Teleoperation of an Experimental Platform of Electrical Machines through the Internet

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Abstract—The remote access to equipment through the Internet becomes an attractive research area. Most current implementations are dedicated to specific applications such as remote laboratory. A remote laboratory offers cost-effective and flexible means for distance learning education and remote experimentation, where students and scientists share the remote access to physical experiments. This paper presents the implementation of an experimental platform of induction motor though the Internet having the following important features: i) easy implementation based on software and hardware, ii) help based on IP telephony, iii) use of several computers to distribute the task. The developed scheme is versatile and robust, allowing the different control and observer actions remotely through the Internet.

Index Terms—Telecontrol, Teleoperation, Remote Laboratory, Electrical machines, Induction Motor.

I. INTRODUCTION

The remote access to complex and expensive laboratory equipment represent an appealing issue of great interest and relevance for research, learning education and industrial applications. The range potentially involved is very large, including among others, applications in all fields of engineering [1]-[3].

The equipment and accessories used for research and learning education are usually expensive and then the implementation and the learning of new strategies or methodologies are difficult. However, several solutions and schemes used in remote laboratories have been proposed, allowing to students and/or scientists to achieve experiments by sharing the resources. Thus the cost per student could be reduced [4].

It is well-known that several experimental platforms are distributed in different laboratories in the word, and all of them are on-line accessible through Internet. Since those labs require specific resources to enable a remote access, several solutions for harmonizing the necessary software and hardware have been proposed and described. Furthermore, due to its versatility, these platforms provide to user services which allow the transmission of information in a simply way, besides being available to many people, having many multimedia resources.

Currently, remote experimentation is used as an excellent alternative to offer access to equipment of high cost to test and validate control strategies. Then, to solve the problem of testing control algorithms on real-time, we take into account the advantages of the computer network, computer communication and teleoperation to develop new tools and give the possibility of using these equipment for research and remote education of the control theory.

Remote laboratories offer to students an alternative to remote experimentation in robotic [5], digital circuit [6], power electronic [7], etc. In electrical engineering, some works related with electrical circuit are given [8]. Nevertheless, there exist few works related with remote experimentation for electrical machines like induction motors or generators.

On the other hand, a teleoperation platform offers an alternative for using remote laboratories, although for long time, this technology was accessible only for qualified people, due to the high cost of the equipment. Now, Internet technology offers the possibility to access for all students and scientists where such equipments are not available. In this case, it is possible to use hardware or software elements to implement teleoperation platform. The software is most often used because many of them are freeware and offer excellent alternatives to remote implementation.

Taking into account the above considerations, a structure of a teleoperation system for electrical machines based on freeware software and the Internet, is given in this paper. More precisely, we present a telecontrol platform through the Internet for remote experimentation of electrical machines control.

The proposed architecture is composed of an induction motor connected by means of a DSpace interface located in a computer. Freeware softwares are used for the remote operation. Several computers are required to distribute the tasks and to give high security. This architecture uses a graphic user interface in order to introduce the commands and to tune the controllers. Finally, a webcam is used for image and video capture online.

The paper is organized as follows: in section II, we introduce some important concepts with respect to telecontrol and teleoperation, section III presents the available software technologies which are used in this paper for the teleoperation of an induction motor. Section IV presents the teleoperation platform proposed and in section V, we introduce the equipment used to implement the control algorithms. In section VI, we show the advantages of using the Internet for controlling an induction motor from the Nuevo Leon University, Mexico. The induction motor is located in IRCCyN

laboratory in Nantes, France. Finally, some conclusions are given.

II. SOME CONCEPTS

Now, we introduce the concepts of telecontrol and teleoperation, which will be used in the sequel.

Teleoperation is defined as the continuous, remote and direct operation of the element control or machine (see Fig. 1). From the introduction of teleoperation technology, it was possible the development of interfaces capable of providing appropriate interactions between man and machine.
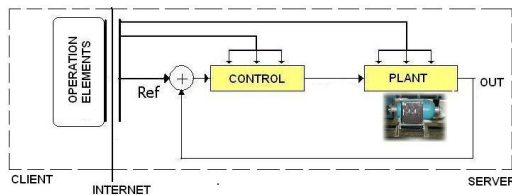

Figure 1.   Teleoperation of machine schema.

Nevertheless, the main aim of telecontrol is to extend the distance between controller and the plant. The distance has been increased with the development of the Internet (see Fig. 2).
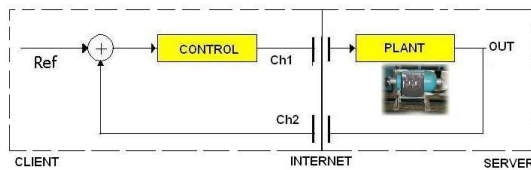

Figure 2.   Telecontrol of machine schema.

