

WebTurning: Teleoperation of a CNC turning center through the Internet

Alberto José Álvares^{a,*}, João Carlos Espíndola Ferreira^b

^a Universidade de Brasília, Departamento de Engenharia Mecânica e Mecatrônica, Grupo de Automação e Controle (GRACO), CEP 70910-900, Brasília, DF, Brazil

^b Universidade Federal de Santa Catarina, Departamento de Engenharia Mecânica, GRIMA-GRUCON, Caixa Postal 476, CEP 88040-900, Florianópolis, SC, Brazil

Abstract

This work describes the implementation of a remote manufacturing system (telemufacturing) aimed at manufacturing rotational parts in a CNC turning center (Galaxy 15 M of Romi). The system is composed of three activities that are described in an IDEF0 model: graphic user interface (GUI) for teleoperation; WebCam for image/video capture; and WebCNC for teleoperation of the CNC machine. The turning center teleoperation system, called WebTurning, is based on a client–server architecture, being composed of two modules: Servers, represented by the programs located at a workstation (Linux platform), connected to the machine tool through an Ethernet network interface, responsible for the capture of images and supervisory control of the CNC turning center; and the client, represented by a Java Applet. The WebCNC teleoperation server is composed of the video server and teleoperation servers of the machine that provides command services, execution of programs, download and upload of programs, mistake proofing and other functions associated with the DNC2 communication protocol, available in CNC Fanuc 18i-TA, accomplishing the remote supervision of the machine. All control action is executed locally, based on the delay of the TCP/IP protocol. The video server is responsible for video and image capture using four cameras, and for their distribution through the TCP/IP protocol. The other servers, associated with the teleoperation services, work in a bi-directional way, receiving commands through the Internet and sending status data regarding the machine. The developed system is quite versatile and robust, allowing the production of parts remotely through the Internet, applying e-manufacturing and telemufacturing concepts, and the teleoperation environment is part of an integrated CAD/CAPP/CAM system for the design, process planning and manufacture of parts through the Internet.

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1. Introduction

It is tremendous the observed growth of the World Wide Web (WWW) along the last few years, with the implementation of several types of services through the Internet. Surveillance systems, sale of goods, remote maintenance and teleoperation of several pieces of equipment are some of the existing applications.

In this context, the development of systems that allow the remote manufacture of parts is important, because the client and the company that manufactures the parts can maintain contact at a distance, but in a direct manner. There is also the possibility of using systems of this type for remote education, because the equipment and accessories used for production,

whose cost is usually large, become accessible to students of institutions that do not possess such pieces of equipment. The system that is being implemented at the Group of Automation and Control at the University of Brasília aims at putting together a Flexible Manufacturing Cell for producing rotational parts. The components already installed in the Cell can be seen in <http://video.graco.unb.br>.

Robotic systems have been applied thoroughly in the automation of factories, space exploration, underwater exploration, military applications, etc., and are able to accomplish a series of tasks without the human presence and interference. Systems such as the Mars Pathfinder [1], which is a mobile robot sent to the surface of Mars, are capable of taking some independent decisions. The control of these systems is made remotely, and commands are transmitted by a great diversity of means, such as radio, microwaves and computer networks. Telerobotics using the Internet as the communication link is a new research field that is growing in the area of teleoperation, and there are many research groups acting in the promising area of telematics [2],

* Corresponding author.

E-mail addresses: alvares@AlvaresTech.com (A.J. Álvares), jcarlos@emc.ufsc.br (J.C.E. Ferreira).

mainly due to the low Internet access costs. Telematics refers to the use of computers in concert with telecommunications systems, which includes dial-up service to the Internet as well as all types of networks that rely on a telecommunications system to transport data.

The advantages of using the Internet for control is due to its versatility, since provides the user with a series of services, such as File Transfer Protocol (FTP), Telnet, WWW, electronic mail, allowing the transmission of information in a simple way, besides being available to many people, having an interface with many multimedia resources, with easy manipulation and low cost. All those characteristics have lead to the emergence of several Internet-controlled robotic systems. Telerobot of Australia (<http://www.telerobot.mech.uwa.edu.au>) is a teleoperated system for the Internet that allows the manipulation of objects through the use of a gripper [3]. RobWebCam (<http://www.graco.unb.br/robwebcam>) allows a remotely controlled manipulator (pan-tilt) to position a video camera transmitting video image in real time [4].

Telerobotics can be defined as an area of telematics and of Robotics for the teleoperation of robotic systems through the use of a communication link [4]. A new terminology is being used in the case of the application of Internet as a telecommunication link. In this case, it is referred to as WWW Robots or Internet Robot systems. This terminology is valid for applications that use industrial robots, manipulators, pan-tilts, CNC machines and other similar industrial equipment.

The present work aims at implementing a teleoperation interface using the WWW environment resources, to control a CNC turning center remotely (Romi Galaxy 15 M with CNC Fanuc 18i-ta), with the Internet as control means.

2. e-Manufacturing

Information technology (IT), especially the network communication technology and Internet, is beginning a new domain for building the future manufacturing environment called electronic-Manufacturing (e-Mfg) using work methods based on collaborative electronic-Work (e-Work), especially for the activities developed during the product development cycle in integrated and collaborative CAD/CAPP/CAM environments [5,6].

e-Work was defined by the PRISM Center [6] as any productive activity that is collaborative, supported by computer and communication in highly distributed organizations of robots and/or people or autonomous systems. In essence, e-Work is composed of electronic-activities (e-activities), i.e. activities based and executed through the use of IT.

