Teleoperation of an experimental platform of electrical machines through the Internet

César Guerra Torres, *Universidad Autónoma de Nuevo León, Mexico*
Jesús de León Morales, *Universidad Autónoma de Nuevo León, Mexico*
Alain Glumineau, *École Centrale de Nantes, France*
Dramane Traore, *Institut de Recherche en Communications et Cybernetique de Nantes, France*
Robert Boisliveau, *Institut de Recherche en Communications et Cybernetique de Nantes, France*

ABSTRACT. Remote access to equipment through the Internet becomes an attractive research area. Most current implementations are dedicated to specific applications, such as the 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 through the Internet, having the following important features: easy implementation based on software and hardware; help based on IP telephony; use of several computers to distribute the tasks. The developed scheme is versatile and robust, allowing the different control and observer actions remotely through the Internet.

KEYWORDS: *Electrical machines, Induction motor, Remote laboratory, Telecontrol, Teleoperation*

Introduction

The remote access to complex and expensive laboratory equipment represents 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 (Finley, 1999; Hackbarth, 1997). 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 students and/or

scientists to achieve experiments by sharing the resources.

Thus, the cost per student could be reduced (Wolf, Madsen, 2000). It is well-known that several experimental platforms are distributed in different laboratories in the world, and all of them are online, accessible through the 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 their versatility, these platforms provide services to the user, which allow for the transmission of information in a simple 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 in 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 this equipment for research and remote education on the control theory.

Remote laboratories offer students an alternative to remote experimentation in robotics (Ramaswamy et al., 2006), digital circuit (Fujii, Koike, 2005), power electronics (Fernandes et al., 2003), etc. In electrical engineering, some works related to electrical circuit are given (Gustavsson, 2002). Nevertheless, there exist few works related to 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 a long time, this technology was accessible only to qualified people, due to the high cost of the equipment. Now, the Internet technology offers the possibility to access for all students and scientists, where such equipment is not available. In this case, it is possible to use hardware or software elements to implement teleoperation platforms. The software is most often used, because many pieces of software are free, and offer excellent alternatives to remote implementation.

Taking into account the considerations above, a structure of teleoperation system for electrical machines, based on freeware (free 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 architecture proposed is composed of an induction motor,

connected by means of a DSpace interface, located in a computer. Freeware is 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 the second section, we introduce some important concepts with respect to telecontrol and teleoperation; section three presents the available software technologies, which are used in this paper for the teleoperation of an induction motor; section four presents the teleoperation platform proposed; in section five, we introduce the equipment used to implement the control algorithms; and in section six, we show the advantages of using the Internet for controlling an induction motor from the Nuevo León University, Mexico.

The induction motor is located in the laboratory of the Institut de Recherche en Communications et Cybernétique de Nantes (IRCCyN), France. Finally, some conclusions are given.

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 control element or machine (Figure 1).

By 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 scheme
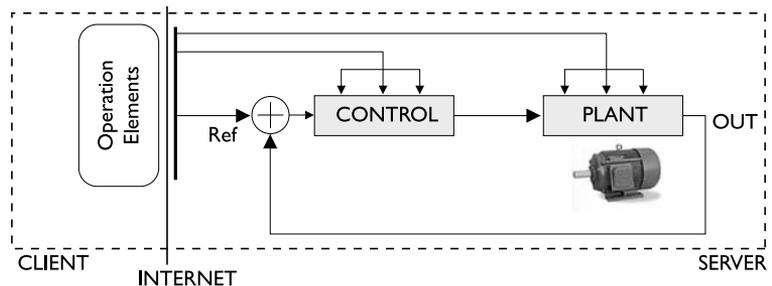
Nevertheless, the main aim of telecontrol is to extend the distance between controller and the plant. The distance has been increased with the development of the Internet (Figure 2).
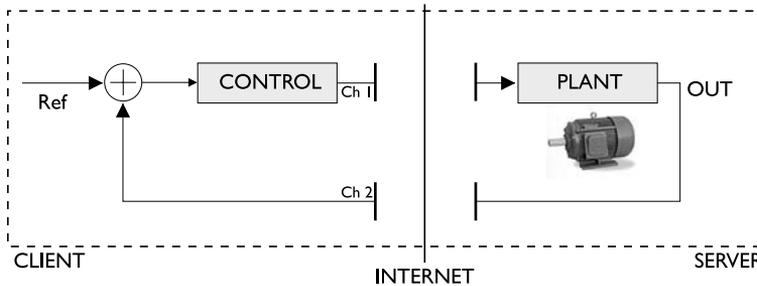
In teleoperation systems through the Internet, the effects of time delay and uncertain property are not considered, because the controller and the plant are in the same layer, as shown in Figure 1. Otherwise, these effects are important in telecontrol systems, in which two channels of communications are required, i.e. forward path (Ch1), and feedback path (Ch2). The time delay must be less than the sampling period (Cho, Parck, 2005; Anderson, Spong, 1989; Overstreet, Tzes, 1999). Network time delay and its uncertain property exist in the process of datagram transfer in the Internet, which can affect the stability of telecontrol systems.