In the teleoperation systems through Internet, the effects of the time delay and uncertainly property are not considered, because the controller and the plant are in the same layer, as shown in Fig. 1. Nevertheless, in telecontrol systems these effects are important, in which two channels of communications are required, i.e. forward path (Ch1) and feedback path (Ch2). The time delay must be less than the sampling period, (see [9] - [11]). Network time delay and its uncertain property exist in the process of data-gram transfer in the Internet, which can affect the stability of telecontrol system.

III. TELEOPERATION BASED ON SOFTWARE

The use of software for remote communication presents some considerable advantages with respect to the hardware. Some of them are:

- Damage in hardware represents maintenance and cost. Nevertheless, damage in software practically is solved with the reinstalling of the program.

- Many programs used like communication resource are freeware.

- Since the use of the computer in the platform is necessary, therefore the use of software also.

- By means of software it is possible to share many resources using a computer, for example: Webcams, VNC services, serial ports (RS232).

- The HTML Pages of the device servers are unalterable and simple. By using software it is possible to develop friendly and interactive HTML Pages.

The aim is to propose a structure based on software in order to develop and facilitate the remote communication between the machine and man, where two strategies, called remote PC, are presented.

A.   UltraVNC

VNC (Virtual Network Computer) is a communication protocol based on RFB protocol which allows the remote access of the desktop of other computer located in the web. VNC protocol transmits the keyboard and mouse events from one computer to another, relaying the graphical screen updates back in the other direction, over a network. In this way, the VNC is considered as a platform-independent.

On the other hand, UltraVNC is an excellent VNC tool, due to it is freeware and operates with high security levels. For those acquainted with Windows Remote Desktop, UltraVNC realizes the same task; however, it allows the connection with UNIX or Linux machines.

B.   LogmeIn Services

LogmeIn [13] offers a freeware VNC service, which is similar to UltraVNC, but LogmeIn offers the services from an external Server, for instances ESS, External Services Server. ESS shares the resources between two computers, so that the concepts server/client appears on both sides.

Another important difference between UltraVNC and LogmeIn is the fact that UltraVNC needs the permission of the administrator's network, when some times this permission is restricted. LogmeIn does not require these permissions, because connect safely bypasses firewalls and proxy servers that normally stop the remotely connections of the PCs.

IV. REMOTE PLATFORM BASED ON INTERNET TELEOPERATION

In Internet teleoperation several time delays can appear during any real time experiments:

- Transmission delay thought Internet (T_I).

- Control algorithm computation (T_C).

- Sampled time of the Data Acquisition (T_S).

These time delays depend on the scheme selected in remote experimentation. In a telecontrol scheme, the total time $T = T_I + T_C + T_S$ could be high and could affect the stability of the system. Nevertheless, if $T = T_C + T_S$ is small, then a teleoperation schema offers an excellent solution in remote experimentation, due to the time delay T_I is not considered by the aforementioned reasons (see section II).

The proposed architecture is constituted by three elements: a) Experimental equipment, b) Server Station and c) Client Station, which allows to facilitate and to improve the efficiency of the remote laboratories.

A. *Experimental equipment.*

The experimental equipment consists of a set-up of the induction motor experimentation. It is known that there exist several laboratories for the control of the induction motors. In [14] an introductory laboratory experiments has been shown to demonstrate how an experimental hardware can be integrated to control induction machines in a laboratory. In [15], an easy procedure of a cage construction of induction motors used for experimental work has been proposed. This scheme consists of a three/phase wound-rotor induction machine that has been converted in a squirrel-cage machine with current measure capability on two bars.

Experimental equipment required for remote control of induction motors is shown in Fig. 3, where the output variables of the induction motor are the stator currents, and the speed, whereas the input variables are the stator voltages and the torque (disturbance).
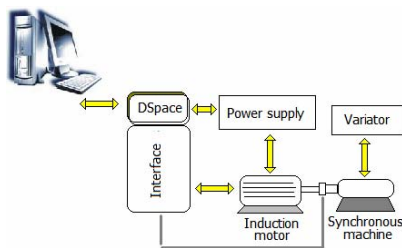

Figure 3. Equipment proposed scheme.

Data acquisition board (DAQ)

The DAQ allows interchange information between the plant's device and the computer. There are different models and characteristics of the DAQ. If a DAQ of general purpose is used, then it is important to consider some properties: a) the number of input and outputs, b) if they have analogical and/or digital signs, c) the sampling time velocity, d) software for the communication with the PC.