This can be the path to be taken by these computer systems based on global environments, network centered and spatially distributed, making it possible the development of activities using e-Work. This will allow the designers to have greater communication, enabling the sharing and collaborative design during the development of the product, as well as the teleoperation and monitoring of the manufacturing devices.

In essence, e-work is composed of the following e-activities: v-(virtual) Design, e-Business, e-commerce, e-Manufacturing,

v-Factories, v-Enterprises, e-Logistics, and similarly, intelligent robotics, intelligent transport, and so on. All these e-activities depend on computer and communication technologies, and all require collaboration and inherent interactions among machines, people and computers. e-Work includes applications such as telerobotics, telemanufacturing, teleoperation and remote services.

2.1. Teleoperation and telemanufacturing

Teleoperation is defined by Álvares et al. [1] as the continuous and direct control of a remote machine. Initially developed for the manipulation of radioactive materials, teleoperation allows an operator to exercise force and accomplish movements through visual, resonant or tactile data. With the introduction of teleoperation technology, it was possible the development of interfaces capable of providing a satisfactory interaction between man and machine, allowing services of great ability to be accomplished.

A large number of classification schemes to describe teleoperation was proposed. One of those classifies teleoperation systems based on the degree of automation of the system. In a spectrum varying from minimum to maximum autonomy, teleoperation can be classified according to Álvares et al. [1]:

- manual control without computational aid;
- manual control with significant computational aid or transformation;
- supervisory control prevailing the control accomplished by the human operator;
- supervisory control prevailing the control accomplished by the computer;
- completely automatic control, where the human operators overlook the process without interventions.

Teleoperation requires synergy between man and machine. The operator is involved with the control and supervision of the system through an operation console and the corresponding man-machine interface. The system console is a graphic station from which the operator controls and supervises the remote system, assuming the existence of visual feedback. This characteristic makes the man-machine interface a fundamental element of the system. The main characteristic of the interface is the integration of all of the necessary information for operating the system, and relevant to the operator, including the display of video images, virtual models and graphic interfaces for control.

The man-machine interface has as main objective to provide a realistic and intuitive supervisory control that allows:

- to monitor the operation continually through displays based on video or virtual environments;
- to intervene interactively and to modify the objectives through the application of control commands while operating a space ball or the mouse in the graphic interface.

2.2. Teleoperation of remote laboratories through the Internet

Internet enables the creation of graphic environments relatively easily, which facilitates the interface with the user, besides having a low cost with regard to the teleoperated equipment. Being a communication network, it is possible to send and to receive information through it, which could be commands to be executed in some device connected to the network, and as examples of such devices there are a robotic system [3] or a CNC machine tool [7,1].

One of the most important characteristics of a network is its transmission rate. Since usually the commands transmitted for teleoperation need just a small volume of data, not demanding high transmission rate, it should not be difficult to implement telerobotic systems operated through the Internet. Another important aspect is the possibility of teleoperation to be performed from any place connected to the Internet at an insignificant cost, which is an interesting solution [8].

Teleoperation of remote laboratories based on the Internet can be accomplished through different methodologies, which include: remote access via Telnet; Common Gateway Interface (CGI) programming with simple HTML pages; and Java client using generic HTTP (Apache) servers and specific servers via sockets [9].

The teleoperation system on the server side can be based integrally on a solution through the WWW server (HTTPD server) providing the client with command actions through CGI or even Servlets. In this system it is not necessary the development of the server, just the programs that will allow the control of the equipment, usually developed in the C or Perl languages in the case of CGI, and Java in the case of Servlets. In Java it is necessary the installation of other APIs besides standard JDK to have access to the serial interface of the server, for instance.

By using specific servers oriented to the connection through sockets, it is necessary to develop the servers besides the programs for equipment teleoperation. This is the approach implemented in the teleoperation systems of the Nomad mobile robot

and the CNC oxi-cutting machine described in [1], which can be classified as “supervisory control prevailing the control accomplished by the human operator.”

3. WebTurning: teleoperation and monitoring of the CNC turning center

The WebTurning system allows the teleoperation of a CNC turning center Romi Galaxy 15 M with CNC Fanuc 18i-ta, which can be accessed in <http://WebDNC.graco.unb.br>, based on a client–server architecture using a methodology developed by Álvares and Romariz [2], composed of two main modules:

- Three servers, represented by the system for capturing images in real time (WebCam) and programs stored in a personal computer with Linux platform, which are connected to the CNC machine tool through the Ethernet interface and TCP/IP (socket) via the cgi-bin mechanism and inetd (WebDNC), and by the FOCAS1/DNC1 server installed in the CNC 18i-ta Fanuc of the machine tool. WebDNC and FOCAS1/DNC1 are modules of the WebCNC server.
- Clients, represented by Java Applets and HTML pages.

This remote control is possible through the remote functions made available by CNC 18i-ta Fanuc (http://www.geindustrial.com/cec/products?pnlid=2&id=cnc_mec_39), through the FOCAS1/Ethernet (Fanuc Open CNC API Specifications) protocol. Starting with this API and the FOCAS1/Ethernet driver installed in the CNC, accessed through a TCP/IP socket (164.41.17.20, 8193) using Ethernet communication network, it is possible to execute about 300 functions associated with the PLC and DNC. Fig. 1 shows the current communication means with CNC Fanuc 18i-ta, which contains the Ethernet network card and FOCAS1 communication protocol and DNC1.

