ABCM Symposium Series in Mechatronics - Vol. 3 - pp.688-700

WEBMACHINING: SYSTEM FOR THE DESIGN AND MANUFACTURE OF FEATURE-BASED PARTS THROUGH THE WEB

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Abstract. *This work describes the implementation of an integrated web-based CAD/CAPP/CAM system for the remote design and manufacture of feature-based cylindrical parts. This system, called WebMachining (http://webmachining.alvarestech.com), was developed in an e-manufacturing context, and the use of features allows the integration among the activities of collaborative design (WebCADbyFeatures), generative process planning (WebCAPP) and manufacturing (WebTurning). Through the WebCADbyFeatures agent-based collaborative design module, cylindrical parts are modeled based on the synthesis of design features, in a Concurrent Engineering context. The WebCAPP generative CAPP module maps design features into machining features (including turning, milling, and drilling), and the mapping considers the setup, geometry, and operation. It uses a data structure similar to STEP-NC, and the generated process plans are nonlinear (i.e. they have alternatives). The WebTurning module performs the remote manufacture of the part, and it is based on a client–server architecture. Some examples are provided in this paper, illustrating the remote design, process planning and manufacture of parts in a CNC turning center.*

Keywords*: E-manufacturing, Telemanufacturing, CAD, CAPP, CNC, Internet.*

1. INTRODUCTION

The global competition and the fast changes in the consumers' demands have been causing significant changes in the production strategies of manufacturing companies. These companies have to work frequently with: (a) an increase in the competition, which is now global, and (b) the consumers' demands being modified continually. These companies now should be capable of foreseeing changes in the market, and to answer these changes satisfactorily. Traditional manufacturing systems, with a centralized structure, have difficulty to satisfy such demands. In recent years, significant changes are being applied to the manufacturing strategy of those companies, particularly in those that work together seeking to stay competitive internationally in a volatile market. New forms of organizational structures have been recognized by the scientific community and by other professionals, which include: extended enterprises, virtual enterprises, virtual organizations, network of organizations, supply chain management, cluster of enterprises, and production networks (Cecil et al., 2005).

The Internet has been providing a tremendous potential for the integration and remote cooperation in world-wide manufacturing applications, because it has become the world platform for sharing all types of information (Haag et al., 1998). Today, a significant amount of companies all over the world explore the use of Internet/Intranet technologies to give support to their factories distributed around of the world (Lee and Lau, 1999).

The Internet is opening a new domain for constructing electronic-manufacturing (e-Mfg) environments, using methods based on collaborative e-Work, especially for the activities developed during the product development cycle in integrated and collaborative CAD/CAPP/CAM environments (Malek et al., 1998 & Nof, 2004). This will allow the product developers and planners to have easier communication, enabling design sharing during the development of the product, as well as the remote manufacturing and monitoring of the manufacturing devices.

This work describes the implementation of an integrated web-based CAD/CAPP/CAM system for the remote design and manufacture of feature-based cylindrical parts. This system, called WebMachining (http://webmachining.alvarestech.com), was developed in an e-manufacturing context, and is composed of three modules: WebCADbyFeatures, WebCAPP, and WebTurning. The WebCADbyFeatures module is an agent-based collaborative design software, through which cylindrical parts are modeled based on the synthesis of design features, in a Concurrent Engineering context. The WebCAPP generative CAPP module maps design features into machining features (including turning, milling, and drilling), and it uses a data structure similar to STEP-NC (ISO, 2000). Finally, the WebTurning module carries out the remote manufacture of the part, and it is based on a client-server architecture. Some examples are provided in this paper, illustrating the remote design, process planning and manufacture of parts in a CNC turning center.

2. DESIGN AND MANUFACTURING THROUGH THE WEB

Nowadays, in design engineering practice, it is usual to consider several manufacturing aspects 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.

It should be noted that it is undesirable and frequently unlikely to require that all participants in the product development activities use the same hardware and software systems. Consequently, the components should be modular and communicate with the others through a communication network, for effective collaboration.

Many research efforts have been made in the development of design environments oriented to computers networks, usually called network-centered. Hardwick et al. (1996) proposed an infrastructure that allows the collaboration among companies in the design and manufacture of new products. That architecture allows information sharing in the Internet using the STEP standard for product modeling. Shah et al. (1997) developed an architecture for standardization of communication between the kernel of a geometric modeling system and the applications. Han and Requicha (1998) proposed a similar approach that enables the transparent access to several solid modelers. Martino et al. (1998) proposed an approach to integrate the design activities with the other manufacturing activities based on features, which supports both feature-based design and feature-recognition. Lee et al. (1999) 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.

Smith and Wright (2001) described a distributed manufacturing service called Cybercut (http://cybercut.berkeley.edu), which used CAD and process planning systems that allow users to have finer control in product design in terms of choosing tools, materials, tolerance and finishing, before actually manufacturing the part at a CNC milling machine. The system developed by Tay et al. (2001) relied on the Internet for the implementation of distributed rapid prototyping, allowing platform independent means of remotely controlling a manufacturing process. Shao et al. (2004) described a process-oriented intelligent collaborative product design system based on the Analysis-Synthesis-Evaluation (ASE) design method and the parameterization of product design, using agents.

The WebSpiff system (Bidarra et al, 2001) is based on a client-server architecture consisting of two main components on the server side: (i) Modeling System SPIFF that supplies all the functionality for feature-based modeling, using the modeling kernel ACIS (Corney e Lim, 2001); (ii) Session Manager that supplies functionality to start, associate, finish and log out a modeling session, as well as manages all the communications between the SPIFF system and the clients.

Li et al. (2004) and Fuh and Li (2004) mentioned several distributed and integrated collaborative design systems and Concurrent Engineering, and none of such 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 (Smith and Wright, 2001), which does not implement collaborative design.

The WebCADbyFeatures collaborative design system proposed in this paper differs from the above systems because it models cylindrical parts, based on the synthesis of design features (which can be symmetrical or 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.

For the construction of CAPP systems, there are two basic approaches: variant and generative (Groover, 2003). For the generation of a processes plan, it is necessary to carry out a detailed analysis of the part. In this way, it is important that the data manipulated by a CAPP system are in the form of manufacturing features (Salomons, 1995). In the case of manufacturing processes with material removal, those features correspond to the machining features, which are the portions of the part affected by a machining operation.

The ISO 14649 standard (ISO, 2000), or STEP-NC, is basically a structured representation of a process plan for turning operations, milling, EDM, etc., based on machining features, and the machining strategy is specified through a *workingstep*. A workingstep associates a machining feature with a machining operation, which contains the following information: cutting tool, cutting conditions, machine-tool functions, and machining strategy associated with the cutting tool movement.

The proposed WebCAPP module uses an approach based on the mapping of design features into turning, milling and drilling features, which performs a decomposition based on the setup, geometry and operation, and it follows the STEP-NC standard, using a similar data structure, and working with nonlinear process plans, that is, with alternatives. The nonlinear process plan is provided to the remote user in the form of an AND/OR graph (Ferreira and Wysk, 2001).

