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ORIGINAL ARTICLE

A system for the design and manufacture of feature-based parts through the Internet

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Abstract The Internet has enabled the development of applications for supporting the design and manufacturing of industrial parts and products. Some actions have been performed by some research groups in different parts of the world aiming at conceiving product modeling systems based on the technology of features to allow information sharing, both for the activities related to product development and for manufacturing. This paper describes the implementation of the WebMachining system (http://www.WebMachining.AlvaresTech.com) developed in a context of e-Mfg and concurrent engineering, aimed at integrating CAD/CAPP/CAM for the remote manufacturing of feature-based cylindrical parts with symmetrical and asymmetrical features through the Internet, using an approach based on multi-agent systems. The information referring to the features is manipulated through a relational database management system. The graphic user interface (GUI) is implemented in Java and HTML. In this GUI, the user inputs the information on the design features that compose the part. Then these data are sent to the server. Since the part is cylindrical, the user models the part in two dimensions, and it can be visualized as three-dimensional through VRML. A database was implemented that stores the information on the product modeled by features, containing information associated with the form features, material features, tolerance features and technological features. These combined pieces of information allow the mapping of design features into machining features, which is fundamental for process planning. The database information is described in this article through the IDEF1X information model.

Keywords Features · Collaborative design · E-manufacturing · Multi-agent system · Internet

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1 Introduction

A new revolution in the labor system adopted in the manufacturing companies is occurring. It corresponds to the change from computer-aided activities (i.e. CAD, CAPP, CAM, etc.), developed in the 1980s and 1990s, to the e-Work activities (electronic-Work), which characterize the principle of work in the information age, with intensive use of information technology (IT).

IT, especially the network communication technology and the convergence of wireless and Internet, is opening a new domain for building the future manufacturing environments called e-Mfg (electronic-manufacturing), using labor methods based on collaborative e-Work, especially the activities developed during product development in integrated and collaborative CAD/CAPP/CAM environments. This is a new approach for these computer systems based on global environments, network-centered and spatially distributed, enabling the development of activities using e-Work. This will allow product designers to have easier communication, enabling the sharing and collaborative design during product development, as well as the tele-operation and monitoring of the manufacturing equipment.

This work presents a description of the implementation of the WebMachining system (http://www.WebMachining.AlvaresTech.com) developed in an e-Mfg context aiming at CAD/CAPP/CAM integration for the remote manufacture of cylindrical parts through the Internet. The system is conceived with the collaborative modeling paradigm based on the synthesis of design features, in order to allow the integration of the activities of collaborative design (WebCADbyFeatures), generative process planning (WebCAPP) and manufacturing (WebTurning). The system is implemented in a distributed agent environment (agents' community), and the architecture is structured in three levels: design, process planning and manufacturing. Additionally, and the knowledge query and manipulation language (KQML) was adopted as the pattern language of messages among the design, process planning and manufacturing agents.

2 Collaborative CAD and related systems

In design engineering practice, even more activities associated with the several manufacturing aspects are being considered during the design phase. Feature-based modeling has been used in the integration of engineering activities, from design to manufacturing. Thus, the concept of features has been used in a wide range of applications such as part design and assembly, design for manufacturing, process planning and other countless applications. These applications are migrating to heterogeneous and distributed computer environments to give support to the design and manufacturing processes, which will be distributed both in space and in time.

Many research efforts have been made in the development of design environments oriented to computer networks, usually called network-centered. Shah et al. [1] developed architecture for standardization of communication between the kernel of a geometric modeling system and the applications. Han and Requicha [2] proposed a similar approach that enables transparent access to several solid modelers.

Smith and Wright [3] described a distributed manufacturing service called Cybercut (http://www.cybercut.berkeley.edu), which makes possible the design of a prismatic part that will be machined using a CAD/CAM system developed in Java in a context of remote manufacture.

Shao et al. [4] described an agent-based process-oriented intelligent collaborative product design system based on the Analysis-Synthesis-Evaluation (ASE) design paradigm and the parameterization of product design. Hardwick et al. [5] proposed an infrastructure that allows the collaboration among companies in the design and manufacture of new products. This architecture integrates WWW for sharing information in the Internet using the STEP standard for product modeling. Martino et al. [6] proposed an approach to integrate the design activities with other manufacturing activities based on features, which supports both feature-based design and feature-recognition.

Collaborative modeling systems typically have a client/server architecture, differing in the functionality and data distribution between customers and servers. A common problem in the client/server systems is associated with the conflict between the limitation of the complexity of the client application and the minimization of the network load. A commitment solution can be conceived between the two ends, the so-called thin and fat clients. A pure thin client architecture typically places all the functionality in the server, which sends an image of its user interface to the client.

On the other hand, a pure fat client offers total interaction and local modeling, maintaining its own local model. Communication with the server is required when it is necessary to synchronize the data modifications in the local model with the other clients.

Lee et al. [7] presented the architecture of a network-centered modeling system based on features, in a distributed design environment, called NetFeature System. This approach combines feature-based modeling techniques with communication and distributed computing technologies in order to support product modeling and cooperative design activities in a computer network.

The WebSpiff system [8] is based on a client/server architecture consisting of two main components on the server side: (1) Modeling System SPIFF, which supplies all the functionality for feature-based modeling, using the ACIS modeling kernel [9]; (2) Session Manager, which supplies functionality to start, associate, finish and logout a modeling session, and manages all the communications between the SPIFF system and the clients.

Li et al. [10] and Fuh and Li [11] mention several distributed and integrated collaborative design systems and concurrent engineering, and none of these systems implements collaborative design activities integrated with process planning and remote manufacturing systems via Web for the cylindrical parts domain, with symmetrical and asymmetrical features. Most of those systems consider prismatic parts, like WebCAD 2000 of the Cybercut system [3], which does not implement collaborative design.

The development of the WebCADbyFeatures collaborative design system differs from the above systems, because it models cylindrical parts, based on synthesis of design features (symmetrical and asymmetrical), having as motivation the development of an integrated CAD/CAPP/CAM system that allows the collaborative design through the web, in a context of concurrent engineering.

3 The Webmachining system

The integration among the production stages is one of the roads that should be explored in the search to reduce manufacturing costs and times. According to Shah and Mantyla [12], product modeling is the central point for achieving such integration. In an integrated production system, the product model, defined in the CAD module, should be available for other modules (CAE, CAPP, CAM, CAQ, etc) so that these can accomplish their functions. These modules should also be capable of sending feedback information to the CAD module, in order to enable the necessary changes in the part to be made during the design stage (for instance, due to problems detected in production). The use of features as an information base for product modeling is the road to reach this integration [13, 14].

IT, especially communication network and Internet technology, is beginning a new domain for building the future CAD/CAPP/CAM environments [7], and these are potential candidates to enable the development of integrated systems. This will allow the designers to have easier communication, enabling the sharing and the collaborative design during product development. With the growth in popularity of the web-based navigators, it is becoming more evident that the network-centered design environment will be increasingly used for product development.

Figure 1 presents part of the IDEF0 model of the proposed system, called WebMachining, which is divided into three basic activities: collaborative product modeling (WebCADbyFeatures), generative CAPP (WebCAPP) and CAM (WebTurning).

The product development procedure in the WebMachining architecture (http://www.WebMachining.AlvaresTech.com) begins with the feature-based collaborative modeling of a part, where two or more design agents cooperate during two-dimensional and three-dimensional part modeling, using the Web as a means of communication, in a client/server computer model.

The client, WebCADbyFeatures interface agent (Fig. 2), is connected to the neutral feature modeler via Web, and it begins the instantiation of a new part to be modeled from a database, using a library of standardized form features, made available by the system.

The graphic user interface (GUI) is implemented in Java and HTML, and through it the user inputs the information about the design features that will compose the part. Then, these data are sent to the server. Since the part is cylindrical, the user models the part in two dimensions, and may visualize it in three-dimensional through VRML. A database was implemented in MySQL that stores the information on the product modeled by features, containing information associated