Fig. 2 shows all the inputs, controls, mechanisms, outputs and functionalities that were proposed for the WebTurning module (using IDEF0 methodology), which define the CAM activities associated with the shop floor, CAM execution phase, in

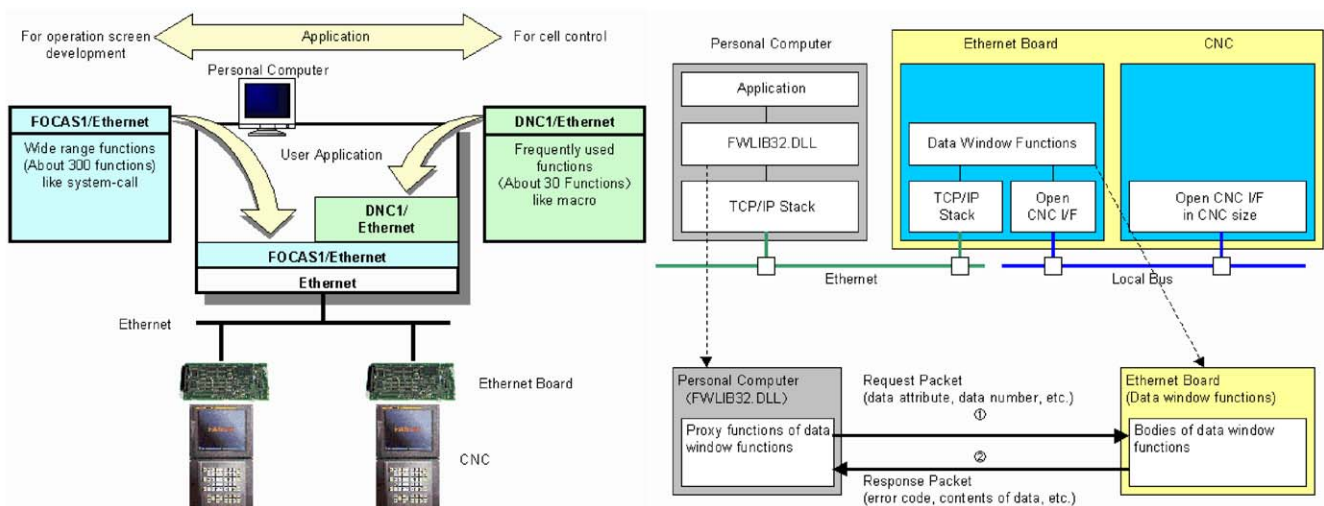


Fig. 1. API FOCAS1/DNC1 protocol [12].

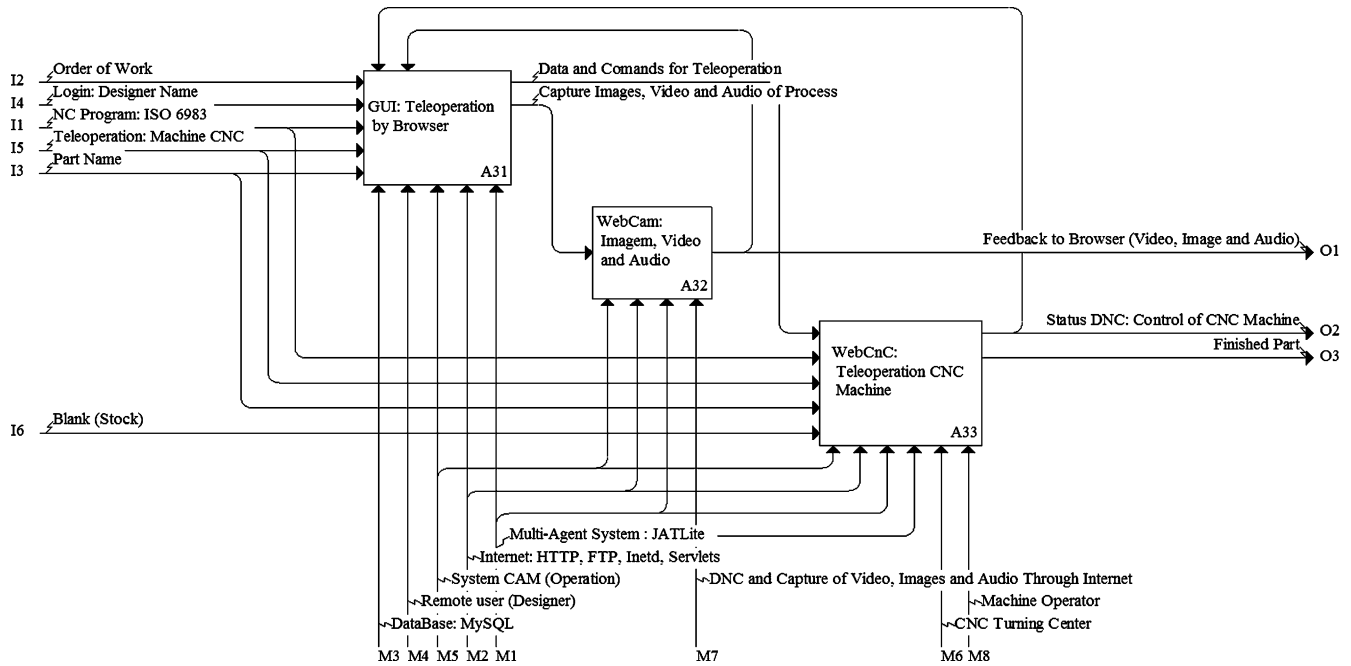


Fig. 2. IDEF0: activities associated with the CAM module (Teleoperation—WebTurning).

the context of the WebMachining architecture [13], for integrating CAD/CAPP/CAM through the Internet (<http://www.WebMachining.AlvaresTech.com>).