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; otherwise, damage in software is practically solved with the reinstalling of the program;

- many programs used as communication resource are freeware;

- since the use of the computer in the platform is necessary, the use of software is therefore necessary too;

- 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 machine and man, where two strategies, called remote PC, are presented.

UltraVNC

VNC (Virtual Network Computer) is a communication protocol, based on RFB-Remote Frame Buffer protocol, which allows for remote access to the desktop of another 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 platform-independent.

On the other hand, UltraVNC is an excellent VNC tool, due to its being freeware, and to the fact that it operates with high security levels. For those acquainted with Windows Remote Desktop, UltraVNC realizes the same task; however, it allows for the connection with UNIX or Linux machines (UltraVNC OpenForge, 2008).

LogmeIn Services

LogmeIn offers a freeware VNC service, which is similar to UltraVNC, but LogmeIn offers the services from an external server, for instance ESS, that is External Services Server. ESS shares the resources between two computers, so that the concepts server/client appear on both sides (LogmeIn Services, 2008).

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

Remote platform based on Internet teleoperation

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

- transmission delay through the 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 scheme offers an excellent solution in remote experimentation; due to the time delay, T_I is not considered for the aforementioned reasons, as in section two.

The architecture proposed is constituted by three elements: a) experimental equipment; b) server station; c) client station, which allows to facilitate and improve the efficiency of the remote laboratories.

Experimental equipment

The experimental equipment consists in a set-up of the induction motor experimentation. It is known that there exist several laboratories for the control of induction motors. In the work of Bruzzese and colleagues, an introductory laboratory experiment has been shown to demonstrate how a piece of experimental hardware can be integrated to control induction machines in a laboratory (Bruzzese et al., 2006). In the work of Wells and colleagues, 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 measurement capability on 2 bars (Wells et al., 2002).

Experimental equipment required for remote control of induction motors is shown in Figure 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 scheme proposed
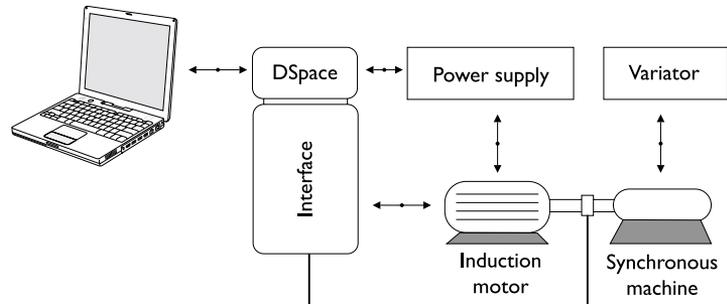
Data acquisition board (DAQ board)

The DAQ (standing for Data AcQuisition - another acronym commonly used is DAS, i.e. Data AcquiSition) allows interchange of information between the plant 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 inputs 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 DAQs 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 architecture proposed 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-Link Libraries

(DLLs) of other programs. The architecture proposed 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 online, and uses an important library of functions, which are available to the 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