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. The main characteristic of the interface is the integration of all the necessary pieces of information for operating the system, including the display of video images, virtual models and graphic interfaces for control.

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 (Taylor and Trevelyan, 1995) or a CNC machine tool (Kao and Lin, 1996).

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 (Álvares et al., 1999).

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 (Álvares and Romariz, 2002), and also for the CNC turning center Romi Galaxy 15M.

3. OVERVIEW OF THE WEBMACHINING SYSTEM

Figure 1 presents part of the IDEF0 model of the proposed system, called WebMachining (Álvares, 2005). The, WebCADbyFeatures module (figure 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 features.

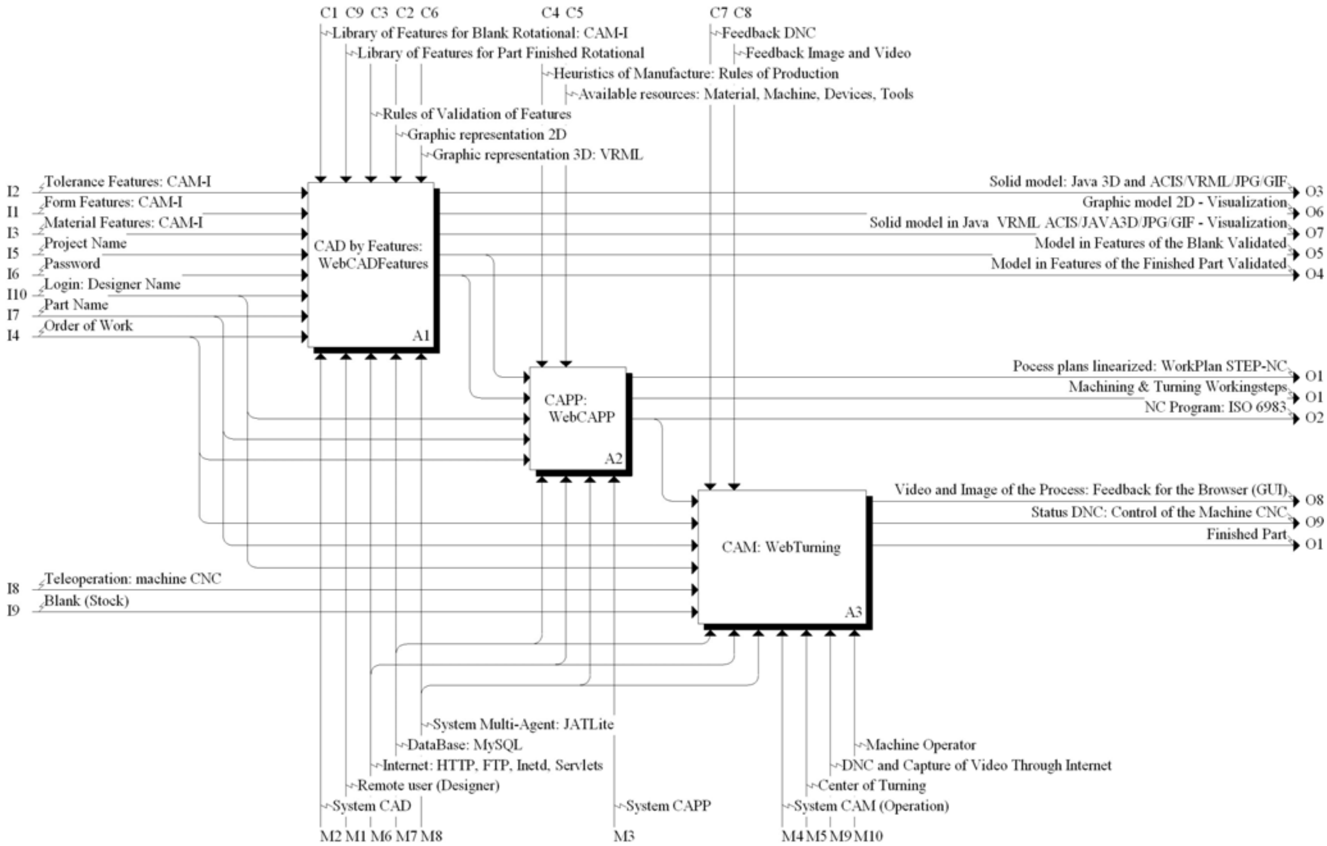


Figure 1. WebMachining: IDEF0 Model (http://webmachining.alvarestech.com/idef0/report_idef0/index.html).

Then, the data about the part are sent to the server. Since the part is cylindrical, the user models the part in two dimensions, and may visualize it in 3D through VRML (figure 2). A database was implemented in MySQL (http://www.mysql.com) that stores the information on the product modeled by features, containing information associated with the form features, material features, and tolerance features.

After completing and validating the model, the designed part is stored and made available to the CAPP module to generate the process plan, and the representation of the linearized process plan is based on STEP-NC. Then, the NC program is generated for a specific CNC lathe, in the case the Romi Galaxy 15M turning center (http://video.graco.unb.br).

The communication with the Romi Galaxy turning center, with CNC Fanuc 18i-Ta (figure 3), is accomplished through an Ethernet connection (physical and data link layers of the ISO/OSI standard), using the TCP/IP protocols (network and transport layers of the ISO/OSI standard) associated with the application protocol Focas1/Ethernet libraries of Fanuc (2003). Focas1 is an API for the development of applications using a standardized data structure to access 300 CNC functions (http://webdnc.graco.unb.br).

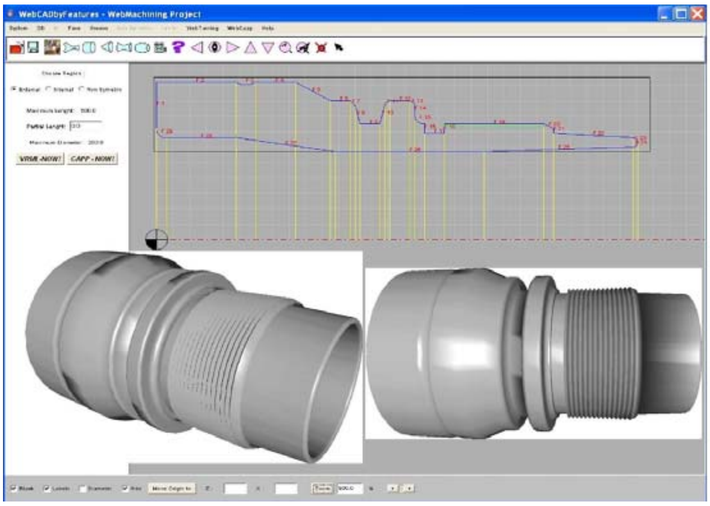


Figure 2. WebCADbyFeatures:2D and 3D Model.