Thus, the WebTurning’s teleoperation server (Fig. 2) is composed of the video server (WebCam) and the teleoperation servers of the CNC machine (WebCnC): WebDNC and FOCAS1/DNC1 servers of the Galaxy turning center. WebDNC server provides command services, execution of programs, download and upload of programs, mistake proofing and other functions associated with the communication protocol provided by the manufacturer, working in a bi-directional way, receiving commands through the Internet and sending status data of the CNC turning center through FOCAS1/DNC1. WebDNC works in an intermediate layer, among the clients (PC) and FOCAS1 server (turning center). The WebCam video server is responsible for the video capture and its distribution through TCP/IP.

Thus, according to the ISO/OSI model for communication networks, we have the use of the Ethernet protocol for layers 1 (physical) and 2 (data link), and of the TCP/IP for layers 3 (network) and 4 (transport). Layer 7 (application) uses Fanuc FOCAS1 standard and DNC1.

To facilitate the use of WebTurning, the WebDNC graphic interface was developed based on Java and HTML (Fig. 3), accessed through <http://WebDNC.graco.unb.br>, from which it is possible to control the functions related to CNC, PLC and DNC, and these functions are divided into three groups, associated with its nature:

- *Reading functions*: they allow the reading of a series of data and configurations of the CNC machine, which allows the controller to know the initial conditions of operation of the turning center.

- *Writing functions*: through the data obtained through the reading functions, the user may want to modify some configurations. These functions allow the alteration of configurations, such as the change of axes of the turning center.
- *Program functions*: they allow the accomplishment of operations associated with the download and upload of NC programs, setup and cutting tool data.

4. Architecture of the WebTurning system (<http://WebDNC.graco.unb.br>)

The teleoperation system of the Galaxy 15M CNC turning center, called WebTurning, is based on a client/server architecture, composed of four basic modules, three of them being servers and one client (Fig. 4): video server (WebCam); FOCAS1 server stored in the turning center, represented by the CNC Fanuc 18i-ta; teleoperation WebDNC server that acts as an intermediate layer between the CNC and the client using access mechanisms through the Web, such as cgi-bin and inetd; graphic user interface (GUI) in Java and HTML. The WebDNC and FOCAS1 servers compose the WebCnC server.

4.1. WebDNC server

The Internet connection is implemented through communication channels called sockets [10] among the WebDNC modules and the user module. Usually this type of connection is programmed using the BSD Library calls (such as socket, bind and accept). In this work, the inetd server was used to establish the connection in order to facilitate the development of the servers [10]. The inetd server is used as a connections manager. This same approach is used by telnet, ftp and finger services,