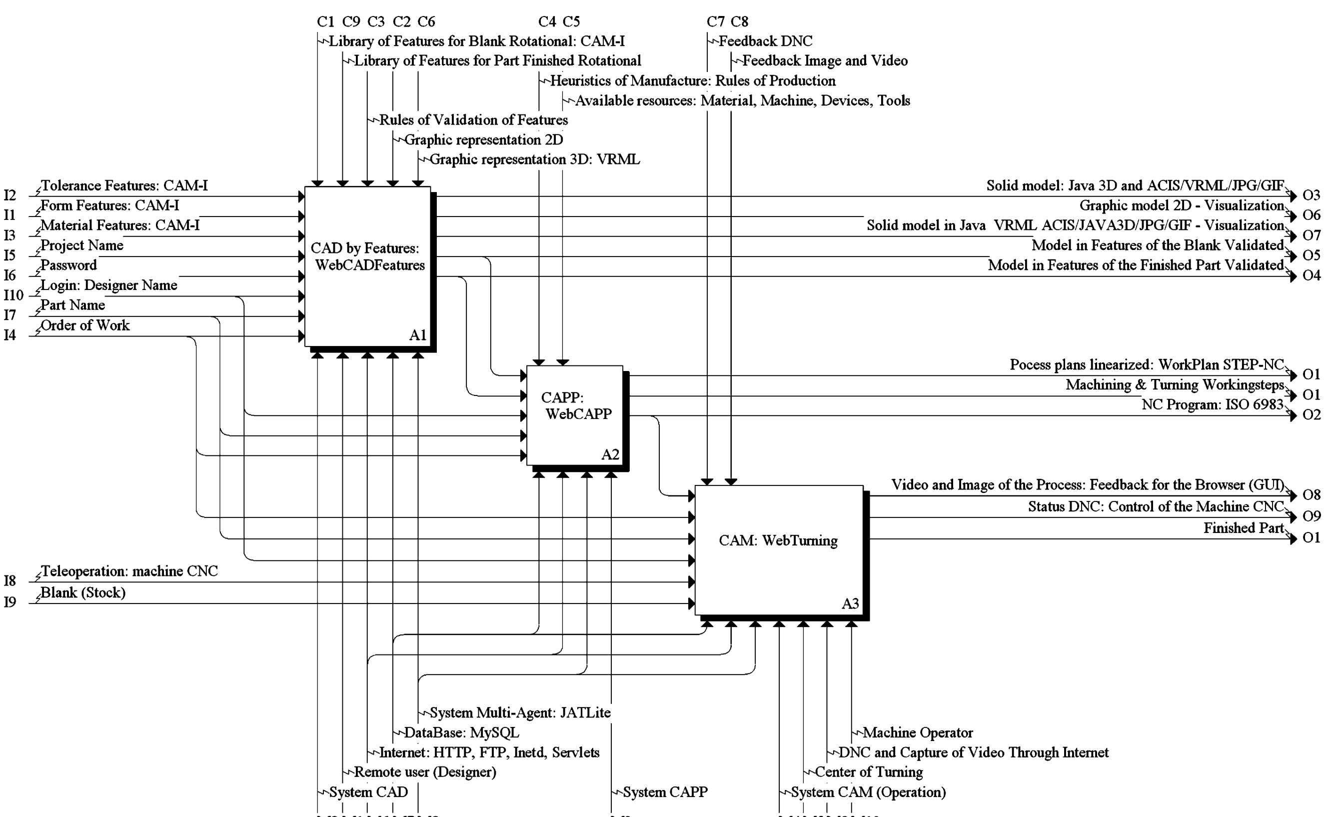


Fig. 1 Modeling of the WebMachining system, using the IDEF0 methodology

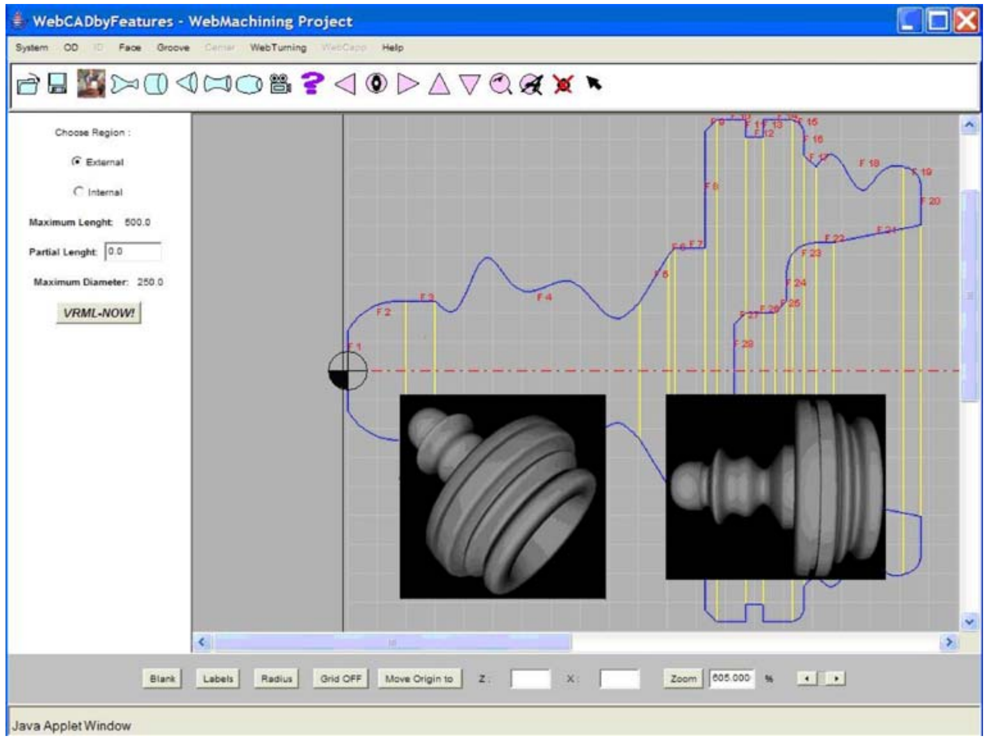


Fig. 2 Main window of the WebCADbyFeatures system, showing the profile of a rotational part

with the form features, material features, tolerance features and technological features (surface treatment, thermal treatment and production data). This combined information allows the mapping of the design features into machining features, which is fundamental for process planning.

After concluding and validating the model, the designed part is stored and made available to the CAPP module to generate the process plan, whose final representation is based on STEP-NC (ISO 14649, part 12). Finally, the NC program for a CNC turning center is generated (http://www.video.graco.unb.br).

The communication with the CNC turning center Romi Galaxy/CNC Fanuc 18i-Ta is accomplished through an Ethernet connection (physical and connection layers of the ISO/OSI standard), using the TCP/IP protocol (network and transport layers of the ISO/OSI standard) associated with the Focas1 application protocol /Ethernet libraries of Fanuc. Focas1 (Fanuc Open CNC API Specifications) is an API for developing applications using a standardized data structure, which has access to 300 CNC functions (http://www.webdnc.graco.unb.br).

The teleoperation system of the CNC turning center, called WebTurning (Figs. 1 and 3), is based on a client/server architecture. The server is composed of two modules: WebCam and WebDNC servers, represented by programs located at a workstation (Linux platform), logically connected via TCP-IP sockets and Ethernet network to the machine-tool and to the clients, being responsible for image capture and supervisory control of the CNC turning center, respectively; the clients' side is represented by Java Applets and HTML pages.

The WebTurning teleoperation server is composed of the video and teleoperation servers of the CNC machine, which makes available command services, program execution, program download and upload, troubleshooting and other functions associated with the DNC1 communication protocol (CNC Fanuc 18i-TA), accomplishing the remote supervision of the machine. Every control action is executed locally, due to the delay of the TCP/IP protocol. The video server performs video and image capture with four cameras, and the images are sent to the client 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 machine status data.

4 Multi-agent architecture for the Webmachining system

The proposed architecture for the multi-agent system (MAS) can be characterized by the agents' behavior as being Deliberative, in the internal organization as being of the Blackboard type, and in the architecture itself as being of the Federated type using the Facilitator approach [15].

Currently, the use of an architecture based on a multi-agent system is certainly the most attractive, mainly due to the evolution of operating systems, especially Unix for personal computers, and the use of network communication

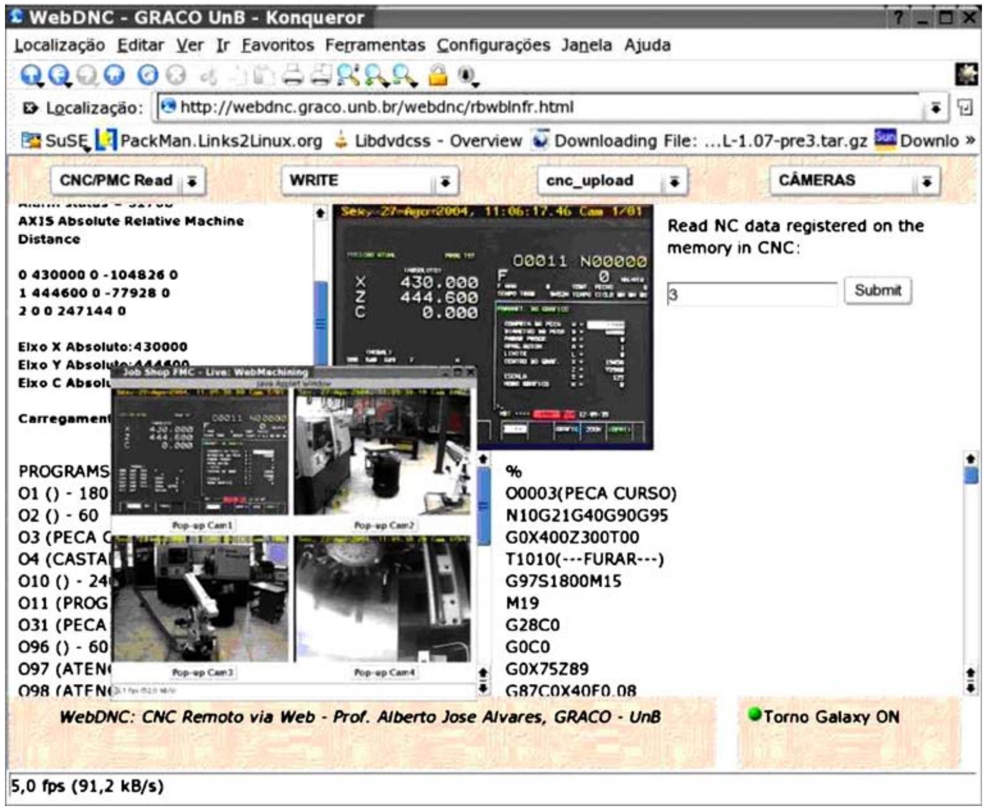


Fig. 3 WebTurning: teleoperation and remote monitoring of the CNC turning center

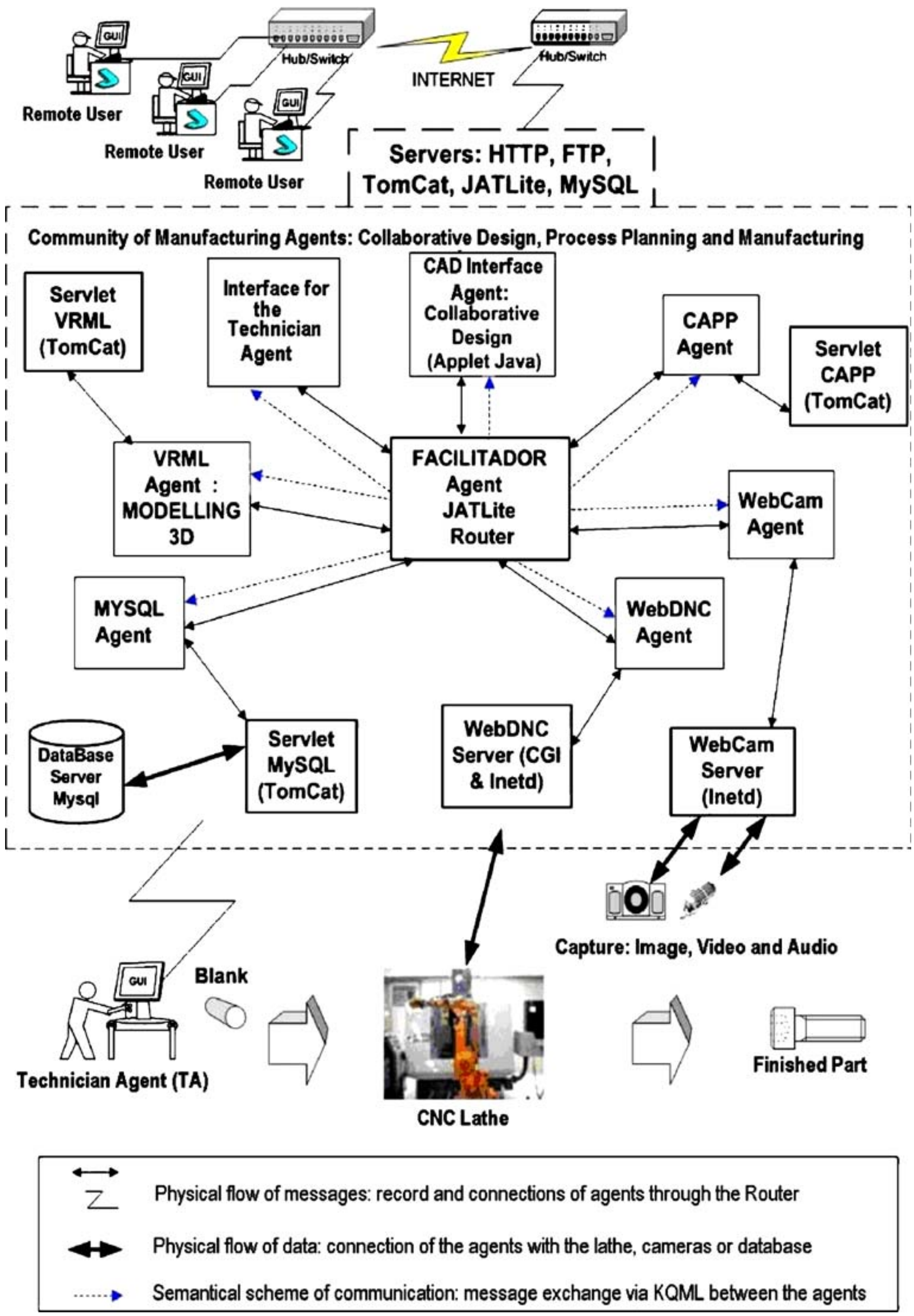
based on TCP/IP in a client/server architecture [16]. In this way, several types of agents working cooperatively and in a distributed way can be used in order to solve many problems associated with CAD/CAPP/CAM integration in a context of a community of agents.