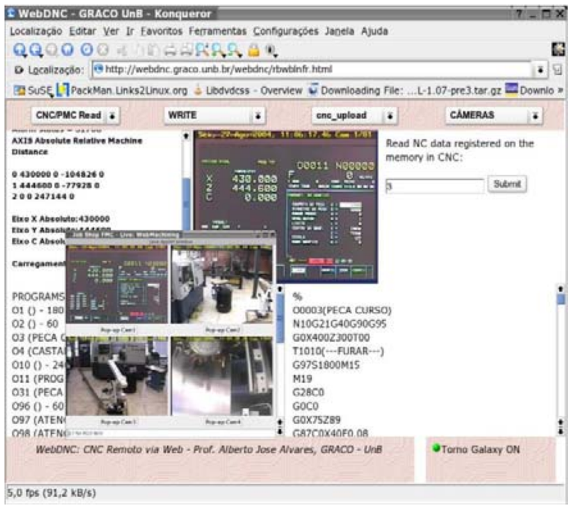


Figure 3. WebTurning.

The teleoperation system of the Romi Galaxy CNC turning center, called WebTurning, is based on a client-server architecture, composed of two modules: WebCam and WebDNC servers, interfaced with the programs in a computer under the Linux operating system, connected logically via TCP-IP sockets and Ethernet to the machine tool and the clients, being responsible for capturing images (http://video.graco.unb.br) and supervisory control of the CNC turning center. The clients are interfaced through Java applets and HTML pages.

The WebTurning teleoperation servers are composed of the video and teleoperation servers of the machine, which provide command services, program execution, download and upload of programs, troubleshooting, and other functions associated with the DNC1 communication protocol, available in the CNC Fanuc 18i-TA, accomplishing the remote supervision of the machine. All control action is executed locally, as a function of the delay of the TCP/IP protocol.

The video server is responsible for video and image capture (with four cameras), and for its 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 about the machine.

In the implementation of the three modules of the WebMachining system, Java, JavaScript, HTML, C and C++ programming languages were used. Some case studies are presented in this paper, showing some parts that were modeled collaboratively, the generation of the process plans, and finally the manufacturing of the parts in a CNC turning center.

3.1 WebCADbyFeatures

The inputs for the WebCADbyFeatures module are the feature model and other necessary information, and it outputs the feature model of the raw material and the finished part, which becomes an input to the CAPP module (figure 1). On the client side the GUI is represented by applets, and two servers are implemented:

- ✓ VRML server based on servlets (TomCat): used for generating the 3D model of the part in VRML, from the feature model of the part;
- ✓ JATLite (Java Agent Template Lite - http://java.stanford.edu/index.html) Router/Facilitator server: allows the management of many sessions of collaborative product modeling, performing the coordination of communication between the WebCADbyFeatures agents, managing the routing of messages between the agents, system security and agent registration. It is implemented through the Agent Message Router (AMR) of the JATLite architecture. The AMR is very important in the JATLite development environment, because the agents always communicate between each other via AMR, performing activities such as sending an e-mail message (e.g. via SMTP) or a file with the feature model in 2D (e.g. via FTP).

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 2D and 3D (via VRML).

It is composed by a GUI that has menus, visualization options, error messages, feature manipulation, communication with the JATLite session manager for collaborative modeling, communication with the database server, communication with VRML server, monitoring of the shop floor (WebCam), teleoperation of the CNC turning centre, among other functions.

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 login and password. Then, the applet is called, downloaded via web, and automatically the local Java machine runs the applet. AWT (Abstract Windowing Toolkit) is used in order to allow a better performance and compatibility with any Java machine version 1.1, which is implemented in a native way in most browsers, without need of a specific plug-in for a certain Java version, facilitating its execution by the user.

The remote user performs part modeling by selecting the desired features from the feature library, which is based on the CAM-I taxonomy (CAM-I, 1986). The part is initially modeled using the union method, and after that the features are subtracted from the part, including the features associated with the C-axis of the CNC turning center, which include keyways, eccentric holes, radial holes, etc.

3.2 WebCAPP

After the part is completed and validated, it is stored and made available to the WebCAPP module, which is responsible for generating the process plan with alternatives for the manufacture of the part, and it also generates the NC program.

For the mapping of design features into manufacturing features, it is necessary to accomplish the following procedures: normalization, setup-oriented decomposition, geometry-oriented decomposition, and operation-oriented decomposition. The normalization phase seeks to identify and remove conceptual mistakes made by the process planner when designing the part in the WebCADByFeatures application, and also to prepare some feature groups so that they can be treated correctly in the following phases.

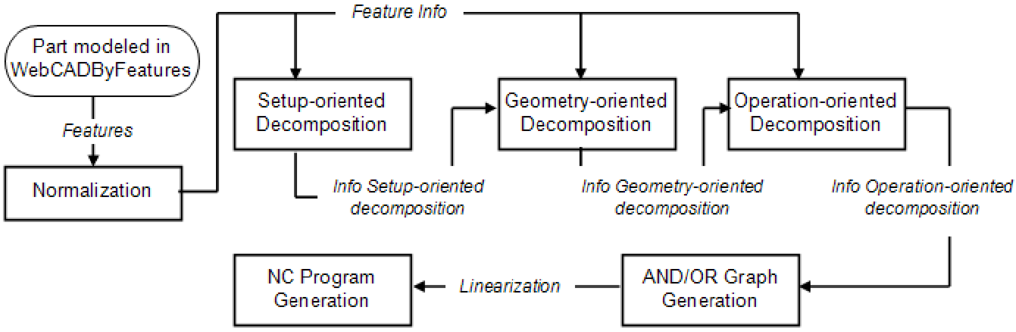


Figure 4. Sequence of activities that are carried out by WebCAPP.

The setup-oriented decomposition takes into account the amount of setups for manufacturing the part, determined as a function of the geometric tolerances, surface quality, stability and part rigidity, and the geometric and functional models of the fixture. It outputs the type of setup, number of setups, and the feature groups to be manufactured in each setup.

After determining the number of setups, and the features groups per setup, the geometry-oriented decomposition is accomplished considering the geometry of the raw material and the final part. The proposed method is based on the decomposition of a polyline, i.e., a closed geometric form composed of a succession of straight lines and connected arcs, which describe in 2D a final area of the cylindrical part, and a global area of material to be removed from the blank. The output of this procedure is the sequence of volumes, represented by machining features, which when removed in the correct sequence, give rise to the desired part.

Table 1. Features available in the developed WebCAPP module.