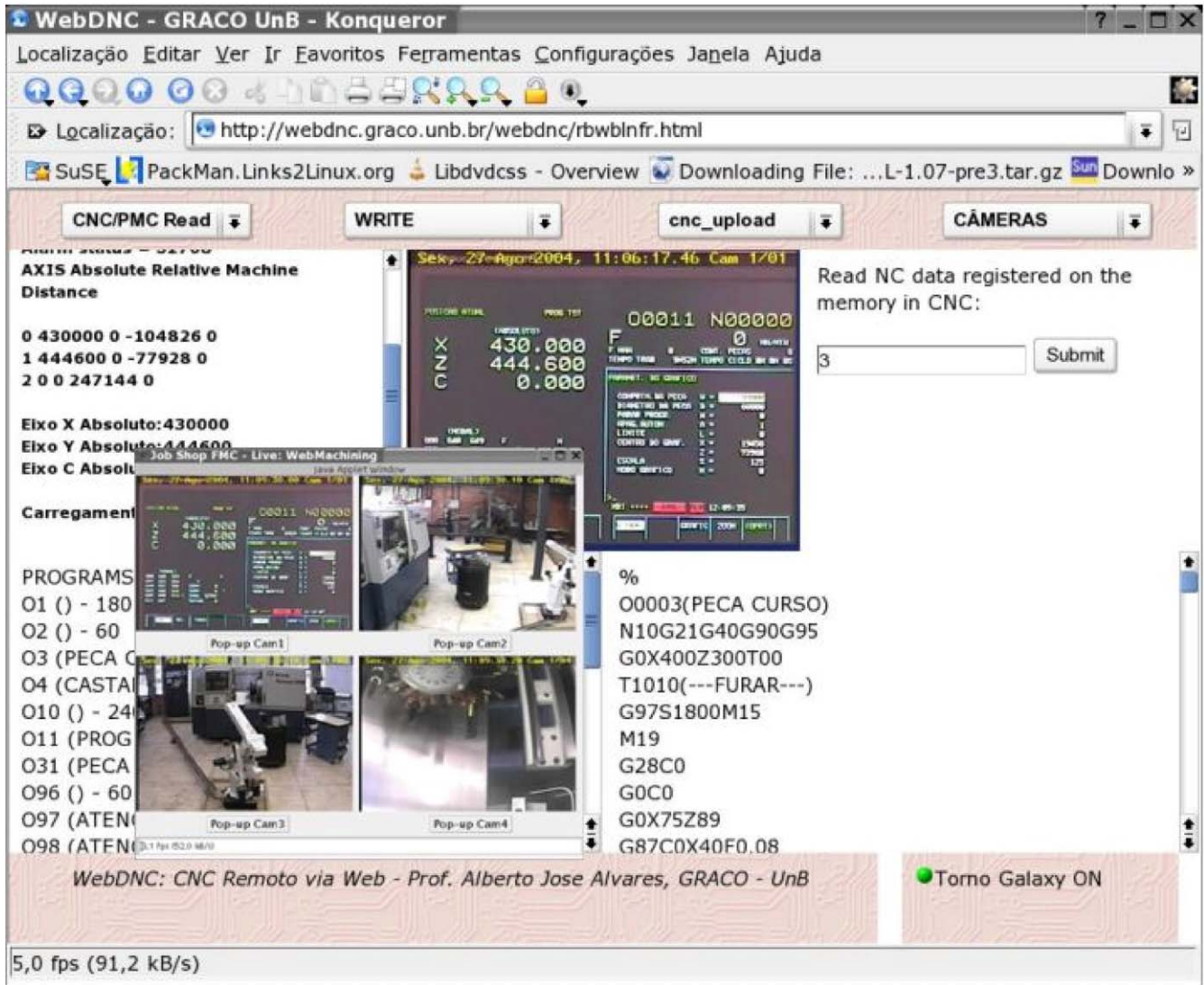


Fig. 3. WebTurning GUI—teleoperation and remote monitoring of the CNC turning center.

among others, in a Unix environment [11]. The inetd server, when receiving a connection through TCP/IP, creates a copy of itself through the fork command, and executes the server program, usually written in C or Perl, through the exec command.

The use of inetd is advantageous compared with conventional programming using the communication channels directly (sockets) because it reduces the load on the operating system and it facilitates the development of programs that accomplish the communication through the Internet.

The WebDNC server is based on HTTP/INETD/CGI-BIN servers, installed in a personal computer, under the Linux platform, allowing the access by the remote user through the Web (HTML and Java), which executes the desired function of FOCAS1 API. When executing the program in the local server, it is connected to the FOCAS1 server in the CNC, sending through the TCP/IP socket the necessary data structure to execute the function in the CNC. After the execution in the CNC, the status of the function is sent to the remote user through the Web (via TCP/IP). Each function provided by the FOCAS1 protocol is made available to the remote user through the following mecha-

nisms: cgi-bin, a function called through inetd or called directly through socket.

4.2. FOCAS1-CNC server

The FOCAS1/Ethernet server is stored in the CNC turning center. It provides a connection to the local Ethernet communication network through TCP/IP, using DNC1/FOCAS1 sockets configured to answer requests for IP 164.41.17.20, in the 8093 port. Through this socket one can access the Fanuc driver, which implements the functions of the FOCAS1/DNC protocol. Through a browser, the remote user is connected to the WebDNC server, and executes the desired function, which through the socket sends a data structure to the CNC, implementing the functions provided by the FOCAS1 protocol. There are about 300 functions that can be accessed through FOCAS1 protocol and 30 functions through the DNC1 protocol. This server is proprietor to FANUC, being activated and configured only in the CNC. The FOCAS1 development API, available only in the Windows platform, is supplied by FANUC at a certain cost, and it is still

