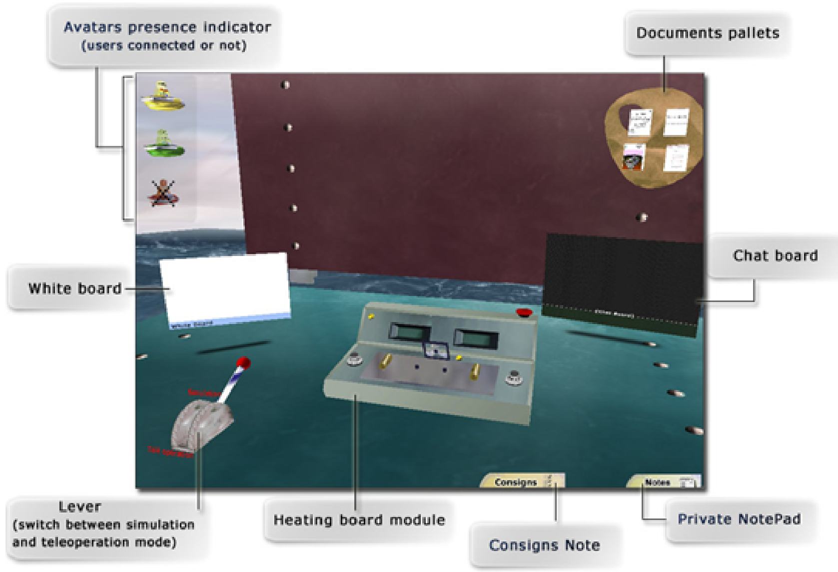

Fig. 3. the 3D desk and its components.

This is done using documents and simulations. For the teleoperated mode, the user may use a force feedback joystick, a mouse or the computer keyboard to pilot the robot. This generate motion commands that are sent to the robot. The robot execute these commands, capture about 31 sensors measurements and reply to the client. These measurments are then used to refresh the client virtual environment. As the robot speed is about 0.5m/s, the user may react in less than 1/2 seconde to avoid obstacles in front of the robot. This response time is obtained by tunning the range sensor dynamics to 1m depth. Following that and considering transmissions time delays in the network, any object about 0.25m has to be considered as very close obstacle. A hidden mobile robot was added to the interface to take into account the effects of time delays and the resulting offset between the user command and the real state of the remote robot.

The classroom metaphore : sharing the working environment. One of the main issues of Sytron is to offer a collaborative platfrom. Collaborative services use the network to share users activities to facilitate the realisation of tasks and communication, by displaying graphical feedback to show connected people and what they are doing. For Sytron, the collaborative framework and the share of the 3D virtual environment are built around a comunication server named reflector. The Reflector supports a set of Peer to Peer or broadcast-like services (chat or voice conferencing for instance). UDP and TCP based protocols are used to handle these services with no specific constraints except the users comfort. The virtual white board is designed to let user share results and formula. With this tool, users can draw whatever they want thanks to the pen tablet (or mouse). The chat board display messages written by users who can type a message at any time. Users can also see the avatars corresponding to the other users connected. When a user has a service as focus, his correspondent avatar flies next to the object corresponding to this service, in order to indicate to the other participants what he's doing.

4 Evaluation

Before developing and writing codes for Sytron, we started by designing a paper prototype based on interviews we done with all actors. Teachers were asked to detail their presence-based lectures regarding structural aspects, timing, exchanges (teacher-students, students-students) during lectures, the most impacting parts, etc. This study leads us to write a script with handmade screens and concepts to include into the virtual desk and the virtual classroom. Our approach was not only objective: some of our considerations are purely subjective to take into account personalities of teachers and how they transmit knowledge. Students also evaluate the quality of knowledge transmission mostly perceptually. They are more sensitive to the way the teacher introduces and explains concepts than the validity of concepts. Following that, we opened the system to two categories of students: normal program for young engineer (12 people) and adult program for which students work mainly from home and nightly (10 people). Individual usages were checked and we verified our pre-conception hypothesis: the interface is fluid and users discovered services in a quasi natural way. The second verification was concerned with the shared space and attached tools. Adults and young engineer reactions were different: for the first category, chat and live talk were more used before and during experiments. For young people exchanges were mainly concerned with simulations/real experiments results. May be cultural gap exists between the two categories and ones are more used with known channels (MSN or Skype for instance) and our offer was disturbing their communication environment.

The last evaluation to do is concerned with the classroom metaphor. All participants may use the system at the same time with the goal to replace the existing lectures. This step is not of evidence and we have to reconsider the previous evaluation approach: marks, credits and public evaluations are to be produced.

5 Conclusion

We detailed the Sytron system, its architecture, its components, its use and some preliminary evaluations. First, we strongly concentrate our work on automatic control aspects (closing high/low speed loops over Internet) which are not described here. The second step was to pre-design the virtual desk and its components. Voice, video and written messages channels were integrated within the system. A central system managing technical and administrative matters finishes our core developments. We have an operational system which can constitute a good basis for further improvements like adding an ITS intelligent Tutoring System for automatic assistance for the teacher. Indeed, teachers currently act in an old fashion by following learners. An ITS can help to personalize more the relationship between each partner. The other contribution we made and which must be also improved in the future is the use of real devices to let learners confront to real problems. In addition VR techniques enable us to augment the reality by adding guides and milestones. This let users use the maximum available information at experimenting time.

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