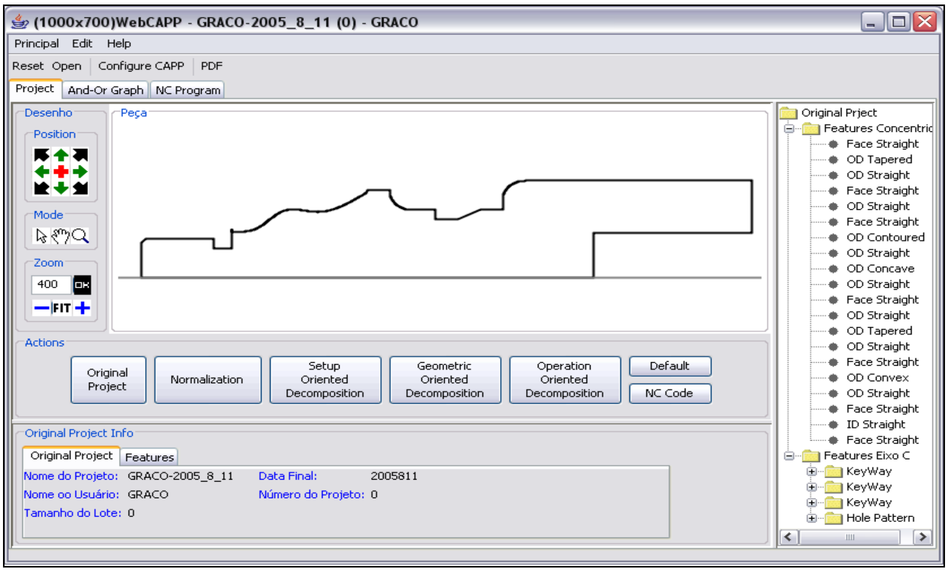
Features			*C-axis Features*
ODStraight	FaceStraight	IDSplineVirtual	HolePattern
ODTapered	FaceTapered	GrooveSquare	KeyWay
ODConcave	IDStraight	Groove_I_Square	
ODConvex	IDTapered	StandardHole	
ODContoured	IDContoured	Complex_Groove	
ODSplineVirtual			

The operation-oriented decomposition performs the decomposition of the volumes to be removed (determined above) into machining features, seeking to associate a sub-volume of a larger volume with a machining operation and a certain type of cutting tool. There is the possibility that a certain volume from the geometry-oriented decomposition cannot be machined in a single operation, and thus it should be mapped into two or more operations. The final result of this stage is the sequence of workingsteps, which when are machined according to the generated sequence from the raw material, the desired part is obtained. After obtaining all possibilities of workingstep sequences, it is possible to determine the process plan with alternatives in the AND/OR graph format. Figure 4 shows the sequence of activities that are carried out by WebCAPP so that the feature-mapping is accomplished, and for the generation of the NC program (G code) for a given part. In the current version the features considered by WebCAPP are shown in table 1.The part shown in figure 5 has external, internal and C-axis (i.e. radial) features, and these are listed in table 2, according to the numbering utilized by the WebCADByFeatures module. In the WebCAPP module, the results obtained in each of the phases of normalization and decomposition can be visualized by clicking in the menu below the image of the part. The results are shown in the form of image, tree, and text, in the panel below the menu of buttons.

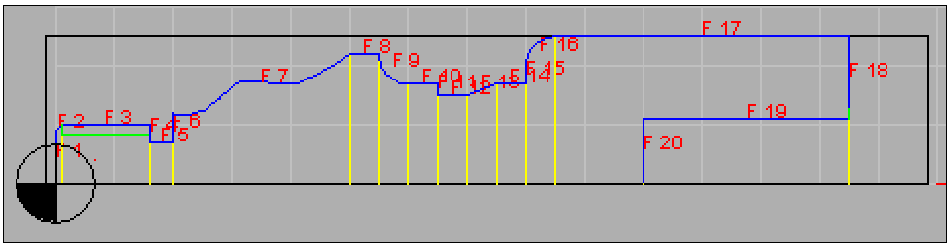
Table 2. Features in the part shown in figure 5.

No	*Features*	No	*Features*	No	*Features*	No	*Features*
1	FaceStraight	7	ODContoured	13	ODTapered	19	IDStraight
2	ODTapered	8	ODStraight	14	ODStraight	20	FaceStraight
3	ODStraight*	9	ODConcave	15	FaceStraight	21	HolePattern**
4	FaceStraight	10	ODStraight	16	ODConvex	22	KeyWay***
5	ODStraight	11	FaceStraight	17	ODStraight	23	KeyWay***
6	FaceStraight	12	ODStraight	18	FaceStraight	24	KeyWay***

* with thread, ** on feature 18, *** on feature 17



(a)



(b)

Figure 5. WebCAPP: features in the part shown in table 2.

Figure 6 shows the result of the normalization of features, where it can be noticed that the normalization transformed the depressions in the part into other types of features, called *Complex Grooves*, and the *spline* was normalized into a feature called ODSpline Virtual. The normalization is applied in order to facilitate the determination of the machining features by the WebCAPP module.

Figure 7 depicts one of the possible groups of setups identified by the setup-oriented decomposition, where the first setup represents the machining of the right-hand side of the part, from the vertical yellow line, and the second represents the left-hand side of the part. This sequence of setups was generated because on the left-hand side there is a feature with a thread (feature no. 3), and thus it is necessary that this portion is the part is the last to be machined. The horizontal yellow line represents the place in which the part will be fixtured in order to machine the surfaces in the second setup. The algorithm chose an internal feature in this case, since on the external feature 17, which could be used for fixturing the part, there are C-axis features.

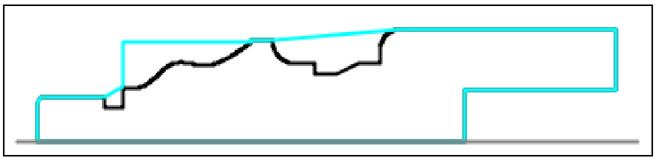


Figure 6. WebCAPP: normalization phase.

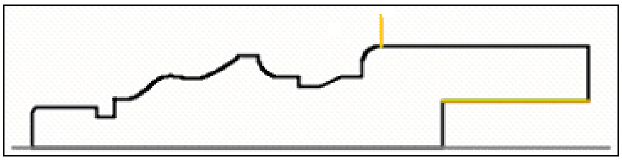


Figure 7. WebCAPP: setup-oriented decomposition.

Figure 8 shows one of the possibilities generated by the geometry-oriented decomposition. It can be noticed that in the first setup there are three machining features that are shown in the figure, whereas four machining features are not shown in the figure, which are the C-axis features. In the second setup, five machining features were determined, and two of those (in pink and grey) refer to the complex grooves, while the one in light blue refers to the spline, which was determined in the normalization phase.

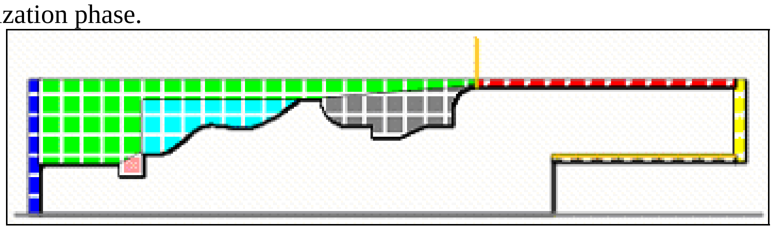


Figure 8.WebCAPP: operation-oriented decomposition phase.

During the operation-oriented decomposition phase, the machining features determined previously are mapped into workingsteps, and the graphical representation of these workingsteps is identical to the one shown in figure 8.

Figure 9 shows the AND/OR graph generated from the previous decomposition phases. It can be noticed the presence of alternatives in the process plan, which are represented by the OR elements. Figure 9 also illustrates one of the possible linearizations, which is shown in green.