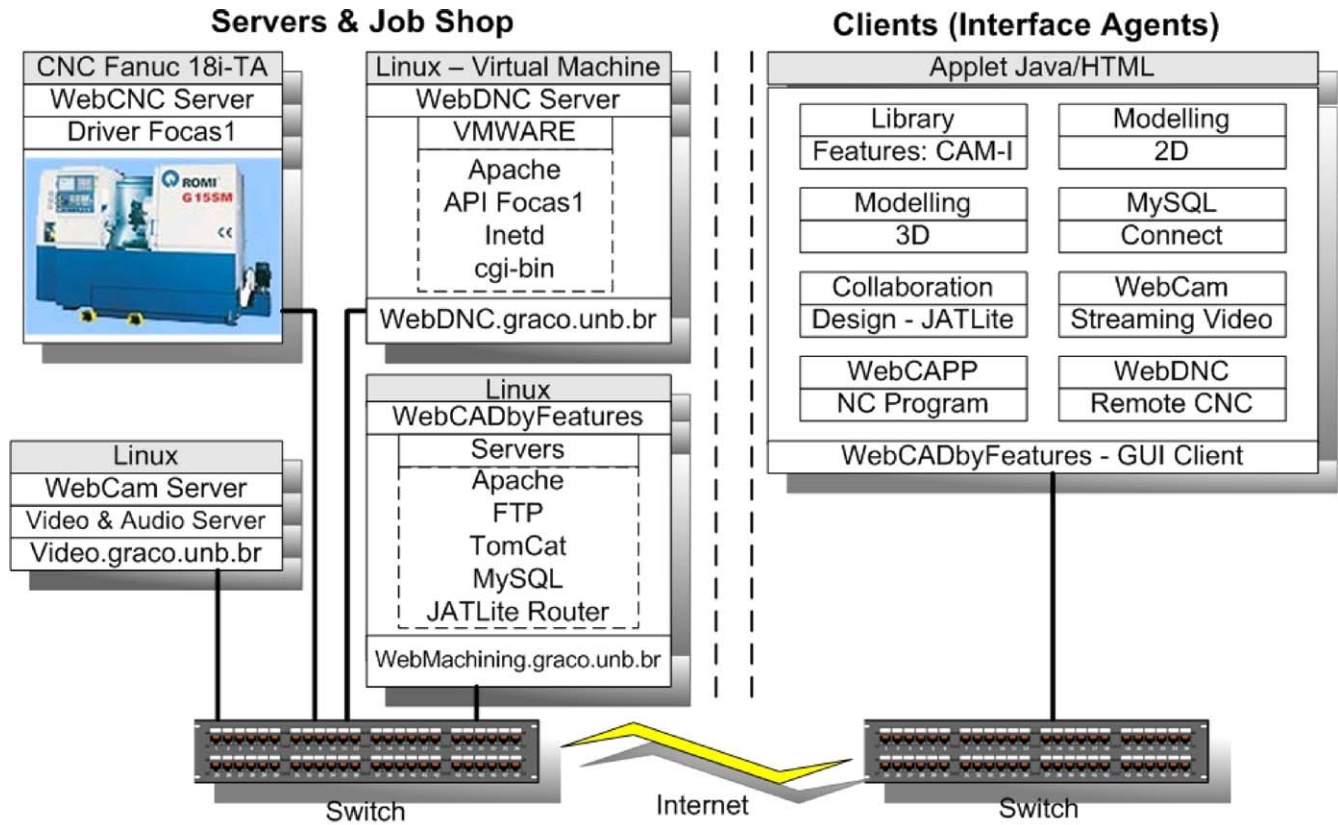


Fig. 4. Detailed architecture: modules of the WebTurning system.

necessary to activate the FOCAS1 drive in the CNC FANUC, as well as to accomplish the configuration of the sockets in the CNC.

4.3. Video server: WebCam

The video server (Fig. 5) is responsible for video capture and sending of images through the Internet. The images are captured by an image capture card based on the Conexant B878 chip, converted to JPG and sent to the remote user in the streaming form, through a TCP/IP socket.

The WebCam video server is implemented in the Linux platform, and it provides the remote user with a connection through sockets to the NetCam system (server and client), allowing the capture of up to 16 video inputs, conversion of the captured images to JPEG format, movement detection and recording of the images in JPEG; and finally the sending the streaming of JPEG images to the remote user (30 frames/s per each image processor per card) for animation on the user’s side through a Java Applet, or even using the server-push animation mechanism present in Netscape and other browsers. The server is available in <http://video.graco.unb.br>.

The video server also allows its configuration through socket, and it can activate movement detection, adjust quality of the JPEG image, determine the template to be applied to the images seeking definition of areas of the image for movement detection, adjustment of brightness, contrast, among other adjustment options. More cameras can be included in the system, due to the

modularity of the WebCam system. In this implementation, four cameras were used, enabling the user’s immersion in the shop floor.

4.4. FOCAS1/Ethernet functions for the teleoperation of the CNC turning center

The functions specified by the FOCAS1/Ethernet library were divided into three groups, and Fig. 6 shows an example of some implemented functions.

Through the reading functions the configuration data and CNC/PLC memory are obtained. With the writing functions the user can alter the configurations. With the program functions the user can download and upload programs, as well as to execute programs stored in the CNC memory.

C, HTML, CGI, Java and JavaScript programming languages were used for the development of the teleoperation system, which is available in <http://WebDNC.graco.unb.br/>.

The remote user accesses the homepage with a command screen divided into frames corresponding to the functions, as well as the several pieces of information regarding the CNC turning center. Each function has a WWW corresponding page, which describes the operation of the function and asks for the user to define the function parameters. The reading of those parameters is performed by CGI or a specific server via inetd. The user is connected to the WebDNC server, which establishes a communication through socket with the CNC according to the FOCAS1/DNC1 protocol, sending through the Ethernet network