The JATLite (Java Agent Template Lite) software tool is used for implementing the collaborative product design system. JATLite (http://www.java.stanford.edu/index.html) is a software written in Java that allows the users to create agents that communicate in a robust way over the Internet. JATLite offers a basic infrastructure in which agents that are registered in an agent message router (AMR), usually called facilitator or mediator, use a name and a password, being connected and disconnected through the Internet, sending and receiving messages, transferring files via FTP and usually exchanging information with other agents via the many computers they run. These means are used for developing the management system of the collaborative design sessions, where a design agent interface makes available its design for the other participant agents of the product modeling session.

The proposed architecture is composed of six groups of agents (Fig. 4), which are as follows:

– Facilitator agent (FA): performs communication management among the agents, managing the routing of messages among the agents, system safety and agents registration. It is implemented through the Message Router Agent. The AMR is very important in the JATLite environment, because the agents always communicate with other agents through AMR.
– Database manager agent (DMA): performs the interaction with the MySQL database. Any agent that wants some information from the database (SQL language) makes a request to DMA, and this sends the answer to the agent that requested the information. The facilitator agent accomplishes the routing of the messages among these agents.
– Collaborative design(CADIA): a GUI for feature-based design, implemented through a Java applet. This GUI is executed by a remote client aiming at specifying the model and geometry of the raw material and the finished part based on features. Also, it has a collaborative design procedure embedded into the interface. This agent will communicate with the community of agents through a connection to FA, and this will perform message routing to the correct agent. Messages are sent to the other modules of the system and users, communicating the data regarding the design underway (i.e. the product model) containing information such as: user, part name, design name, etc. This will allow the identification of the product model that the client is creating. The connection with the MySQL database is accomplished directly with the PHP (personal home page) mechanism, in order to improve the execution of the system; the GUI is not used for this

Fig. 4 Multi-agent architecture of the WebMachining system



purpose. In other words, the creation of the part by features and the verification of the feature library are carried out through PHP. The three-dimensional visualization of the product model is managed through CADIA, which communicates with the three-dimensional modeling agent. Figure 2 shows a prototype of the developed GUI, a Java applet, and the three-dimensional visualization of a part through VRML.

– Remote user CAM interface agent (CAMIA): every GUI associated with CAM that is executed by a remote user and is used to teleoperate the CNC machine, has CAMIA embedded in the interface. This agent communicates with the community of agents through a connection to the FA, performing message routing to the corresponding agent.
– Three-dimensional VRML based modeling agent (VRML): responsible for three-dimensional modeling using the VRML (virtual reality markup language). It receives messages from CADIA for building three-dimensional part models based on features.

- Process planning agent (WebCAPP): responsible for process planning.
- WebCam agent (WebCam): responsible for the video and image capture of the teleoperation system, sending the captured images directly to the GUI associated with CAM. It receives messages from FA regarding the user identification, login and password, to allow the execution of the WebCam server (Fig. 4).
- WebCNC agent (WebCNC): responsible for the remote control of the CNC machine, receiving commands and sending the machine status to the GUI associated with CAM. It receives messages from FA regarding the user identification, login and password, name of the file with the NC program and process planning data (fixtures, tools and raw material), and is responsible for the implementation of the distributed numeric control (DNC) protocol through the Web (Fig. 3).
- Machine operator interface agent (MOIA): a GUI that instructs the operator on the shop-floor, and is implemented through a Java applet. The operator interface agent (MOIA) gives the instructions to the operator about fixturing the raw material, tools setup, machine preparation, production scheduling, among others.
- Operator agent (OA): corresponds to the machine-tool operator, who receives instructions for fixturing the raw material, tool setup, machine setup, production scheduling of a part and other data associated with process planning that can only be treated by a human operator.

5 Feature-based design

According to Shah and Mäntylä [12], two design-by-features methodologies are commonly used: Destruction by Machining Features and Synthesis of Design Features. The destructive approach is also known as Destructive Solid Geometry or Deforming Solid Geometry (DSG).

The Destruction by Machining Features approach begins with a model of the raw material that will be machined. The part model is created by subtracting from the raw material the features that correspond to the material removed by machining operations, usually milling and drilling. The advantage of this method is that the machining features are directly available in the part model, being unnecessary feature-recognition. A disadvantage consists of the fact that the designer should have a wide knowledge of manufacturing, which forces the designer to think in terms of manufacturing features. Usually, the designer is interested, initially, in the shape of the part and in the functional aspects.

In the second approach, Synthesis of Design Features, the model can be built both by union and subtraction, not being necessary to begin with a model of a raw material. In the Feature-based Design approaches, the parts are created using features directly, and the geometric model is generated from the feature-based model. This requires that the design system has generic definitions of features made available by the Library of Features, allowing the instantiation of the features for specifying dimensions, location parameters, the feature/face/edge on which it is located, and several other attributes, constraints and relationships.

The WebCADbyFeatures module uses the synthesis of design features approach, applying a features taxonomy (Fig. 5) based on CAM-I [17] and on the ISO 10303-224 standard (STEP: standard exchange of product model data).

The form features are added to the feature model, associated with the turning operations in a turning center. It also has form features that are subtracted from the part model such as grooves and holes, which are associated with C-axis operations.

5.1 WebCADbyFeatures: conceptual information modeling

The conceptual information model was modeled through the IDEF1X methodological approach (Integrated Computer Aided Manufacturing DEFinition). With this IDEF1X model, the physical database model and the MySQL database management system (found in http://www.WebMachining.AlvaresTech.com/db/modelo_fisico) were generated, and also the library of classes associated with the features. This information model is divided into domains associated with the feature database (form features, tolerance features, manufacturing features and material features) and the machining technology database (machine-tool library, cutting tool library, machinability library and fixture library). The feature database is linked with the product model, whereas the machining technology database is linked with the resource model. The features used in the implementation of this first version of the WebCADbyFeatures module were cylindrical concentric, shown in the hierarchical diagram in Fig. 5. Figure 6 shows an example of UML diagram, with a portion of the feature library that was implemented.

5.2 WebCADbyFeatures: physical information modeling - MySQL

For the implementation of the data models, the server of the MySQL relational database was selected. A library of Java classes with the UML models (Fig. 6) was also developed, in order to increase the functionality of the database.

The connection between the WebCADbyFeatures Java applet and the MySQL database is done through servlets, adopting a three-tiered approach, as shown in Fig. 7.