Server station

The server station has the task of sharing the necessary resources, in order to allow remote access to the local station. Right side of Figure 5 shows the main elements of a 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)
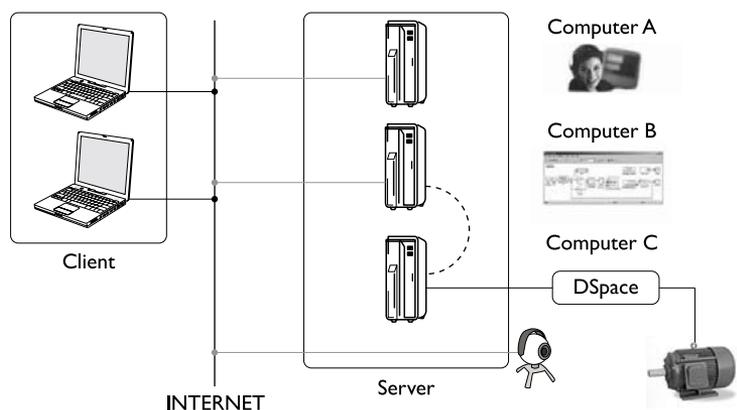
Computer A. *Help online module*

The computer A allows establishing a communication - textual and oral - between the local and remote user, so that this computer provides a help online.

This computer uses the following freeware:

- 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 piece of software belonging to the family of VNC software.

- LogmeIN: it is an ESS software.

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

Computer C. *Motor interface module*

This computer has an interface with the data acquisition board (DAQ board), 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 ControlDesk software. 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 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.

Client station

The client station is any computer containing the UltraVNC client, for establishing the connection with the server station, and interacting with the experiment equipment. Furthermore, it is possible to use the LogmeIn services to establish the connection with the server station. In this case, the client only requires a Web navigator, like Internet Explorer, Mozilla, etc., to start an experiment.

Experimentation set-up

The methodology described in the section above is applied to show remote access to the set-up of the electrical motor, located in IRCCyN. The main components of the set-up are: an induction motor, connected to a synchronous motor; inverters; 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 two pieces of software applied are Matlab/Simulink and ControlDesk. For teleoperation of this induction motor, the structure proposed requires three computers and accessories, in order to execute the desired control task. Each computer executes 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 the 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 UltraVNC server, in order to isolate and protect Computer C from intruders. Furthermore, Computer B sends and receives information from Computer C. By using the UltraVNC service, the client controls Computer B. Thanks to the remote control mode of ControlDesk, the client can also 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 mention that this computer is not connected to the Internet, for security reasons, and then the resulting information is sent to Computer B, which is connected to the Internet; 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 implemented using Matlab/Simulink/ControlDesk. The methods and techniques developed in control theory are easily implemented using these pieces of software.
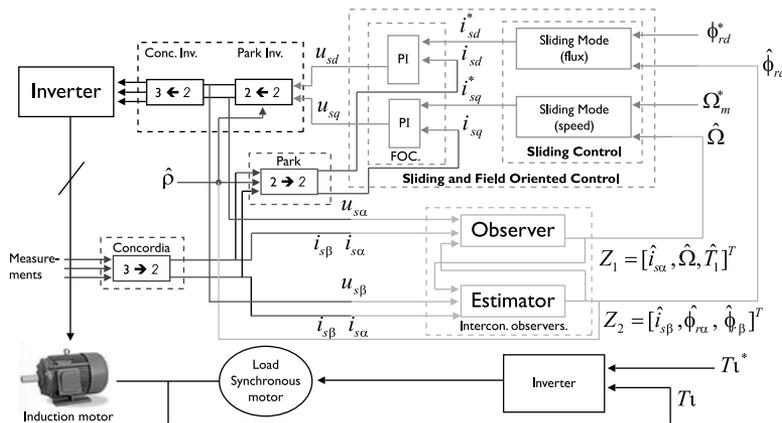

Figure 6. Matlab/Simulink strategy of control and observation

Figure 7. Control by a Mexican user

Figure 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.