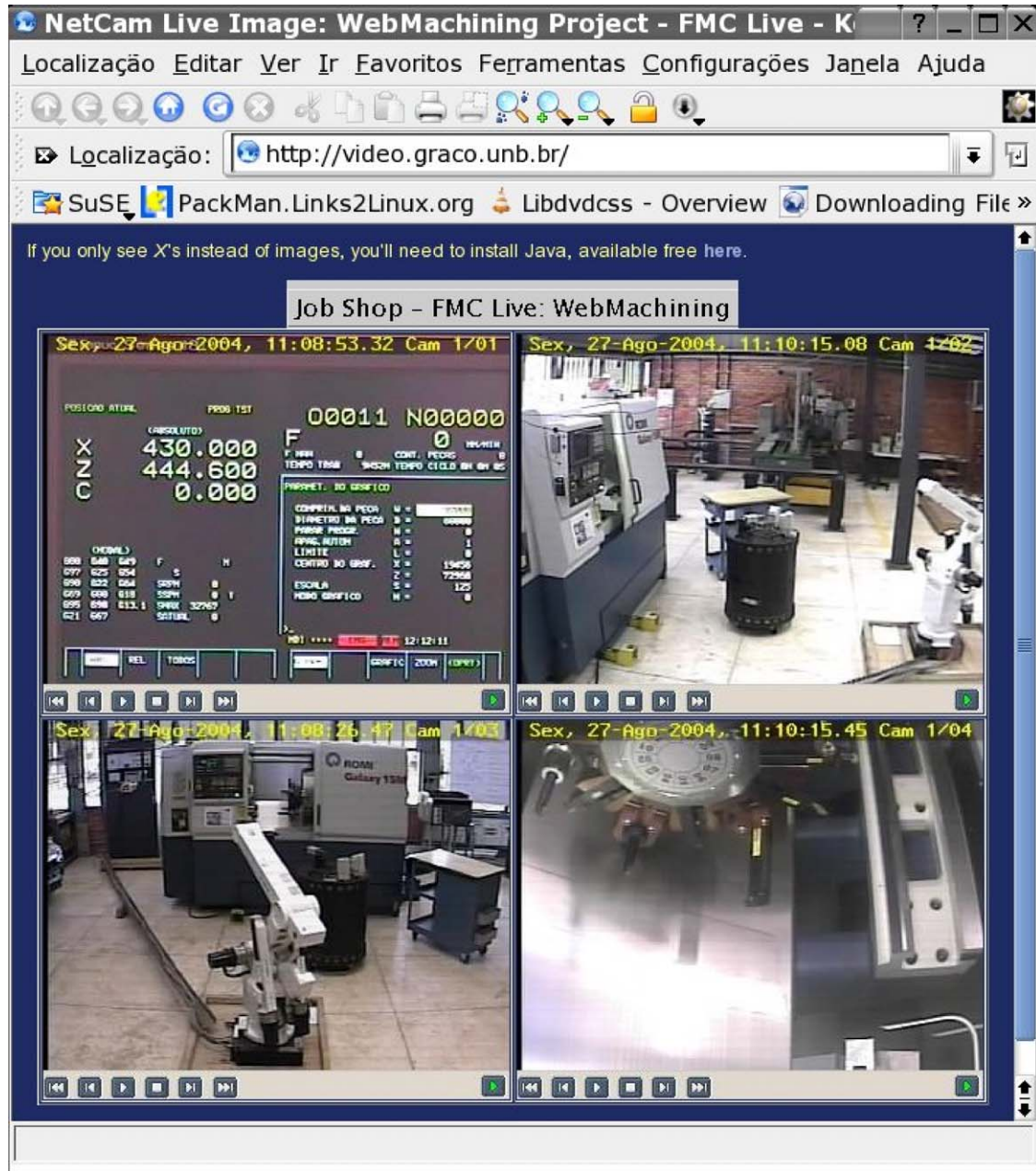


Fig. 5. WebCam (NetCam) monitoring system by image, composed of four Applets, which monitor the CNC screen, the inside and the outside of the machine.

and TCP/IP the telegrams and receiving their respective answers or error messages, which are presented in the HTML format and streaming of data, and visualized in the command screen and on Applets.

5. Implementation of the WebTurning system (<http://WebDNC.graco.unb.br>)

5.1. WebCNC: WebDNC and FOCASI servers

The WebDNC server (in the PC), which accesses the WebCNC server (in the CNC) was developed in Microsoft Visual C++ in the Windows platform and installed in a Windows virtual machine in a PC with Linux operating system,

using the VMware server (<http://www.vmware.com>). Thus, the WebTurning servers are executed in the Linux platform, in spite of the FOCASI API having been developed for the Windows platform. The programs were developed to be executed through WWW/HTTP for CGI-BIN executable programs via sockets/inetd, which implement the FOCASI protocol. This way, each of the functions has its corresponding program. Each CGI program through FOCASI API has modules that accomplish the following tasks: reading of the data sent by the form; assembly of the telegram to be sent; initialization of the socket (IP and TCP port of the CNC: 164.41.17.20, 8193); establishment of the communication through the FOCASI data structure; sending and receiving of telegrams; closing of the socket; verification of the received telegram; assembly of the home-