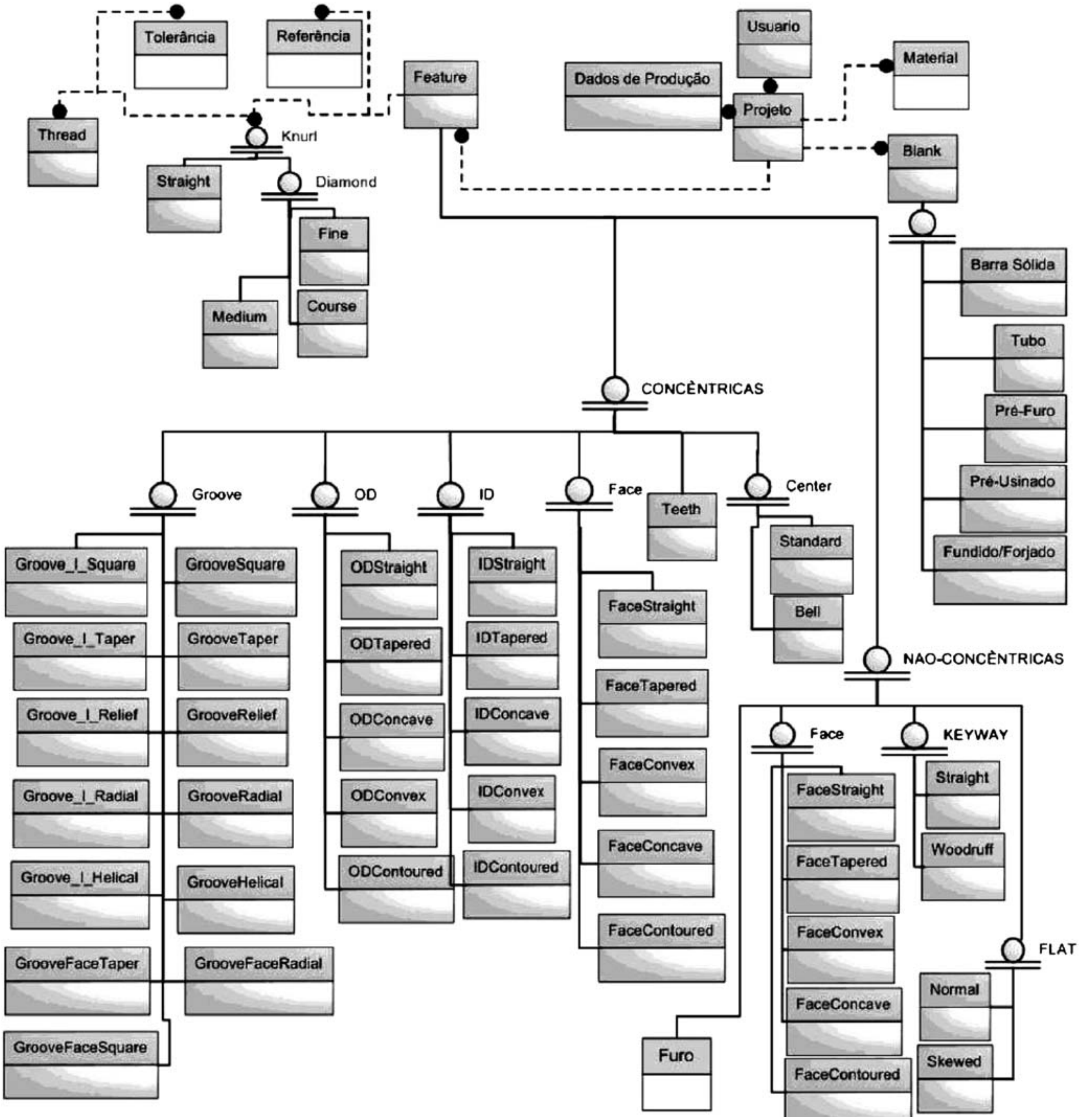


Fig. 5 Modeling information on some used form features (CAM-I, 1996) via IDEF1X

5.3 WebCADbyFeatures: implementation

The implementation of the WebCADbyFeatures system for collaborative design of cylindrical parts was conceived to allow CAD/CAPP/CAM integration, in a distributed environment through the Web. The feature model and other necessary information are input to the software, and it outputs the feature model of the raw material and the finished part, which in turn becomes an input to the CAPP module.

5.3.1 Basic characteristics of WebCADbyFeatures

WebCADbyFeatures allows the creation and manipulation of the feature model for the raw material and finished part in a collaborative way, the storage of that information in a MySQL database, the validation of the model and the visualization of the geometric model in two-dimensional and three-dimensional (via VRML).

Its architecture (Fig. 8) is composed of a GUI that has menus, visualization options, error messages, feature

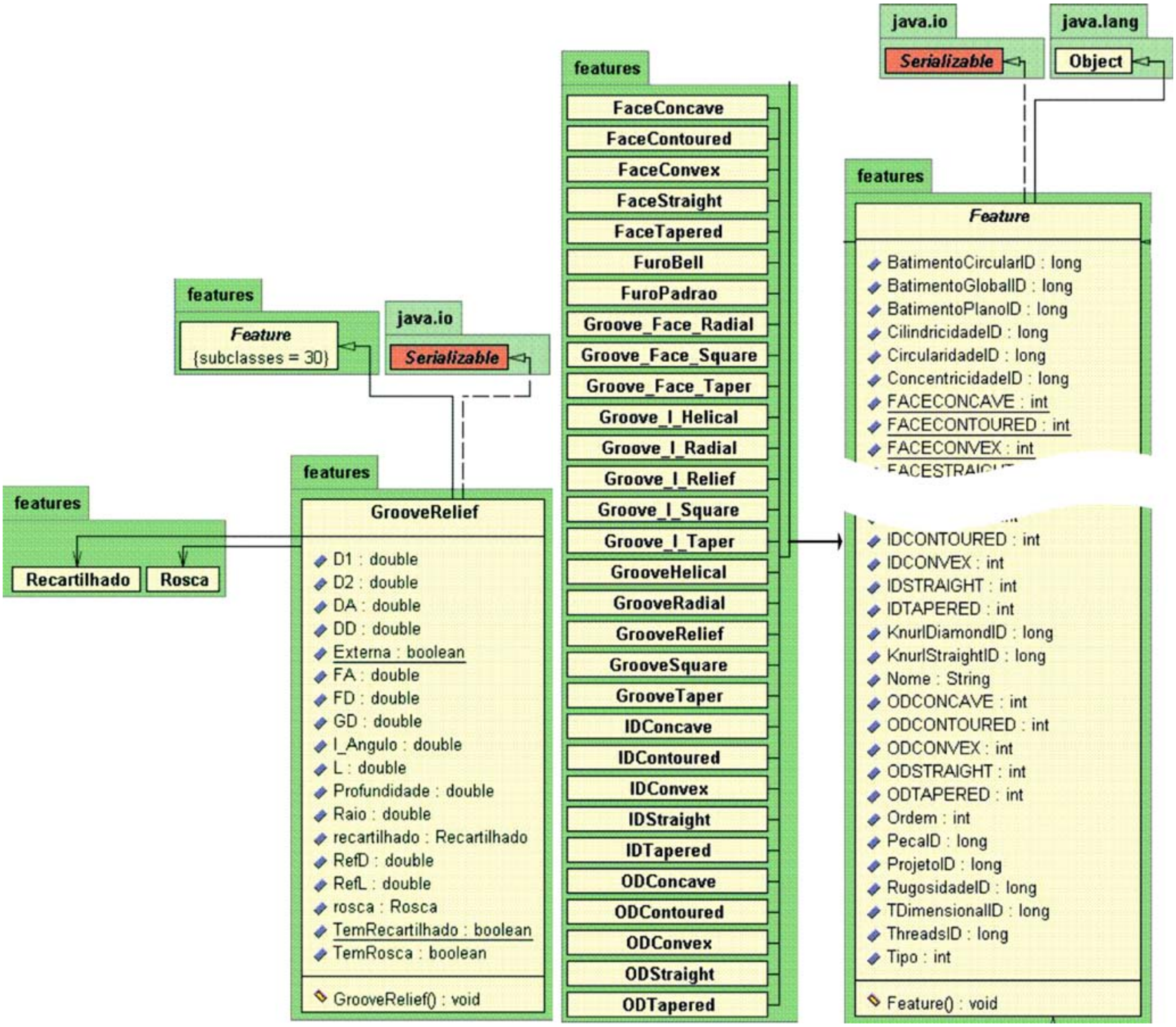
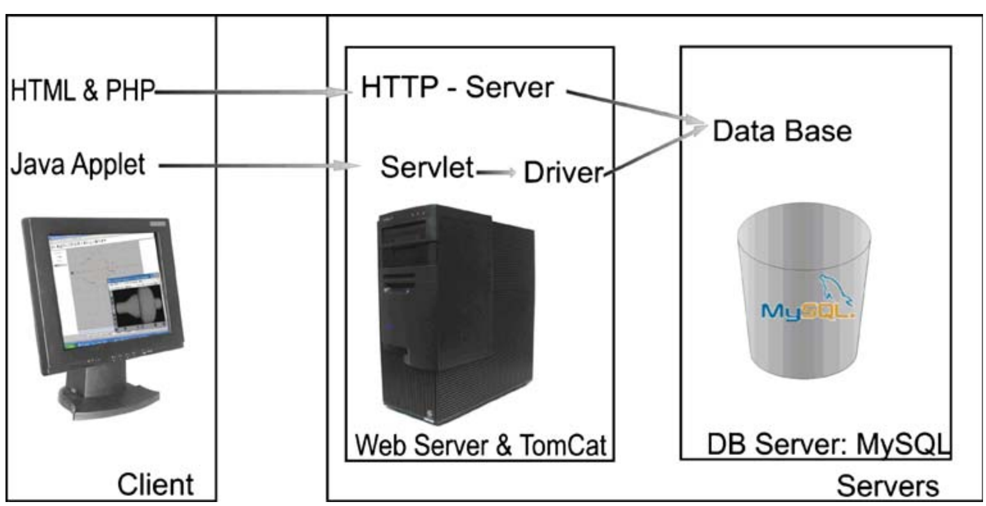


Fig. 6 UML modeling of the feature library

Fig. 7 The three tiers for database access



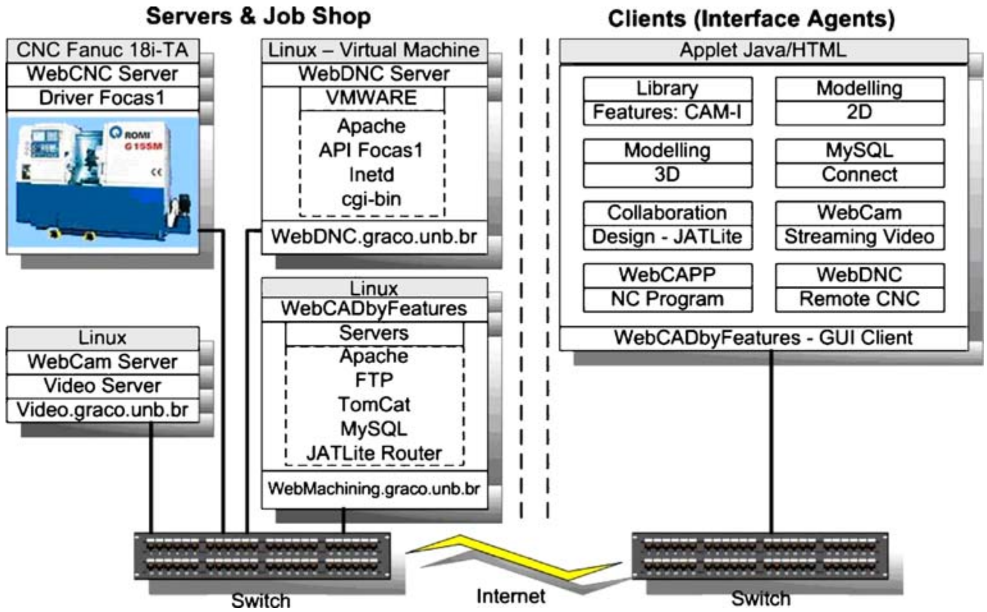


Fig. 8 Detailed architecture: WebCADbyFeatures system modules

manipulation, communication with the JATLite session manager for collaborative modeling, communication with the database server, communication with the VRML server, shop floor monitoring (WebCAM), teleoperation of the CNC turning center, among other functions.

The main components of WebCADbyFeatures are: GUI as a Java applet, feature library, two-dimensional Graphical Interface, Collaborative Design IPLayer Router Client, components for two-dimensional visualization (graphical primitives such as straight lines and arcs) and components for three-dimensional visualization (VRML). The information regarding the features is handled through a database management system.

The modeling of the part begins with the access by the client to the Web page for running the CAD Java applet. If the user is registered, an access to the database is made in order to verify the user's login and password, and it is connected on-line with the integrated CAD/CAPP/CAM system.