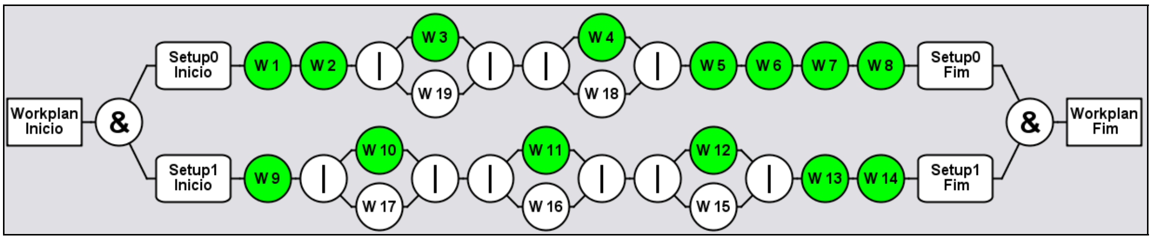


Figure 9. WebCAPP: linearization of Workplan.

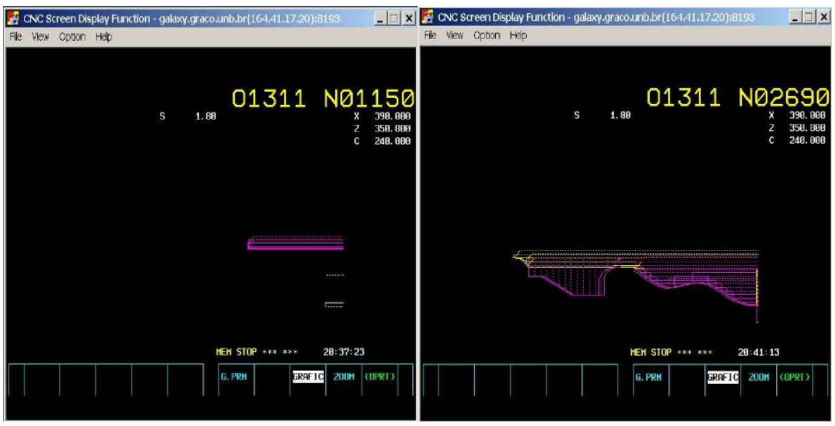


Figure 10. WebTurning: CNC Simulation.

Figure 11. WebTurning: machined part.

From the linearization shown in figure 9, the complete NC program (G code) for the machining of the part was generated and upload to the CNC turning center Romi Galaxy 15M in the GRACO laboratory at the Universidade de Brasília, Brazil. The images shown in figure 10 illustrate the simulation carried out in the CNC, whereas figure 11 shows the machined part.

3.3 WebTurning

The WebTurning system allows the teleoperation of a CNC turning center Romi Galaxy 15M with CNC Fanuc 18i-ta, which can be accessed in http://webdnc.graco.unb.br/webdnc, based on an client-server architecture using a methodology developed by Álvares and Romariz (2002), composed of two main modules:

- ✓ Three servers, represented by the system for capturing images in real time (WebCam - http://video.graco.unb.br, shown in figure 3) 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, 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.

The teleoperation server of WebTurning is composed of the video server (WebCam) and the teleoperation servers of the CNC machine (WebCNC): WebDNC and FOCAS1/DNC1 servers of the Romi Galaxy turning center. The WebDNC server (http://webdnc.graco.unb.br) 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.

Table 3. Features present in the parts considered as case studies.

Face	*OD*	*ID*	*Thread*	*Spline*	*Arc*	*Taper*	*Groove*	*Radial Slot*	*Axial Hole*	*No. 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	-	5	23
King	6	6	-	-	1	-	1	2	-	16
Complex Part	6	7	1	1	1	2	2	3	3	26

Table 4. Cutting tools available at the CNC turning center Romi Galaxy 15M.

No.Turret	*Tool Holder*	*Insert*	*Operation*
T0101	L166.5FA-2020-16	L166.0G-16VM01-002 1020	External threading
T0202	Twist drill	High Speed Steel	Drilling (6 mm)
T0303	LF123g20-2020B	N123G200300003-GM4025	Grooving (circular - 4 mm)
T0404	R416.2-0200C 3-31	LCMX030308-53 1020	Drilling (20 mm)
T0505	SVVBN-2020K1 1	VBMT1604 08-MM2025	External turning - neutral
T0606	R 166.4kF-20F1 6	L166.0G-16VM01-002 1020	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 (circular - 12 mm)
T1212	DDJNL-2020-K15	DNMG1 50608QM235	External turning

4. PARTS CONSIDERED AS CASE STUDIES

Table 3 shows the features that are present in the modeled parts, whereas table 4 shows the cutting tools that are available in the turret of the CNC turning center Galaxy 15M. The parts are as follows:

- ✓ Six parts representing a chess game (pawn, tower, horse, bishop, queen, and king) modeled with the following features: OD, ID, splines, faces, groove, radial slots (C-axis) and axial holes (C-axis). The blank is a 50 mm diameter nylon bar. All these parts are machined in a single setup.
- ✓ A part called “example2 part”, composed of the following features: OD, ID, arc, spline, groove, external thread, face, slot (C-axis) and a pattern of holes (C-axis). The blank is a 50 mm nylon bar, and the part is machined in two setups.

4.1. Chess Parts

4.1.1. WebCADbyFeatures: Modeling of the Chess Parts

The design of the parts, and the VRML 3D models associated with the parts, generated by the WebCADByFeatures module, are shown in figure 12. The tower has a C-axis feature, which is a radial slot, and the information about the C-axis features is input from a menu associated with an OD feature (i.e. external diameter). The pawn has a spline feature, whereas the queen presents two views of the VRML model generated by the WebCADByFeatures.