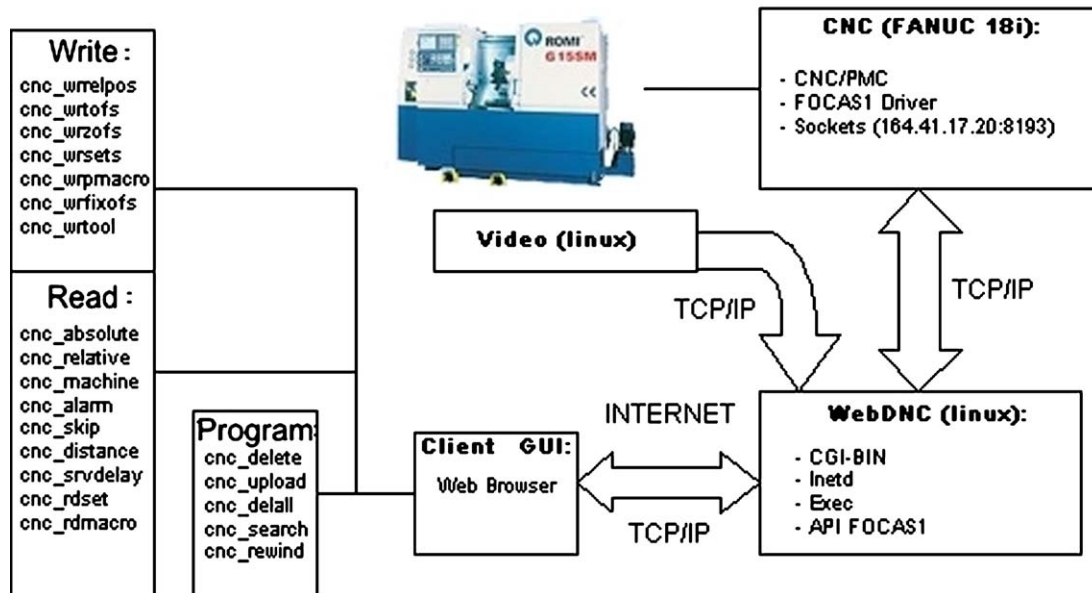


Fig. 6. Architecture, data flow and some functions provided by WebTurning.

page and Applet that will be presented to the user with the answer.

The FOCAS1 server in the CNC accepts connections through TCP/IP via the program/server `inetd` (daemon) configured to accept connections through the 8193 port. Once established the connection, the server awaits for commands sent by the user (browser) executing them if the syntax is correct. Fig. 6 shows the commands accepted by the WebTurning server.

5.2. User interface: client–server GUI

The GUI (Fig. 3) is implemented using Web technology, especially the HTML, JavaScript and Java programming languages. The GUI consists of several Applets and HTML forms, which are loaded by the browser (<http://WebDNC.graco.unb.br>).

The functions that request a streaming of data, such as images captured by the cameras and dynamic data sent by the Fanuc CNC, are implemented in Java, reading the data flow received by the socket. The static functions (e.g. download and upload of programs) were implemented, in this first version of the GUI, through HTML and forms, connecting to the WebDNC server through the `cgi-bin` mechanism.

Fig. 4 presents the detailed architecture of the system, where the main modules of the teleoperation system are presented through TCP/IP.

A Web interface with the user was developed where all functions are controlled (Figs. 3 and 6). Through the menus the remote services for teleoperation corresponding to the functions of the FOCAS1/Ethernet library can be accessed. A HTML file was created for each function, which can be executed by the CNC (screen of functions). There is a menu of options that allows the activation of the graphic feedback. The status screen allows the state of the CNC to appear on the screen (position, operation mode and main configuration). The sending screen presents the telegram to be sent, and can be corrected or edited before being

sent. The reception screen shows the field of data of the telegram received by the CNC.

Fig. 3 shows the main screen of the WebTurning system, in which it can be visualized, in the upper frames, the menus through which the user selects the functions. In the second line of frames the three windows are: the status window, the graphic feedback window and the function window. The third line contains the sending windows and reception of messages.

6. Conclusions

The implemented GUI for the teleoperation of the CNC turning center is presented in Fig. 3. The system can be accessed in <http://WebDNC.graco.unb.br>. The developed system is one of the modules of the methodology and architecture for e-Manufacturing called WebMachining, which implements a CAD/CAPP/CAM integration methodology through the Internet (<http://www.WebMachining.AlvaresTech.com>).

This first version is partially finished, having completed the WebCam server and the client for on-line monitoring. The CNC teleoperation servers are under implementation, having finished so far about 70 functions, of the 300 available functions. It was chosen the most pertinent functions for teleoperation of the turning center. After the implementation of the other functions in the WebDNC server, it will be developed one more client totally based on Java, emulating the CNC screens, increasing the remote user's degree of immersion in the shop floor.

The FOCAS1/Ethernet protocol only allows direct access to the CNC machine and some PLC functions, associated with the ladder, and are carried out indirectly through calls to the PLC through FOCAS1. Functions associated with the CNC keyboard, such as "cycle start", "MDI", "Edit", "Jog", are accessed through ladder, and are under implementation.

Fanuc has several pieces of software for teleoperation of CNC 18iTa, such as CNC Screen and BOP (Basic Operation

Package), all being developed as part of the Cimplicity architecture, having a high cost. None of the FANUC programs allows teleoperation through the Web and multiplatform, only working under Windows architecture. The WebTurning system presents as contribution a client/server architecture, based on the Web technology and multiplatform, which can be accessed through the browser without any software proprietor's need for teleoperation. It also allows the remote user's immersion in the shop floor through the monitoring with video in real time and for movement detection, recording of images and playback of events in the shop floor.

The bandwidth and the inherent delays of TCP/IP impose a strong restriction to the teleoperation systems through the Internet. To solve this problem it is necessary to endow the teleoperation system, in the server close to the CNC, with mechanisms that enable decision making in critical situations, without depending on the client side, in the case of the user/operator. The capture of images in real time is fundamental to allow immersion of the operator in the system, enabling greater safety for sending commands. As there is an inherent delay to TCP/IP, a lot of care should be taken in the command actions executed remotely.

Therefore, it is necessary to endow the system with some intelligence to solve conflicts that can happen during the teleoperation process. To provide the system with safer teleoperation, an architecture for supervisory control should be used, where the control actions are executed locally, starting with the request by a remote command performed by the client. Thus, the WebTurning system is classified as "supervisory control prevailing the control accomplished by the human operator."

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