There exist DAQ for specific uses. They are connected directly to the electromechanical device. Usually, they are associated to a manufacturer's software to use the computer as a way of communication. The proposed architecture uses DAQ of a dSPACE board DS1104.

DAQ Communication software

This element allows reading and interchange of information between the PC and the DAQ, which has to be considered in the selection of the DAQ. Most of these programs can realize actions of control. Some of them have graphics interfaces and virtual instrumentations that allow the user to interact with the board in a more pleasant, friendly, easy and comprehensible form.

A necessary important point to consider is if the software has development tools in some language of programming and/or it has the resources allowing the access to dynamic libraries (DLL's) of other programs. The proposed architecture uses the ControlDesk software (dSPACE).

Control software

It is important to have an application that allows the implementation of algorithms for experimentation. Simulink/Matlab is an excellent software for the implementation of control strategies, since it has libraries which allow communicating with other applications. Due to these requirements, the software selected for the communication with the DAQ interacts mainly with Matlab; otherwise it will be necessary to adapt it with other computational software. The architecture proposed here is developed using Matlab/Simulink software, because several control algorithms can be easily implemented, downloaded, modified on-line, and uses an important library of functions, which are available for user for control design, and they are easily programmed and executed remotely. The dSPACE software easily integrates the Matlab/Simulink Scheme that is executed on the dSPACE board (DS1104) (after compiling and linking steps).

Electrical machines

The set-up located at IRCCyN is composed of an induction motor, a synchronous motor, inverters, a real time controller board of dSPACE DS1103 and interfaces which allow to measure the position, the angular speed, the currents, the voltages and the torque between the tested machine and the synchronous motor. The motor used in the experiments has the following values: 1.5kW normal rate power; 1430 rpm nominal angular speed; 220V nominal voltage; 7.5A nominal current; $np = 2$ number of pole pairs, with the motor nominal parameters: $Rs = 1.633\Omega$ stator resistance; $Rr = 0.93\ \Omega$ rotor resistance; $Ls = 0.142H$ stator self-inductance; $Lr = 0.076H$ rotor self-inductance; $Msr = 0.099H$ mutual inductance; $J = 0.0111/rad/s2$ inertia (motor and load);

$fv = 0.0018Nm/rad/s$ viscous damping coefficient. The experimental sampling time T is equal to 200µs.

Figure 4. Experimental equipment for electrical machines .

B. *Server Station.*

Server station has the task of sharing the necessary resources in order to allow the remote access to local station. Right side of Fig. 5 shows the main elements of the server station, where we can see there are three computers in the server layer. These computers are connected in order to realize different tasks.
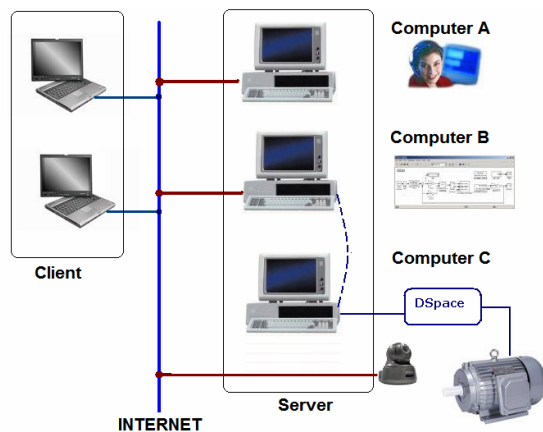
Figure 5.   Server station.(right side)

Computer A. *Help online module.*

The computer A allows establishing a communication textual and oral between the local and remote user, so that this computer provides a help on line. This computer uses the following freeware software:

- Messenger: Textual communication and webcam (Videoconference)
- Skype: Oral communication (IP Telephony).

Computer B. *Software control module.*

Computer B has the task of sharing the resources of the computers through VNC. The main objective of this computer is to share the software for control and operation of the plant. Furthermore, computer B uses the following software:

- Matlab/Simulink. This Software is used typically in control systems.
- ControlDesk. It is a graphical tool for controlling in real-time the induction motor.
- UltraVNC Server. It is a software belonging to he family of VNC software
- LogmeIN. It is ESS software.

UltraVNC allows to use Matlab/Simulink or ControlDesk tools without any cost, so that the user doesn't require the installation or payment of these software.

Computer C. *Motor Interface module.*

This computer has an interface with the data acquisition board (DAQ), and does not share any resources in the Web. This computer is only used to share information with the Computer B throughout the remote control using the software ControlDesk. Furthermore, this computer protects the access to the plant (experimental equipment) in order to avoid damages caused by unauthorized users.