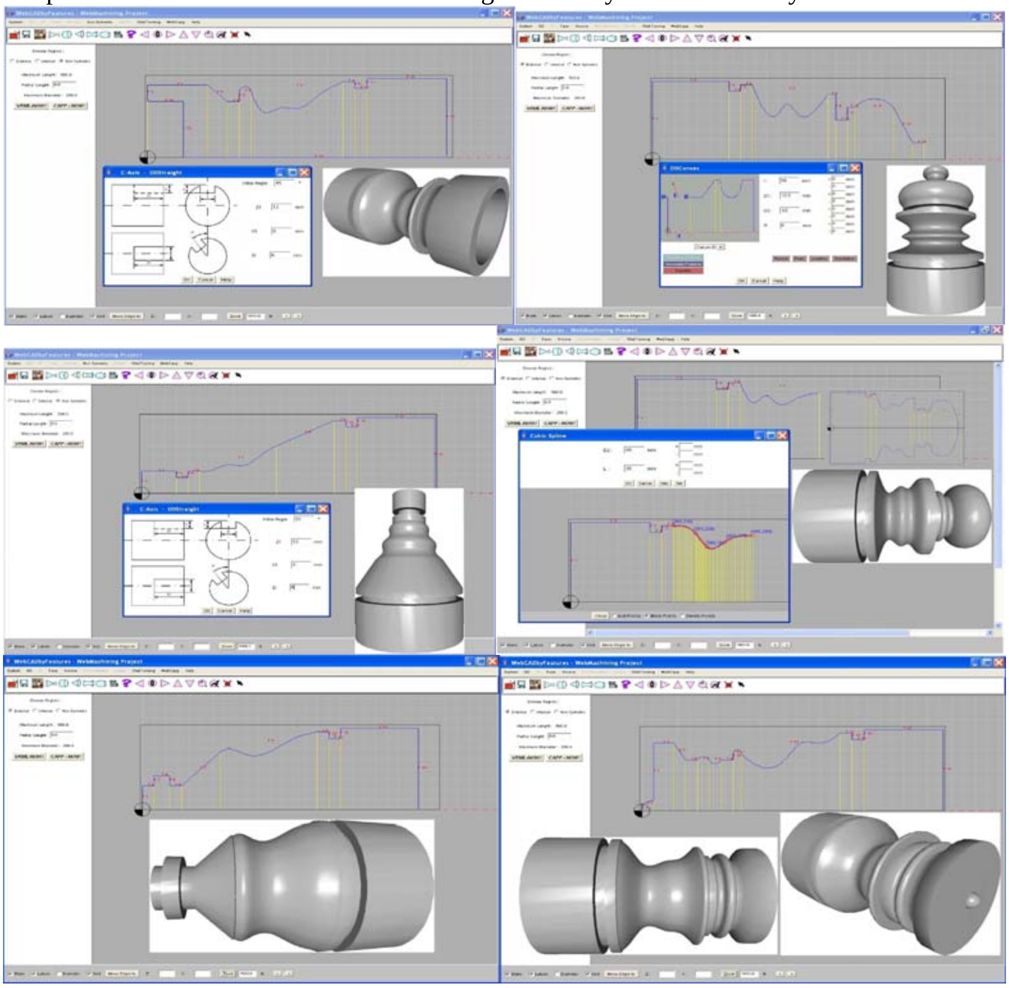
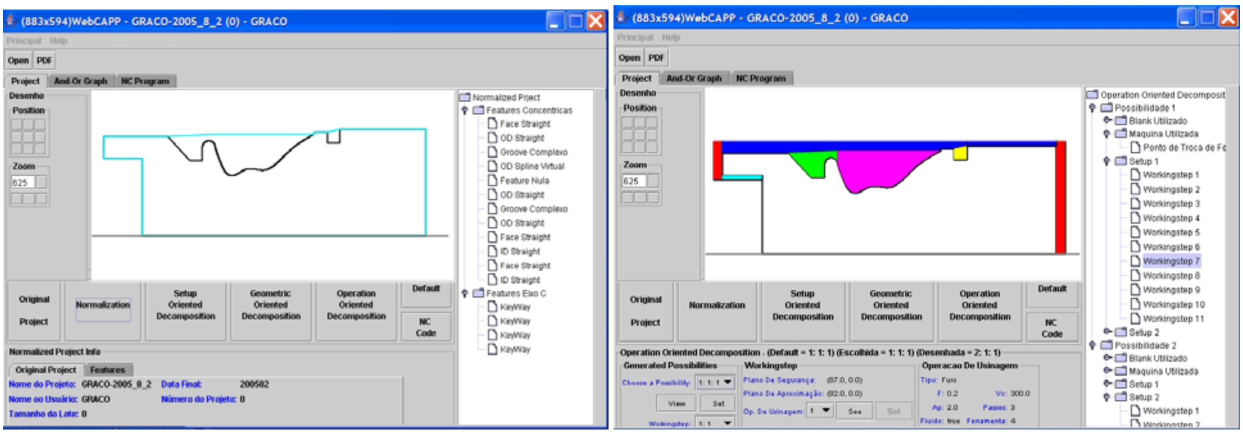


Figure 12. WebCADbyFeatures: modeling chess parts.

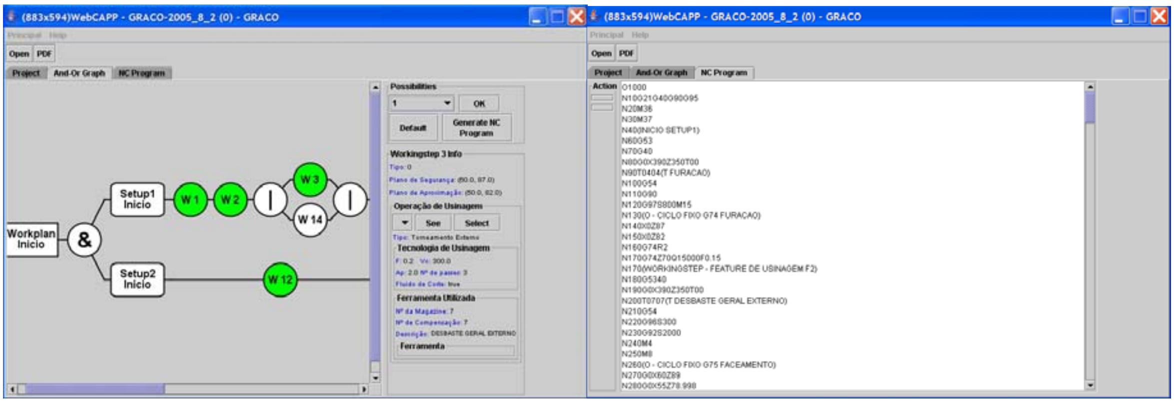


(a) (b)

Figure 13. WebCAPP tower part: normalization and operation decomposition phase.

4.1.2. WebCAPP: Process Planning

Figure 13(a) shows the output from the WebCAPP module for the normalization procedure associated with the tower, where it can be noticed the identification of features such as complex groove and virtual spline. Then the setup-oriented decomposition starts, and figure 13 (b) shows the output of WebCAPP for this procedure for the tower, which shows the external and internal fixturing features, the lines that limit the features for each setup, as well as the presence of the C-axis features (in this case there are four keyways). Then, the geometry-oriented procedure is applied, where the fixturing features for each setup are identified, as well as the type of blank available in stock, and the machining features that will be removed in each setup (figure 13).



(a) (b)

Figure 14. WebCAPP tower part: nonlinear workplan and NC program.

Figure 15. WebTurning: six chess parts were simulated in the CNC of the turning center.

The operation-oriented decomposition is carried out afterwards, which is responsible for determining the workingsteps and a nonlinear workplan. Figure 14 (a) shows the workingsteps and the alternative machining operations for each mapped machining feature, with all the technological pieces of information necessary for the manufacture of the tower. The data referring to the machining operations for each machining feature are presented, including the safety and approach planes, machining conditions, cutting fluid, selected cutting tool and its location at the turret of the CNC turning center, as well as the number of the cutting tool length offset, among others.

Then the NC program is generated for the part, and figure 14 (b) also shows the NC program generated for the tower, and the AND/OR graph with the alternative workingsteps, which compose the workplan for the part. The workingsteps shown in green in figure 14 (a) indicate the path of the linearized AND/OR graph that gave rise to the NC program. The NC programs generated by WebCAPP for the six chess parts were simulated in the CNC of the turning center, and these screens are shown in figure 15.

4.1.3. WebTurning: Teleoperation of the CNC turning center

Figure 16 illustrates the WebDNC graphical user interfaces, which show the teleoperation interfaces for the chess parts, fixturing of the parts, NC program, CNC screen, CNC status, available programs in the CNC memory, among other pieces of information related to teleoperation. The six machined chess parts are shown in figure 17.