Navigation in the system begins only after user registration via PHP. Thereafter the applet is downloaded via web, and automatically the local Java machine runs the applet. AWT (abstract windowing toolkit) is used for GUI development, so that a better performance and compatibility with Java machine version 1.1 is achieved without need of a specific plug-in for a certain Java version.

The first window in the applet shows the initial options (Fig. 9a), and for a non-registered user it is only possible to create a new project. Then, a new window opens up (Fig. 9b) that gathers the design information. If the user does not wish to alter anything, the fields are filled out with default values, based on the user's name and current date. The system guides the user, asking for the relevant information for part modeling and process planning.

If the raw material "solid bar" is chosen, a new window appears (Fig. 9c), requesting the geometric information about the solid bar, which are its diameter and length. The last window in this preparation phase (Fig. 9d) provides the options for selecting the floating zero (left or right) and whether he/she prefers to begin modeling with the external or internal portion of the part. The default is the modeling from the left-hand side, and beginning with the external features, which is the most common procedure among designers.

Proceeding with modeling, a drawing window opens up (Fig. 2), where the part is modeled through the form features available in the feature library. Initially, the part is modeled using the feature union method, i.e. the features are used as blocks for building the part geometry (like bricks).

After finishing this union phase, part modeling by feature subtraction begins, and these features include those associated with the C-axis of the CNC turning center, which are obtained through radial and longitudinal milling and drilling operations. Examples of such features are: keyways, eccentric holes, radial holes, etc. The user has the option of zooming the drawing as two-dimensional, moving it on the screen, and also generating the VRML representation at any moment for three-dimensional visualization. When selecting the "VRML-NOW!" button, the part model is sent to WebMachining server through servlets, which saves the file in the server, and it is sent to the client's browser via FTP, which calls the available VRML plug-in.

There is the option for saving the geometric model locally in two dimensions and three dimensions (.wrl extension) and features (.ftr extension), since the security policy of the local Java machine is changed, allowing reading and writing files in the client computer. The Java machine is configured in a safe way, preventing applets from having access to the local resources of the machine. In Fig. 2 an example part is shown in two dimensions with the corresponding three-dimensional solid in VRML.

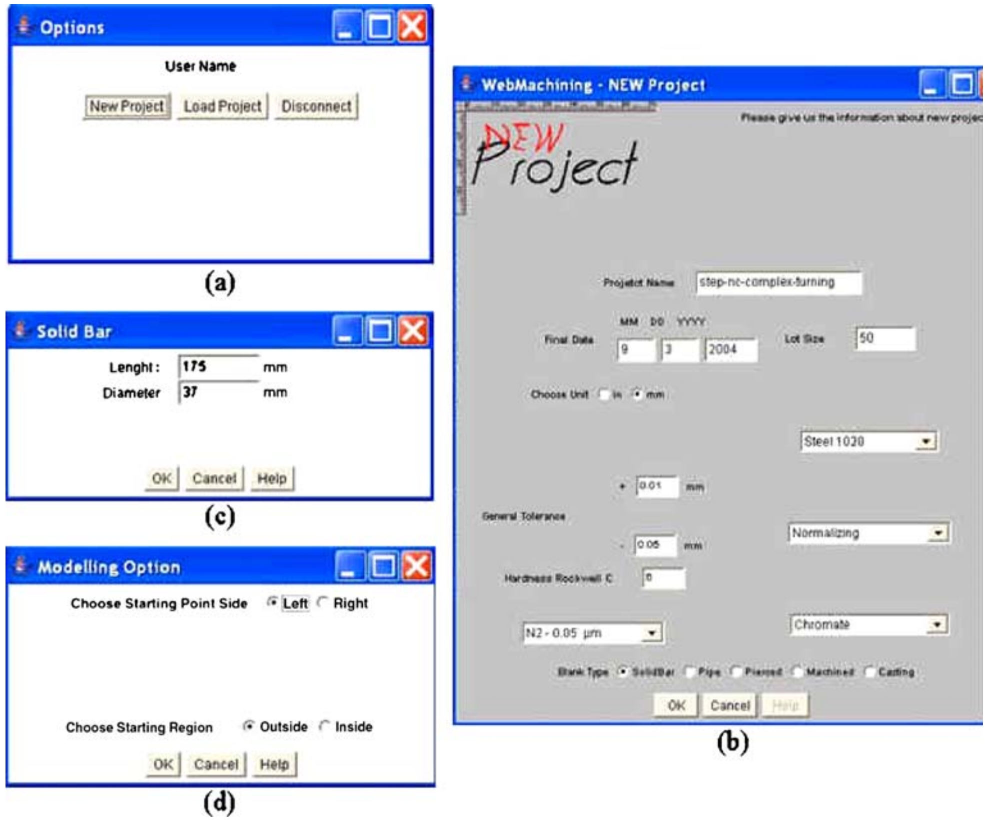


Fig. 9 Stages in part design: **a** initial options window; **b** window with data about a new project; **c** window with data about the raw material (*solid bar*); **d** window with modeling options

5.3.2 Collaborative modeling

Initially it is necessary to access the so-called "WebCADby-Features Collaborative Design IPLayer Router Client" client interface, through the third icon of the main bar (Fig. 2), called "Connect WebCADbyFeatures Collaborative Design" (Fig. 10). This applet is composed of several panels, which provide the necessary functionality to allow the management and communication for carrying out collaborative modeling.

The registration in the router is made through the "Register" panel in the interface agent, filling out the fields "Agent Name=Alvares", "Password=alvares" and "Email= alvares@AlvaresTech.com". The other data related to the router name (facilitator. AMR) and the TCP ports are already filled out. Then the previously registered agent is connected with the JATLite server/router through the "Request" panel (Fig. 10a). The "Compose", "FTP" and "Reserve" panels are used for communication with the other agents that will participate in the collaborative modeling session.

On the right-hand side of the GUI (Fig. 10b), information on the connection with the router can be obtained. KQML is used as the communication language among the agents. Some directives used are: sender, content, receiver, performative among many more provided by KQML.

Figure 11 shows an example of collaborative modeling, where "Alvares" interface agent shares its feature-based product model with the interface agent "Jones". Agent "Alvares" sends its design file via FTP, called "Alvares_2004_12_11", using the agent router (session manager), to agent "Jones", who will receive it directly in its GUI, and then it will analyze it and carry out any necessary modifications.

Then Agent "Jones" sends the file with their modifications, called "jones_2004_12_11" by the system (or any other name), to Agent "Alvares", who will receive it in its design interface, with the modifications performed by Agent "Jones" (Fig. 12).

Both agents can talk directly via the router, exchanging messages through the "Compose" panel, where an ontology is defined, which is associated with the terminology of product development, called "project", and "content" of this message is sent to the other agent using KQML, with their directives "sender: jones", "receiver: Alvares" and "performative: tell". For instance, agent "Alvares" receives a message from agent "Jones" about the modifications accomplished in the design. If there is a need to communicate with another agent, an email message can be sent via the router.

6 CAPP/CAM system: implementation

The CAPP system, called WebCAPP is composed of ten activities (Fig. 13):

– Mapping of design features into machining features: accomplishes the mapping of design features into

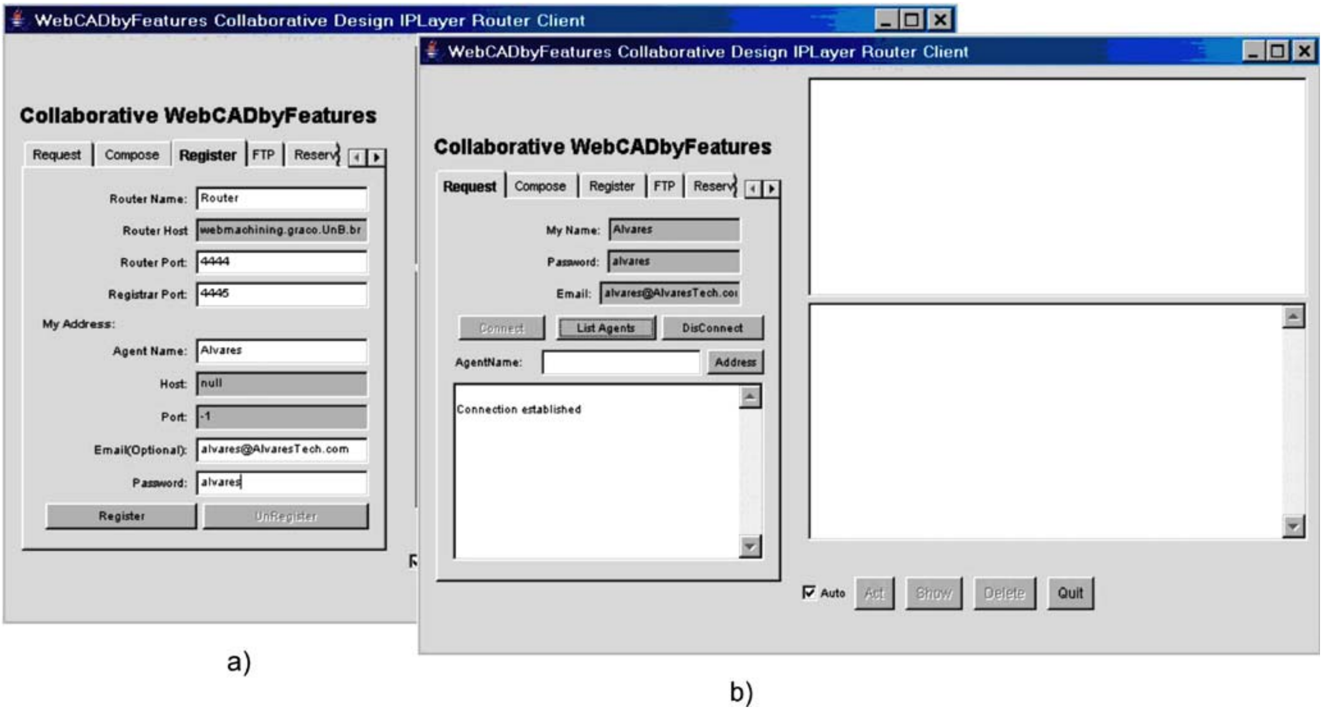


Fig. 10 Client interface for collaborative design: **a** WebCADbyFeatures Collaborative Design IPLayer Router Client, showing the Register panel; **b** Request of the Interface Agent "Alvares" in the router server in the JATLite environment

manufacturing features, including machining operations such as internal and external cylindrical turning, facing, boring, parting-off, threading, etc