Webcam

This camera transmits images of the induction motor and its environment, since the remote user can be move the camera and see the operation around the machine.

This camera is different from the one used with Messenger. Nevertheless, the time delay does not affect the performance of transmission since it is just used as a visual support in the teleoperation of the machine. Furthermore the camera allows visualizing the disposition and connection of devices for measuring or controlling the main variables of the induction motor.

C.   Client Station.

The client station is any computer containing the UltraVNC-Client for establishing the connection with server station and interacting with the experiment equipment.

Furthermore, it is possible to use the LogmeIn services to establish the connection with server station. In this case, the client only requires the Web Navigator, like Internet Explorer, Mozilla, etc. to start an experiment.

V.   EXPERIMENTATION SETUP

The methodology described in above section is applied to show remote access to the set-up of electrical motor located in IRCCyN. The main components of the set-up are: an induction motor connected to a synchronous motor, inverters, and a real-time controller board dSPACE DS1104 and interfaces to connect all these elements. For the control of the plant (Induction Motor, inverters, load motor), the applied software are MATLAB/Simulink and ControlDesk.

For teleoperation of this induction motor, the proposed structure requires three computers and accessories in order to execute a desired control task. Each computer executes the different tasks:

Computer A is used to establish the communication between local and remote users. In our platform, this computer is located in France and connected through internet to another computer located in Mexico, using IP telephony and/or chat.

Computer B is used to provide a remote communication, by means of an Ultra VNC server, in order to isolate and protect Computer C from intruders. Furthermore, Computer B sends and receives information from Computer C. By using the Ultra VNC service, the client controls Computer B, and thanks to the remote control mode of ControlDesk, the client can control Computer C, and hence the plant (the induction motor).

Computer C is related to the DSpace DS1104 card that communicates the desired actions (the commands obtained by the control algorithm running in DS1104) to the induction motor. It is worth to mentioning that this computer is not connected to internet for security reasons, and then the resulting information is sent to Computer B, which is connected to internet, and by this way the remote user can manage the information.

For security reasons, an operator is required in situ in order to supervise all tasks of the experimental platform and to start/stop the electrical power.

In this experiment the registered time delays were:

- T_I (ping) = 400 mseg. avg.
- T_I (camera) = 3 seg. avg.
- T_I (screen feedback, VNC) = 2 seg. avg.
- T_C < 70 mseg.
- T_S = 120 μseg. (DS1104)

To illustrate the user interface, the experimental results are shown in the next figures.

Figure 6 shows the scheme of control and observation strategies to control the induction motor, which is implement using Matlab/Simulink/Control_Desk. The methods and techniques developed in control theory are easily implemented using these softwares.

Fig. 7 shows the control by a Mexican user to access the remote laboratory, located in Nantes France. From the figure, we can see the computer A showing the images sent by the webcam and the response obtained when the control algorithm is applied to the induction motor which are transmitted by the computer B using Controldesk and Matlab.
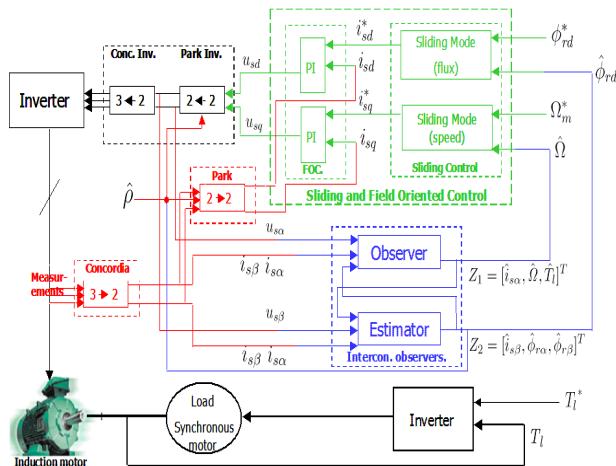

Figure 6.   Matlab/Simulink strategy of control and observation.