Figures 8a and 8b show the screenshots obtained from this experiment. Figure 8a shows the images, given by Webcam, of the machine (with the sound); Figure 8b shows the use of the remote software ControlDesk via UltraVNC.
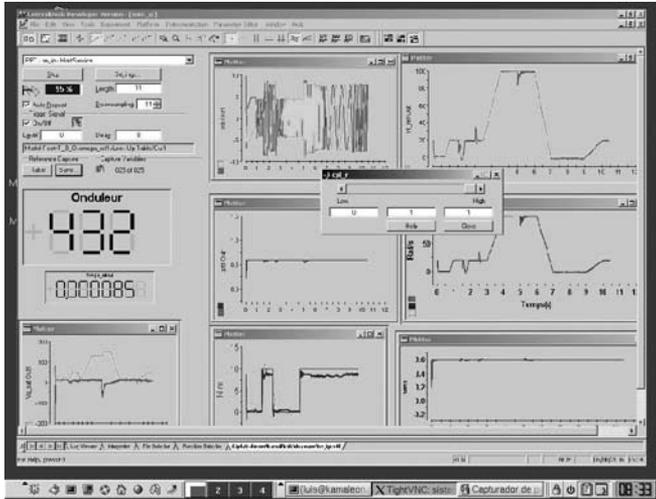
Figure 8a. Webcam screenshot

Conclusion

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 has 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 (free software) for remote operation;

- using a security scheme and distributed tasks, based on three computers.

Acknowledgements

All URLs checked June 2008

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Sintesi

Il sistema di teleoperazione per macchinari elettrici, basato su un software gratuito e su Internet, si presenta come una piattaforma di telecontrollo in rete, per una sperimentazione a distanza. I vantaggi nell'utilizzare Internet per il controllo, da parte dell'università messicana di Nuevo León, di un motore asincrono, collocato nel laboratorio francese IRCCyN di Nantes, sono insiti nell'obiettivo di sviluppare e facilitare l'interazione e la comunicazione a distanza tra essere umano e macchina.

Basilari risultano i concetti di teleoperazione e di telecontrollo. Il termine teleoperazione indica generalmente la possibilità di manovrare un macchinario a distanza; qui viene definita come l'azione continua, diretta e a distanza, esercitata sulla macchina o sull'elemento di controllo. L'obiettivo principale del telecontrollo è quello di aumentare la distanza tra chi o cosa esercita il controllo e l'impianto stesso (distanza di fatto aumentata nello specifico grazie all'introduzione del World Wide Web).

Le due tecnologie software gratuite disponibili, UltraVNC e LogmeIn, entrambi freeware, offrono servizi VNC-Virtual Network Computer, protocollo di comunicazione che a sua volta è basato sul protocollo RFB-Remote Frame Buffer, e che permette l'accesso a distanza al desktop di un altro computer, connesso alla rete mondiale. Simile a Windows, UltraVNC opera ad alti livelli di sicurezza e permette la connessione con macchine Linux o UNIX; LogmeIn offre invece servizi da un server esterno. UltraVNC e LogmeIn presentano ancora una differenza: in casi di restrizione di permesso, UltraVNC si rivolge all'amministratore del network, mentre LogmeIn bypassa in modo sicuro firewalls e proxy servers che normalmente bloccano le connessioni a distanza dei PC.

La piattaforma di teleoperazione è di fatto un'architettura che permette la sperimentazione a distanza di macchinari elettrici e, in genere, deve avere le seguenti caratteristiche di base: facile implementazione, basata su software e hardware; aiuto basato sulla telefonia IP; utilizzo di computer multipli per distribuire i diversi compiti. L'architettura proposta consiste pertanto di un motore asincrono, connesso per mezzo di un'interfaccia DSpace, collocata in un computer; utilizza un freeware per la teleoperazione; utilizza tre diversi computer per un'equa distribuzione dei compiti e per mantenere alto il livello di sicurezza; utilizza inoltre un'interfaccia utente grafica, per una migliore interazione a distanza tra uomo e macchina, e una Webcam per captare i segnali video e audio online.

Lo schema sviluppato è dunque versatile e solido, permettendo controllo diversificato e azioni di osservatori attraverso Internet; è stato implementato e testato sul motore asincrono, situato in Francia, e manovrato a distanza dal Messico, mediante MATLAB/Simulink.

Gran parte delle implementazioni attuali sono dedicate ad applicazioni specifiche, quali il laboratorio a distanza, che offre mezzi flessibili ed economici per la formazione e la sperimentazione a distanza. Qui, studenti e scienziati condividono l'accesso a distanza ad esperimenti fisici.