– Determination of the machining operations with alternatives, associated with the machining features (i.e. the working-steps in STEP-NC): selects the machining processes for the identified features, and it also considers the constraints associated with the dimensions, tolerances, material of the part, among others

– Determination of the machining sequence with alternatives: determines the machining sequence with alternatives and setup for fixturing the part (setups 1 and 2)

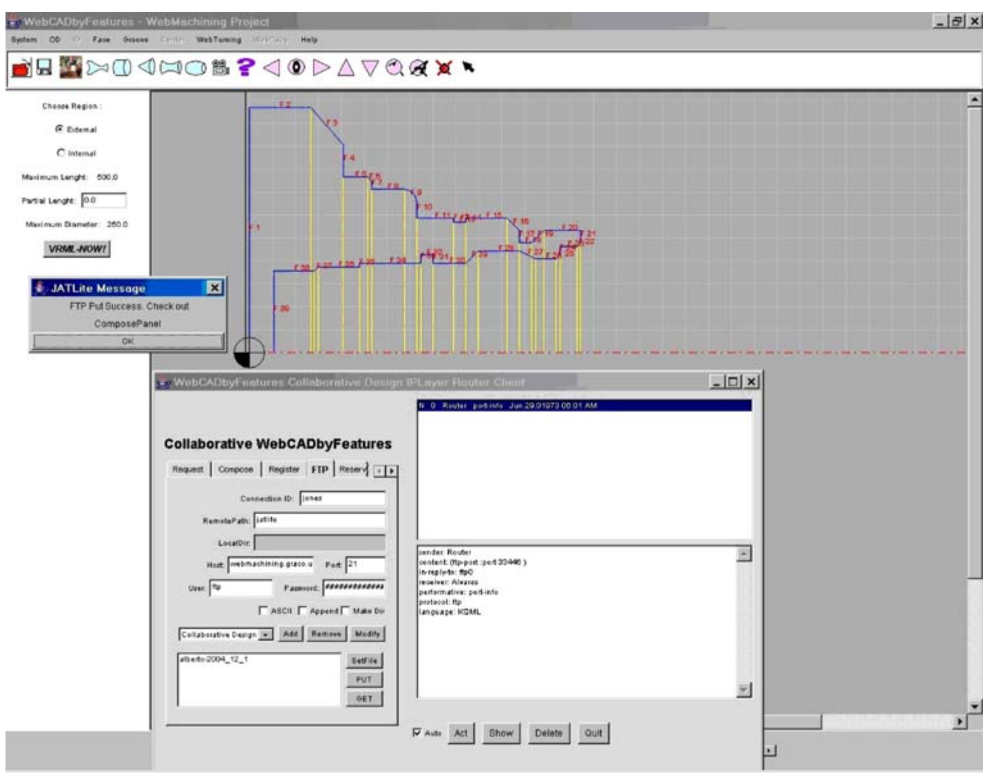


Fig. 11 Collaborative modeling between the "Alvares" and "Jones" agents: "Alvares" agent sends the feature model to the "Jones" agent

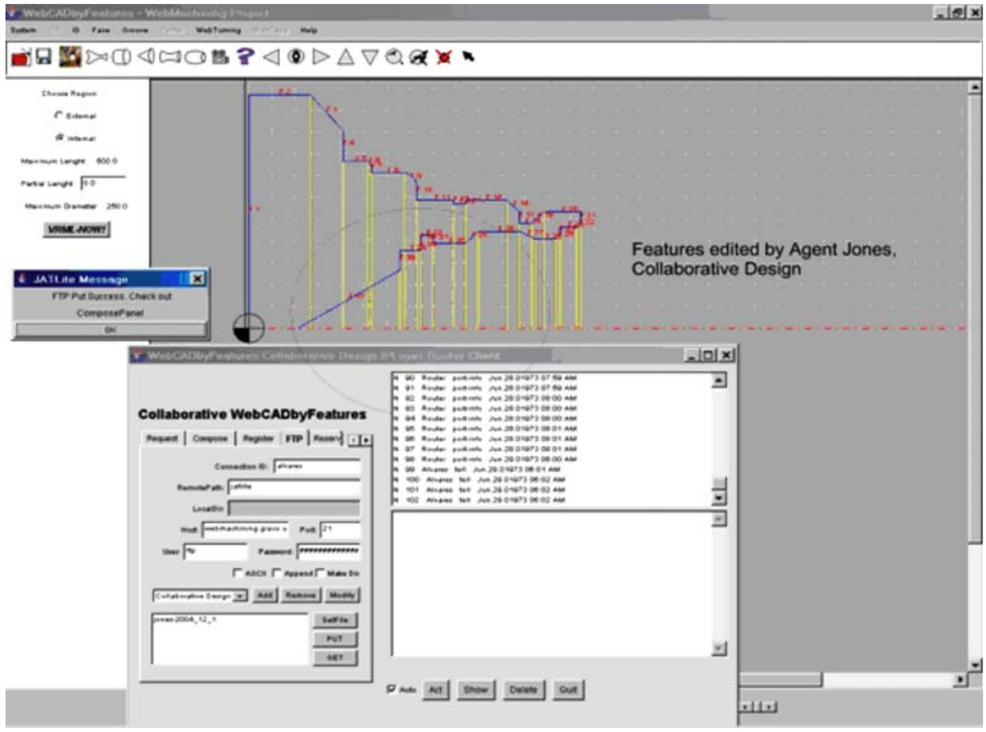


Fig. 12 Collaborative modeling between the "Alvares" and "Jones" agents: "Alvares" agent receives the feature model from the "Jones" agent, after performing changes in the feature model

- Strategies for generating tool paths: determines the strategies for the generation of tool paths based on STEP-NC
- Determination of the cutting tools, which includes inserts and tool holders: selects the cutting tool considering the machine-tool, the type of material of the pair part/tool, dimensions and tool geometry, tool life, etc.
- Determination of the model of times and calculation of the time standards for each working-step
- Determination of the machining conditions: determines the cutting conditions considering the tool parameters and material, subject to the following constraints—the tool life criterion used, machine power and machine capacity.
- Generation of the NC program (ISO 6983): determines the collision-free tool path considering the feature-based product model
- Generation of the process plan: sets up the document regarding the process plan

A detailed description of these activities is outside the is not presented in this paper.

7 Achieved results

Table 1 shows the form features that are present in the parts that were considered in this paper, in which:

- The first parts correspond to chess parts, which include pawn, tower, horse, bishop, queen and king. They are modeled with the following features: outer diameter, inner diameter, splines, faces, groove, and axial holes. The blank is a nylon bar with a diameter of 50 mm. The parts are machined in a single setup.
- The last part is a standard part used by Romi in its training courses for operation and programming of the CNC turning center used in this work. This part has external and internal features, which include: outer diameter, inner diameter, faces, cone, arc, groove, metric thread, radial grooves and axial holes. The blanks are nylon and brass tubes with an internal diameter of 37 mm, and an external diameter of 75 mm. The part is machined in two setups.

Table 2 contains information about the cutting tools setup at the CNC turning center for machining these parts.

7.1 Chess parts

7.1.1 WebCADbyFeatures for the chess parts

The design of the tower is shown in Fig. 14, in which can be seen the instantiation of a C-axis feature (in this case a radial groove). The information about this feature are input through a menu associated with the outer diameter feature. This groove will be machined with a milling cutter with a 12 mm diameter. The design of the pawn is shown in Fig. 15, in which there is an inset showing an instantiation of a feature spline.

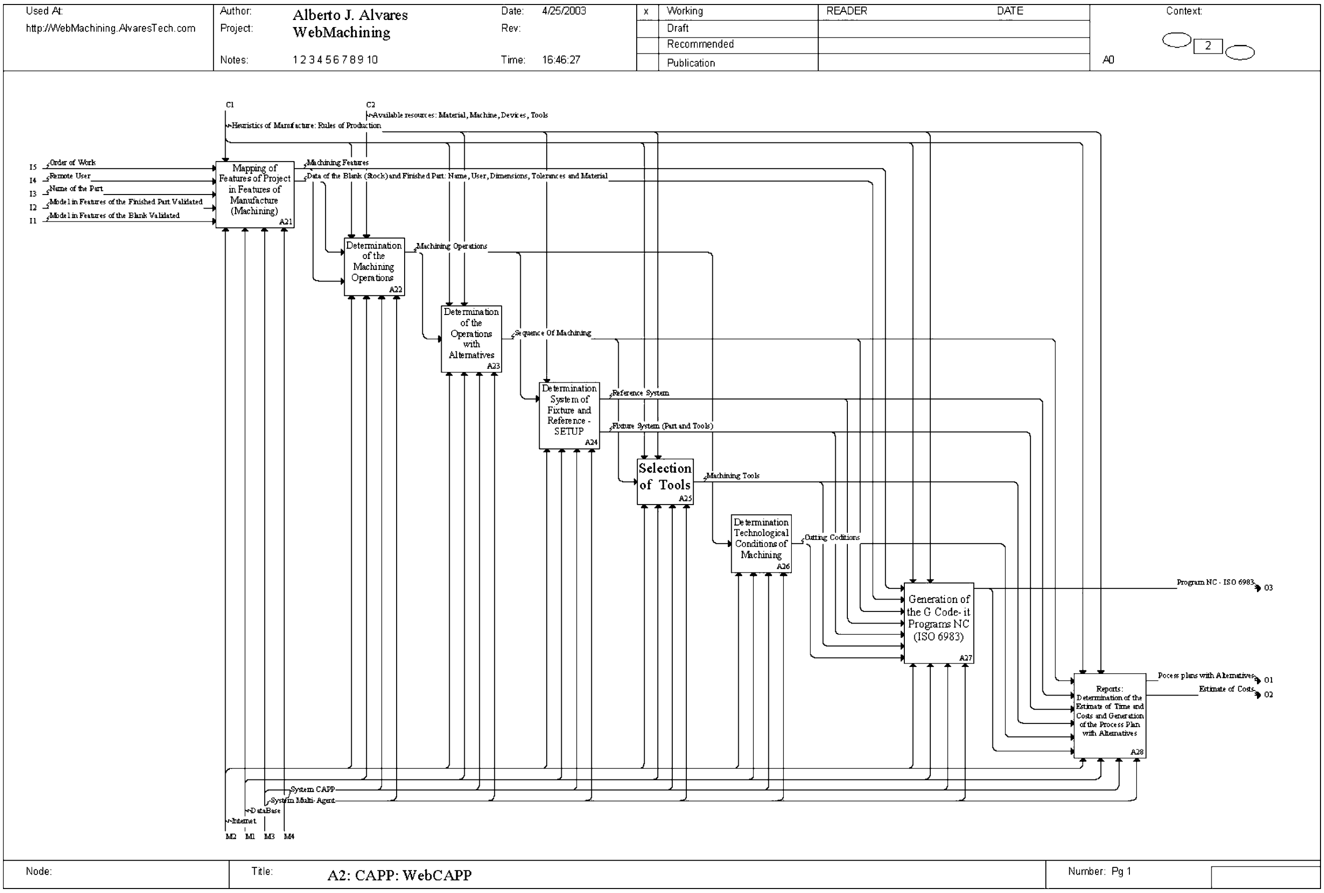


Fig. 13 IDEF0 for the WebCAPP module

7.1.2 WebCAPP and WebTurning for the chess parts

The WebCAPP module is called via an applet or servlets, generating a process plan for machining the part from the model of the design features, as well as generating the NC program for the CNC turning center. Then feature mapping is started, which is performed for each of the setups necessary to machine all the machining features.