Fig. 8 shows the screenshots obtained from this experiment. The first image shows the images given by webcam of the machine (with the sound), the second figure shows the use of the Remote software ControlDesk via UltraVNC.
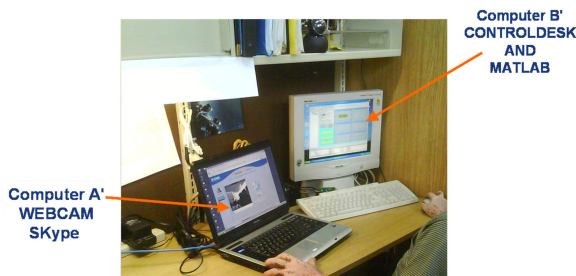

Figure 7.   Control by a Mexican user
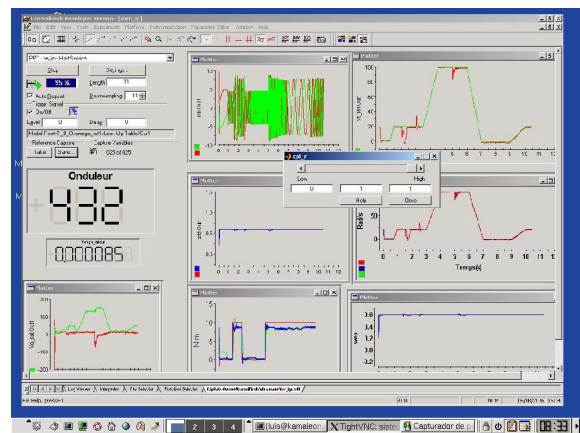

Figure 8.a Webcam screenshot

Figure 8.b Remote operation via UltraVNC

VI. CONCLUSIONS

The access to laboratories for remote experimentation is now possible thanks to the internet services and new technologies. Now, it is possible to have security access to an experimental laboratory in order to make experiments and/or to validate theoretical results.

In this paper, we have presented an architecture designed for teleoperation allowing remote experimentation of electrical machines. This architecture have been implemented and tested on an induction motor located in Nantes, France, which has been teleoperated from Mexico for developing control strategies using Matlab /Simulink.

The main characteristics of this architecture are:

- Teleoperation through the Internet technologies.
- Using freeware software to remote operation.
- Using a security scheme and distributed task based on three computers.

REFERENCES

[1]   M.J. finley. "Tele-learning: The killer app?". *Guest Editorial, IEEE Common, Mag*, Vol. 37, No. 3, pp. 80-81, Mar. 1999.

[2]   Y. L. Wu, T. Chan, B.S. Jong, and T.W. Lin, "A web-based virtual reality physic laboratory". In *Pro. 3rd IEEE ICALT, Athens, Greece*, pp. 455, Jul 2003.

[3]   S. Hackbarth. "Introduction to special issue on web-based learning". *Education technology*, Vol. 37, No.3, pp. 5-7, May-Jun 1999.

[4]   Wolf, W; Madsen. "Embedded systems education for the future". *Proceedings of IEEE*, Vol. 88 No.1, pp. 23-30, 2000..

[5]   Bharahat Ramaswamy, YanQwan Chen and Kevin More "Omni directional robotic wheel- a mobile real time control system laboratory", *Proc. in 2006 ACC, Minneapolis Minnesota*, pp. 14-16, June 2006.

[6]   Fujii N., Koike N. "Work in progress - a new time-sharing remote laboratory e-learning system for hardware design and experiment of digital circuits". Frontiers in Education, 2005.

[7]   Fujii N., Koike N., "Design and implementation of a power electronic remote-laboratory", *Industrial Electronics, 2003. ISIE '03.*, Vol. 1, pp 9-11 , June 2003

[8] Gustavsson, I., "Remote laboratory experiments in electrical engineering education". Devices, Circuits and Systems, 2002, pp I025-1 - I025-5, April 2002.

[9] Hyun Chul Cho, Jong Hyeon Parck. "Stable bilateral teleoperation under time delay using robust impedance control". *Mechatronic*, Vol. 15, pp. 611-625, 2005.

[10] R.J. Anderson and M.W. Spong, "Bilateral Control of teleoperators with time delay", *Transactions on Automatic Control*, Vol. 24, pp. 541-552, Aug 1979.

[11] J. W. Overstreet, A. Tzes. "An Internet-based real-time control engineering laboratory", *IEEE control Systems Magazine*,Vol. 19 No. 5, pp. 19-34, 1999.

[12] http://ultravnc.sourceforge.net/, "UltraVNC OpenForge.".

[13] http://www.logmein.com, "LogmeIn Services".

[14] Wells, J.R.; Chapman, P.L.; Krein, P.T. "Laboratory prototype for induction motor bar breakage experimentation and bar current measuring", *Power Electronics, Electrical Drives, Automation and Motion*, 2006, pp. 734 – 739, 2006.

[15] Bruzzese, C.; Honorati, O.; Santini, E., "Development and application of a linear induction machine for instructional laboratory use", *Devices, Power Electronics Specialists Conference*, Vol. 2, pp. 479 - 482, 2002.

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