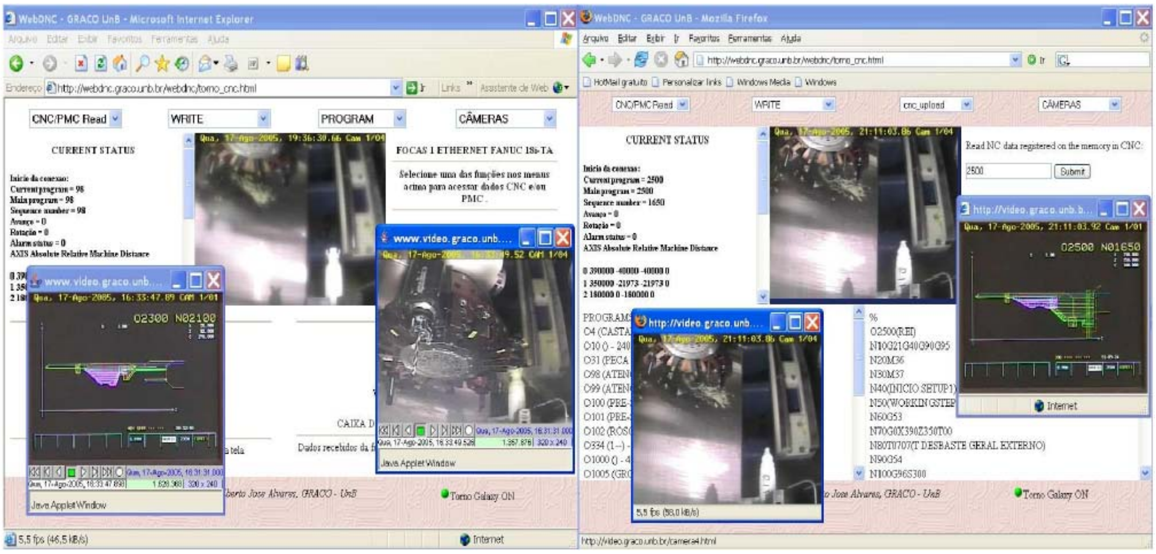


Figure 16. WebTurning: WebDNC graphical user interfaces.

Figure 17. Six machined chess parts.

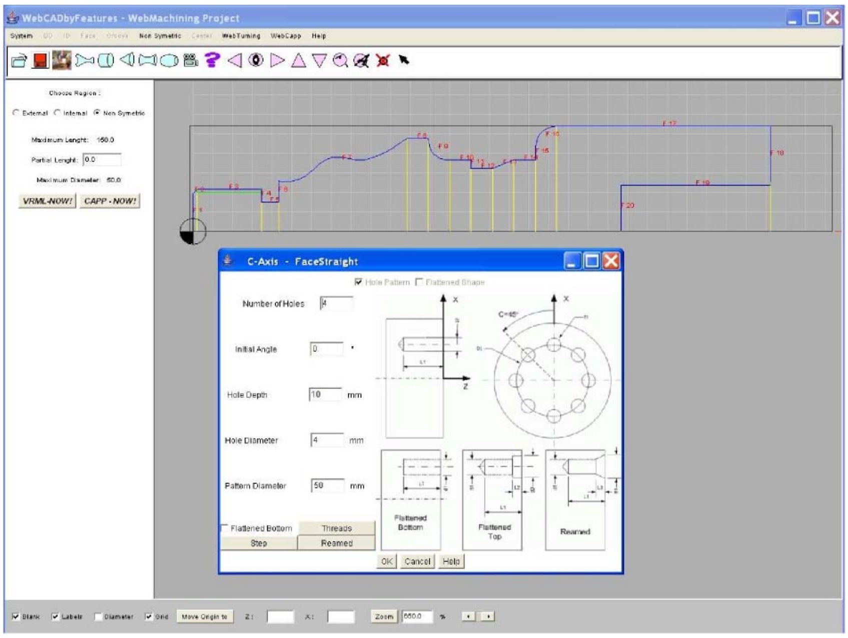


Figure 18. Example2 part is composed of concentric and non-concentric features.

4.2. Example2 Part

4.2.1. WebCADbyFeatures: Modeling of the Example2 Part

The example2 part is composed of concentric and non-concentric features, and it is shown in figure 18, where it can be seen a pattern of Axial holes, located on the face feature F18. This part has a total of 36 features, which include: thread, ODs, IDs, grooves, hole, arcs, spline, transition features, and tapers. It also has the following C-axis features: radial slot, and pattern of axial holes.

4.2.2. WebCAPP: Process Planning

The procedure for feature-mapping generates a process plan with two setups, where in setup1 the following features are machined: external features F17 and F18, internal features F19 and F20, and C-axis features three radial slots and three axial holes. It should be pointed out that the roughing of feature F19 is performed with a non-rotating tool, since the diameter is equal to 22 mm, being greater than the diameter supported by the rotating tools. In setup2 the following features are machined: external features F1 to F16, including a complex groove, splines, and the thread (figure 18).

4.2.3. WebTurning: Teleoperation of the CNC turning center

Figure 19 illustrates the WebDNC graphical user interface, which shows a screen with the monitoring of the machining process of the example2 part associated with the two setups, and details of the features in the external region of the machined part.

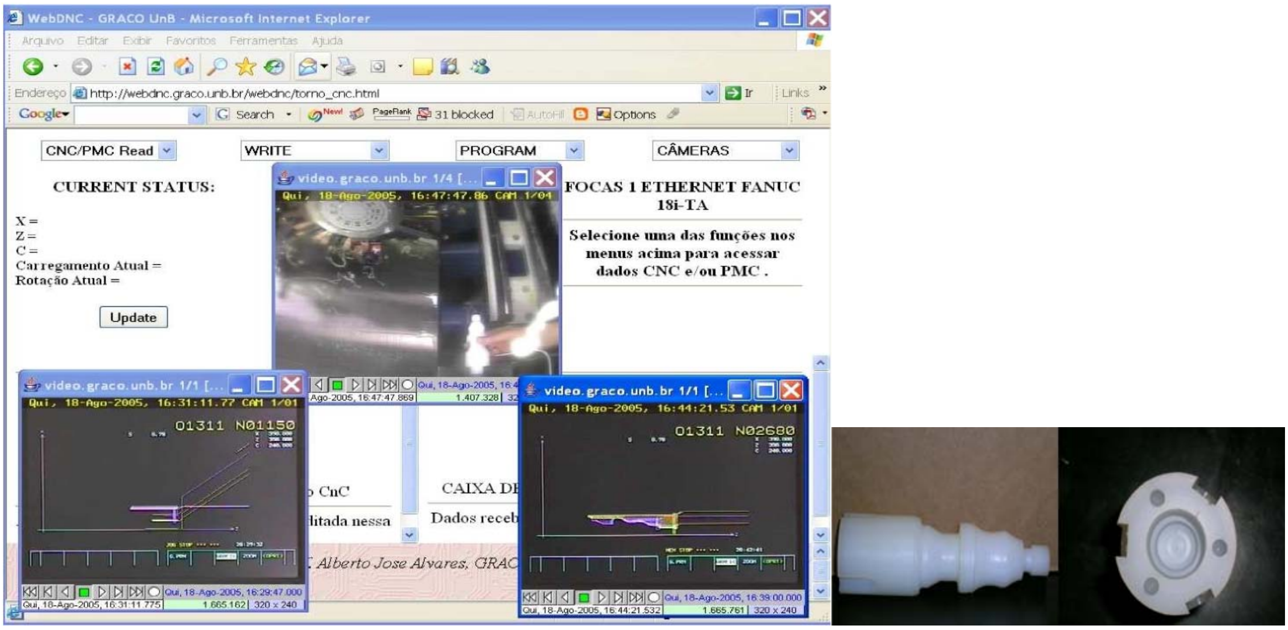


Figure 19. WebDNC and machined part.