The machined features are then mapped into working-steps and a workplan, which contain the necessary technological information for the generation of the process plan associated with the part. This information includes approximation planes, machining conditions, cutting fluid, selected cutting tool and its position in the turret, etc. Then the NC program is generated for the part.

Figure 16 illustrates the WebDNC interfaces, which shows the teleoperation of some of the chess parts, their

Table 1 Features present in the example parts

	Face	Outer diameter	Inner diameter	Thread	Spline	Arc	Cone	Radial groove	Eccentric axial hole	Total number of features
Pawn	5	5	–	–	1	3	1	–	–	15
Tower	6	5	1	–	1	1	1	4	–	19
Horse	6	6	–	–	1	2	1	–	–	16
Bishop	6	7	–	–	1	2	1	–	–	17
Queen	5	6	–	–	1	5	1	0	5	23
King	6	6	–	–	1	–	1	2	0	16
Training Part	4	7	2	1	–	8	4	3	3	32

Table 2 Available cutting tools at the CNC Turning Center Galaxy 15M

Turret number	Tool holder	Insert	Operation
T0101	L166.5FA-2020-16	VBMT1 10312-PF4015	External theading
T0202	Twist drill	High speed steel	Drilling (~6 mm)
T0303	LF123g20-2020B	N123G200300003-GM4025	Cutting-off (width 4 mm)
T0404	R416.2-0200C 3-31	LCMX030308-53 1020	Drilling (~20 mm)
T0505	SVVBN-2020K1 1	VBMT1604 08-MM2025	External turning
T0606	R 166.4kF-20F1 6	VBMT1 1031 2-PF4015	Internal threading
T0707	SVJBL-2020K-16	VBMT1 604 08-MM2025	External turning
T0808	DWLNL-2020-k06	WNMG060408-PM4015	External turning
T0909	A16R-SDUPL 07-R	DPMT070204-PM4015	Internal turning
T1010	Milling cutter	High speed steel	Milling (~12 mm)
T1111	N176.39-2020-10	RCMT0602M0-4025	Cutting-off (width 12 mm)
T1212	DDJNL-2020-K15	DNMG1 50608QM235	External turning

fixturing, the NC programs, the CNC screen, CNC status, available programs in the CNC memory, among other pertinent pieces of information. A photograph of the machined chess parts is shown in Fig. 17.

7.2 Training part

7.2.1 WebCADbyFeatures for the training part

The design for this part is shown in Fig. 18. This part has external and internal concentric features, as well as radial grooves and holes, and axial holes. This figure also shows VRML models automatically generated by the WebCADby-Features module.

7.2.2 WebCAPP for the training part

The procedure for feature mapping generates a process plan with two setups. In the first setup, machining of the external features F1 and F4 takes place (see Fig. 18), and also the machining of the internal features F27, F28 and F29. In the second setup, external features F4 to F23 and internal features F24 to F26 are machined. Figure 19 shows the WebDNC module, through which the user can visualize the machining operation of the training part. A photograph of the training part after being machined is shown in Fig. 20.

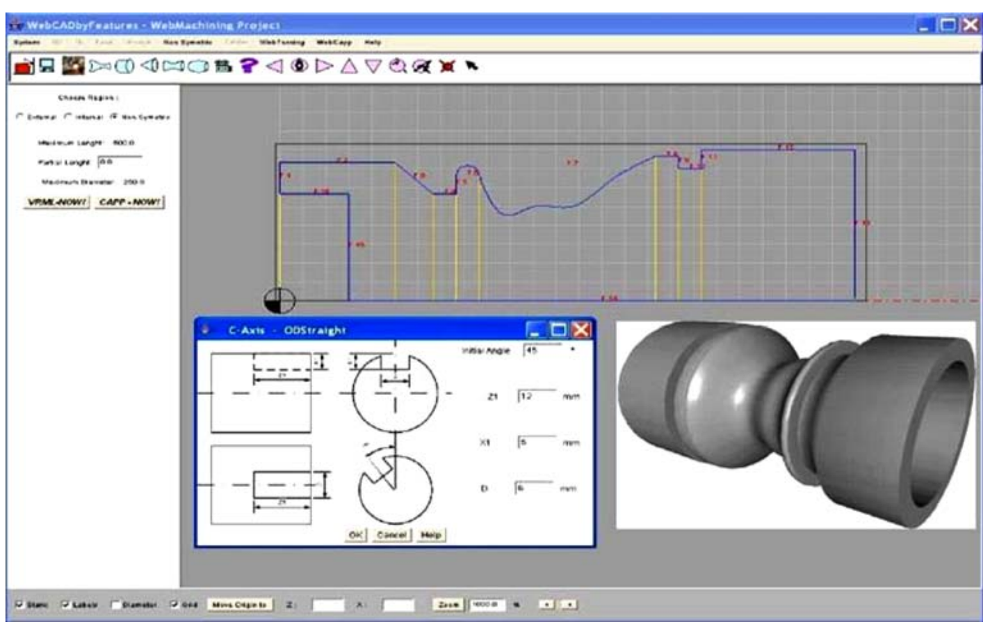


Fig. 14 Modeling a tower using a C-axis feature associated with a concentric feature

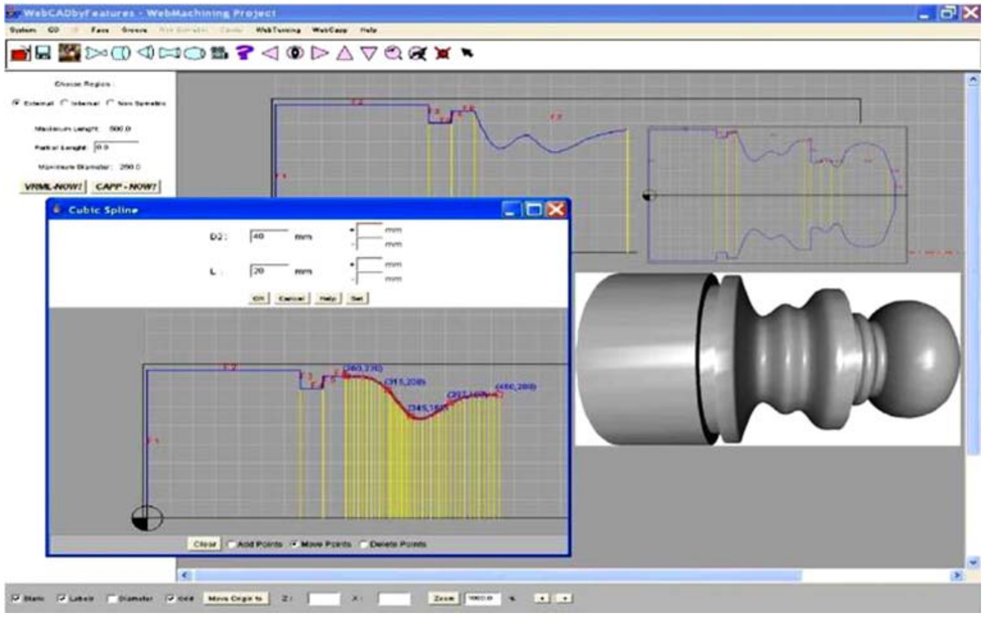


Fig. 15 Modeling a pawn using the spline feature and the VRML file associated with the concentric features

8 Conclusions

Described within this paper is the implementation of an integrated Internet-oriented CAD/CAPP/CAM system for cylindrical parts that may have C-axis features. The developed system can be applied to both industry and institutions. In academic applications, it can be used in distance teaching in the context of remote laboratories, whereas in industrial applications it can be used as part of a service of rapid prototyping for a trial use of parts or for the supply of a functional prototype for the interested company or remote customers. Part modeling is based on the synthesis of design features (symmetrical and asymmetrical features) through the Internet, made available to the remote user by a Java applet.

A multi-agent system was developed that enables collaborative design, implemented in an client/server architecture, composed of servers, HTML pages and Java applets, which allows the remote user to carry out the collaborative modeling of the part in two dimensions, and visualize it as two-dimensional and three-dimensional.

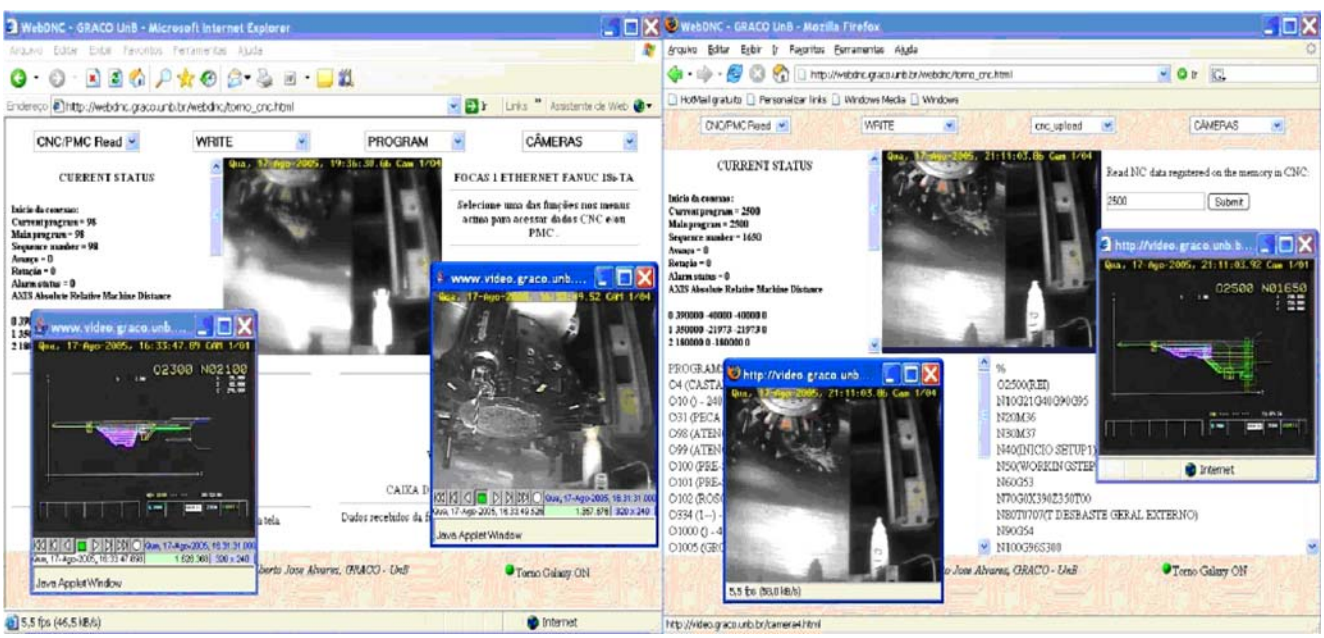


Fig. 16 WebDNC interface showing the manufacture of a part and the uploading operation of a NC program of a part to the CNC turning center. This figure also shows some simulations and images of the machining operation

Fig. 17 Photograph of the machined chess parts

The WebMachining system can be accessed via the Internet through the following URL: http://www.WebMachining.AlvaresTech.com. It has the following characteristics:

- Uses multi-platform servers based on servlets, JATLite, HTTP, MySQL and FTP; implemented in Java, HTML, Javascript and PHP. The servers were developed under the Linux platform, since it is more stable and robust when compared to the Windows platform, which can also be used.
- The client is based on a Java applet, using AWT, not being necessary a Java plug-in, making it possible to have total compatibility with the browsers.
- Complementary software for product modeling is not necessary, just the installation of a plug-in for visualization of the part in VRML.
- A multi-user and multi-task system, based on threads, both on the server and on the client side.
- Provides remote communication among people, eliminating the geographical and temporal barriers for product development, allowing the implementation of concurrent engineering.
- Enables modeling using splines for "general revolution" type features, and offers the possibility of introducing eccentric features (C-axis), moving beyond STEP NC-Part 12 (ISO 14649).
- Allows speed and safety in the communication among the agents.

The implemented GUI for the teleoperation of the CNC Turning Center Galaxy 15M can be accessed through the following: http://www.WebDNC.AlvaresTech.com. This

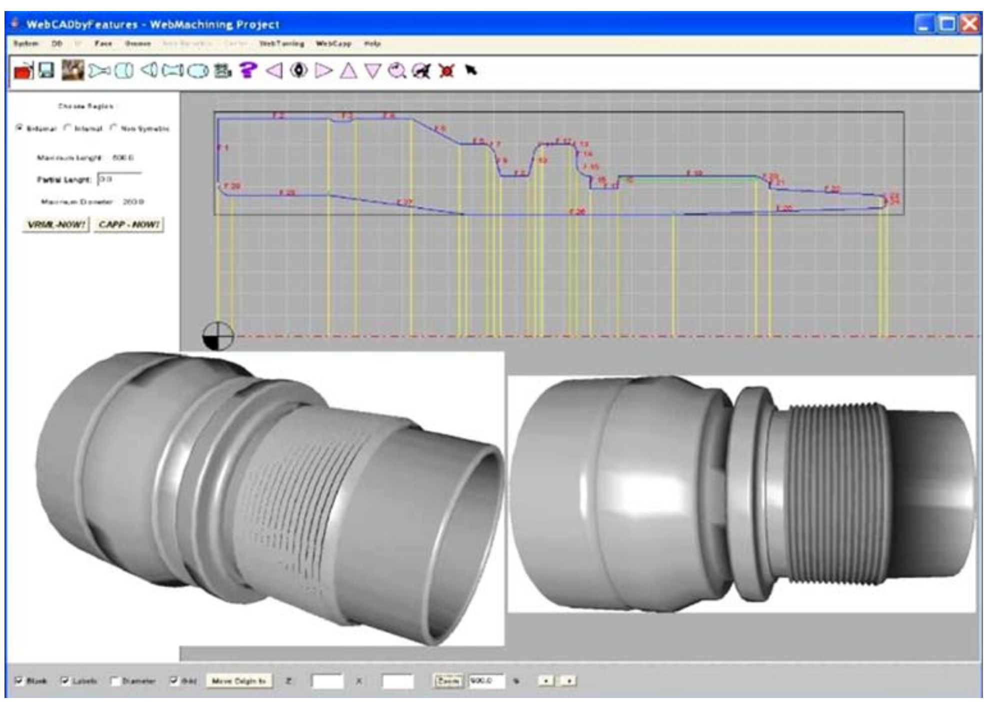


Fig. 18 Modeling of the training part, which has concentric and eccentric features, and their VRML models, including a metric thread and grooves

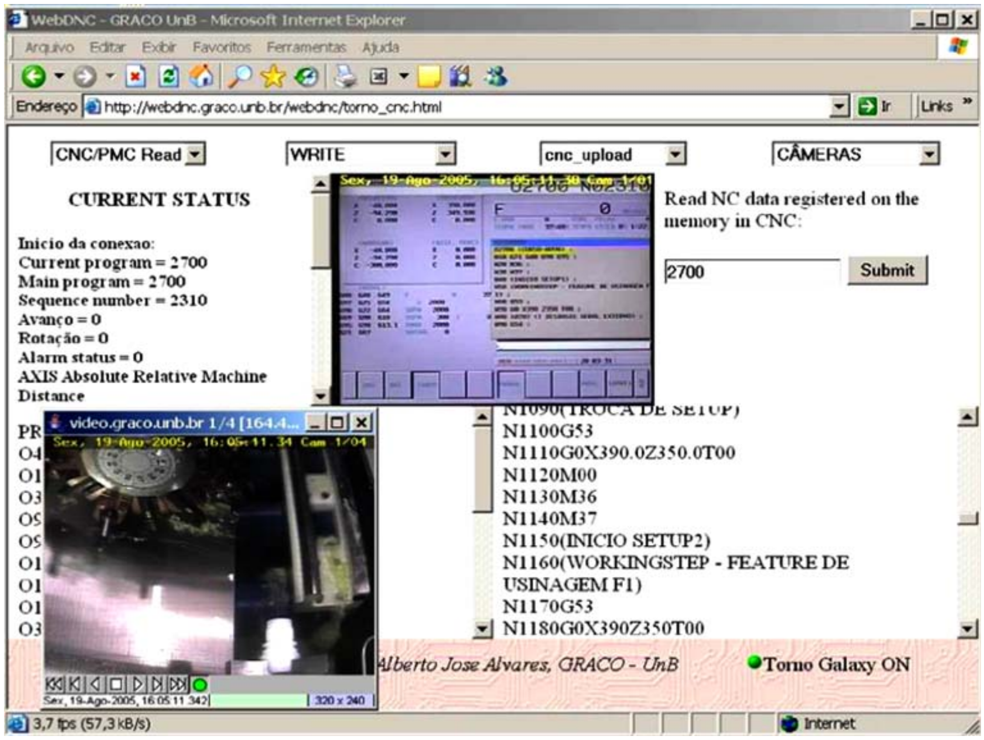


Fig. 19 WebDNC interface performing the monitoring of the machining operation of the training part

implementation includes the WebCam server and the client for on-line monitoring (audio and video). The teleoperation servers implemented allow the execution of 70 functions of the 300 available functions.

The WebTurning module was implemented in a client/server architecture, and it can be accessed via browser without the need of a proprietary software for teleoperation. It also allows the immersion of the remote user on the shop floor through the monitoring via video and audio in real time with motion detection, image recording and event playback.

Fig. 20 Photograph of the training part after being machined

References

1. Shah JJ, Dedhia H, Pherwani V, Solkhan S (1997) Dynamic interfacing of applications to geometric modeling services via modeler neutral protocol. CAD 29:811–824
2. Han JH, Requicha AAG (1998) Modeler-independent Feature Recognition in a distributed environment. CAD 30(6):453–463
3. Smith CS, Wright PK (2001) Cybercut: an Internet-based CAD/CAM system. ASME J Comput Inf Sci Eng 1(1):1–33
4. Shao X, Li Y, Li P, Liu Q (2004) Design and implementation of a process-oriented intelligent collaborative product design system. Comput Ind 53(2):205–229, February
5. Hardwick M, Spooner DL, Rando T, Morrir KC (1996) Sharing manufacturing information in virtual enterprises. Commun ACM 39(2):46–54
6. Martino TD, Falcidieno B, Hasinger S (1998) Design and engineering process integration through a multiple view intermediate modeler in a distributed object-oriented system environment. CAD 30(6):437–452
7. Lee JY, Han SB, Kim H, Park SB (1999) Network-centric feature-based modeling. Pacific Graphics
8. Bidarra R, Van den Berg E, Bronsvoort W F (2001) Collaborative modeling with features. Proceedings of DET'01, ASME Design Engineering Technical Conferences, Pittsburgh, PA
9. Corney J, Lim T (2001) 3D modeling with ACIS, 2nd edn. Saxe-Coburg, Edinburgh
10. Li WD, Ong SK, Fuh JYH, Wong YS, Lu YQ, Nee AYC (2004) Featurebased design in a collaborative and distributed environment. CAD 36(9):775–797
11. Fuh JYH, Li WD (2005) Advances in collaborative CAD: the-State-of-the-Art. CAD 37(5):571–581

12. Shah JJ, Mäntylä M (1995) Parametric and feature-based CAD/CAM: concepts, techniques, and applications. Wiley, New York
13. Tönshoff HK, Aurich JC, Baum T (1994) Configurable feature-based CAD/CAPP system. Proceedings of the IFIP International Conference on Feature Modeling and Recognition in Advanced CAD/CAM Systems. Valenciennes, France, pp 757–769
14. Salomons OW, van Houten FJAM, Kals HJJ (1993) Review of research in feature-based design. J Manuf Syst 12(2):113–132
15. Shen W, Norrie DN, Barthés JPA (2001) Multi-agent systems for concurrent intelligent design and manufacturing. Taylor and Francis, New York
16. Shen W, Norrie DH (1999) Agent-based systems for intelligent manufacturing: a state-of-the-art survey. Knowl Inf Syst Int J 1(2):129–156
17. Deere (1986) Part features for process planning. CAM-1, Deere, Moline, Illinois