5. CONCLUSIONS

The WebMachining system, whose modules were described in this paper, can be accessed via web in the URL http://webmachining.alvarestech.com, making it available a remote laboratory and a system for rapid prototyping by machining, in a context of e-Mfg, allowing collaborative modeling, process planning and remote machining through the Internet.

Through the WebCADByFeatures module, the remote user can carry out collaborative product development, and it is based on the synthesis of design features for cylindrical parts (symmetrical and asymmetrical features).

The WebCAPP module is responsible for generating quickly a process plan for the modeled part, which confers agility to the integration between CAD and CAPP. The methods for feature-mapping of cylindrical parts, which include turning, drilling and milling features, consider the possible machining alternatives.

The teleoperation of the CNC turning center (WebTurning) can be carried out in the URL http://webdnc.graco.unb.br. WebTurning has 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.

6. REFERENCES

Álvares, A.J., Romariz, L.J. (2002). Telerobotics: Methodology for the Development of a Through-the-Internet Robotic Teleoperated System. *Journal of the Brazilian Society of Mechanical Sciences, 24(2)*, 122-126.

Álvares, A.J. (2005). A Methodology for the CAD/CAPP/CAM Integration for the Remote Manufacture of Cylindrical Parts Based on the Internet. Ph.D. Thesis. Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil (in Portuguese).

Álvares, A.J., Paulinyi, S.C.A. (1999). Telerobotics:Through-the-Internet Teleoperation of the ABB IRB 2000 Industrial Robot. Telemanipulator and Telepresence Technologies V - SPIE, 259-269, Boston, USA.

Bidarra, R., Van den Berg, E., Bronsvoort, W.F. (2001). Collaborative Modeling with Features, *Proceedings of DET'01, ASME Design Engineering Technical Conferences*, Pittsburgh, USA.

CAM-I, Deere & Company (1986). Part Features for Process Planning. Moline, Illinois, CAM-I.

Cecil, J., Davidson, S., Muthayan, A., (2005). A Distributed Internet-based Framework for Manufacturing Planning. *International Journal Advanced Manufacturing Technology*, Springer-Verlag. Published online.

Corney J., Lim T. (2001). 3D Modeling with ACIS. Saxe-Coburg Publications, 2nd Edition.

FANUC (2003). FOCAS1: FANUC Open CNC API Specifications version 1 - FOCAS1/Ethernet CNC/PMC Data window library. http://www.graco.unb.br/alvares/romi/Focas1/Disk2/Doc/FWLIB32.HTM

Ferreira, J.C.E., Wysk, R.A. (2001). An Investigation of the Influence of Alternative Process Plans on Equipment Control. *Journal of Manufacturing Systems, 9(6)*, 393-406.

Fuh, J.Y.H., Li, W.D. (2005). Advances in collaborative CAD: the State-of-the-Art. *Computer-Aided Design, 37(5)*, 571–581.

Groover, M. (2003). Automation, Production Systems, and Computer Integrated Manufacturing. Prentice Hall, 2nd Edition.

Haag, S., Cummings, M., Dawkins, J. (1998). Management Information Systems for the Information Age. McGraw-Hill.

Han, J.H., Requicha, A.A.G. (1998). Modeler-independent Feature Recognition in a Distributed Environment. *Computer-Aided Design, 30(6)*, 453-463.

Hardwick, M., Spooner, D. L., Rando, T, Morrir, K. C. (1996). Sharing Manufacturing Information in Virtual Enterprises. *Communications of the ACM, 39(2)*, 46-54.

ISO - STEP-NC Project (2000). STEP-Compliant Data Interface for Numerical Controls. ESPRIT Project EP 29708, STEP-NC Newsletter, Issue 1, April, also available at http://www.step-nc.org

Kao, Y.C., Lin, G.C. (1996). CAD/CAM Collaboration and Remote Machining. *Computer Integrated Manufacturing Systems, 9(3)*, 149-160.

Lee W.B., Lau, H.C.W. (1999). Multi-agent Modeling of Dispersed Manufacturing Networks. *Expert Systems with Applications, 16(3)*, 297-306.

Lee, J.Y., Han, S. B., Kim, H., Park, S. B. (1999). Network-centric Feature-based Modeling. Pacific Graphics.

Li. W.D., Ong, S.K., Fuh, J.Y.H., Wong, Y.S., Lu, Y.Q., Nee, A.Y.C. (2004). Feature-based design in a collaborative and distributed environment. *Computer-Aided Design, 36(9)*, 775–797.

Martino, T. D., Falcidieno, B., Hasinger, S. (1998).Design and Engineering Process Integration Through a Multiple View Intermediate Modeler in a Distributed Object-oriented System Environment.*Computer-Aided Design, 30*,437-452.

Malek, L.A., Wolf, C., Guyot, P. D. (1998). Telemanufacturing: A Flexible Manufacturing Solution. *International Journal of Production Economics, 56-57*, 1-12.

Nof, S.Y. (2004). Collaborative E-Work And E-Mfg: The State Of The Art And Challenges For Production And Logistics Managers.11th IFAC Symposium on Information Control Problems in Manufacturing, 5-7/4, Salvador, Brazil.

Shah, J.J., Dedhia H., Pherwani V., Solkhan S. (1997). Dynamic Interfacing of Applications to Geometric Modeling Services Via Modeler Neutral Protocol. *Computer-Aided Design, 29*, 811-824.

Shao, X., Li, Y., Li, P., Liu, Q. (2004). Design and implementation of a process-oriented intelligent collaborative product design system. *Computers in Industry,53(2), February*, 205-229.

Smith, C.S., Wright, P.K. (2001). Cybercut: An Internet-based CAD/CAM System. *ASME Journal of Computing and Information Science in Engineering, 1(1)*, 1-33.

Tay, F.E.H., Khanal, Y.P., Kwong, K.K., Tan, K.C. (2001). Distributed Rapid Prototyping - A Framework for Internet Prototyping and Manufacturing. *Integrated Manufacturing Systems, 12(6)*, 409–415.

Taylor, K., Trevelyan, J. (1995). A Telerobot on the World Wide Web. National Conference of the Australian Robot Association, Melbourne, July 5-7, http://telerobot.mech.uwa.edu.au.

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