A WEB-BASED SYSTEM FOR THE DESIGN AND MANUFACTURE OF FEATURE-BASED PRISMATIC PARTS

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Abstract. *Globalization has caused a significant increase in the competition among companies, but it also allows the cooperation among them, even if they are geographically distant among themselves. A research area resulting from that virtual approach is the remote design and manufacture of parts, which has the participation of the following actors: (a) a remote customer who inputs the order; (b) a company responsible for modeling the development and deployment of the computer modules for the design and manufacture of the parts, and for the planning of the operations to be executed on the ordered parts; and (c) a company where manufacture will actually take place. It should be mentioned that these actors can be located anywhere in the world. This paper describes a methodology for integrating CAD/CAPP/CAM for the remote manufacture of prismatic parts using the Internet, and especially the protocols associated with the World Wide Web. It is also described each of the developed modules. The procedure begins with the modeling of a prismatic part based on features in the context of remote manufacturing, using the Web as a means of communication, in a client-server computer model. Part modeling is based on synthesis of design features, with the objective of allowing the integration of the design activities (CAD), process planning (CAPP) and manufacturing (CAM). The system makes available a library of standard features, and the features considered in the current implementation are: hole, shoulder, slot and rectangular pocket. The result is tested in a rapid prototyping milling machine that uses commands of the HPGL language.*

Keywords**:** *Remote Manufacturing, CAD, CAPP, CAM, Internet.*

1. INTRODUCTION

In a market that is becoming each day more globalized, the increasing variety of products offered at competitive prices causes the companies to seek for cheaper and faster ways to manufacture their products way. The current demand is that new products are launched with a greater frequency than in the past, and with better quality, greater variety of models and lower costs, and all of this in an ever decreasing time scale (Blake, 1992).

A technology that has been accelerating the globalization is the Internet, through which the consumer can sell or buy products without leaving his/her house or workplace. Since the Internet allows the virtual approach between people or companies located geographically distant amongst them, it can also be used as a technology to allow the remote manufacture of parts. This type of manufacture is motivated by the fact that the customer does not necessarily need to possess the pieces of equipment and accessories for producing the product.

Described within this paper is the implementation of a software for the design and manufacture of prismatic parts via Internet, using the TCP/IP communication protocols. The modeling of the parts is carried out through features made available in a library. In the current version the following features compose the library: hole, step, slot, and rectangular pocket. The CAPP module receives the data from the CAD module, and it maps them into manufacturing data. Finally, the CAM module generates the HPGL code, which can then be sent to the rapid prototyping three-axis milling machine, through a serial port.

The system was implemented in the Java programming language (http://java.sun.com), which is appropriate for the development and execution of web-based applications.

2. LITERATURE SURVEY

Modern manufacturing enterprises are built from facilities spread around the globe, which often contain equipment from different manufacturers. Immense volume of product information must be transferred between the various facilities at different locations. Today's digital communication technology has solved the problem of reliably transferring information across the global networks.

Internet can be considered a means that enables a direct cooperation between the customer and manufacturing companies. It can also be used to support activities of the manufacturing company, such as in the cooperation among different departments of a company, aiming at reducing the manufacturing costs, besides the improvement of product quality (Ferreira and Andriolli, 2005). Another application of the Internet is in the support to the remote manufacture of parts, allowing that a remote user located anywhere in the world becomes a potential customer of the system, without the need to have the necessary pieces of equipment to manufacture the product. Several research works were developed in this research area, and some of those systems will be described in the next section.

2.1. Design by Features

According to Shah and Mantyla (1995), features are entities that represent the meaning of engineering of a product or a manufacturing process in a more intelligent way than the explicit geometry. Some examples of features include holes, chamfers, steps, etc.

Shah and Mantyla (1995) mention that there are two approaches for feature-based design:

- Destruction by Machining Features, which begins with a model of the workpiece (raw material) that will be machined. The part model is created by subtracting the features that correspond to the material removed from the workpiece. Through this system, the user (i.e. designer) is supposed to remove geometric entities from a part with a regular shape, via the machining of the workpiece, in such a way that the manufacturing process of the part is built-inherently into the design. The advantage of this approach is that the machining features are explicitly available in the part model, thus being unnecessary any kind of feature-recognition or feature-mapping.
- Synthesis of Design Features, in which the part model can be composed of both positive and negative features, thus being unnecessary to start with a workpiece.

By using features for designing parts, the parts are created using features directly, and the geometric model is generated from the feature model as show in Fig. 1. This requires that the CAD module has generic definitions of features made available by the feature library, allowing the instantiation of the features by the specification of dimensions, position parameters, the feature/face/edge on which it is located, and several other attributes, constraints and relationships.

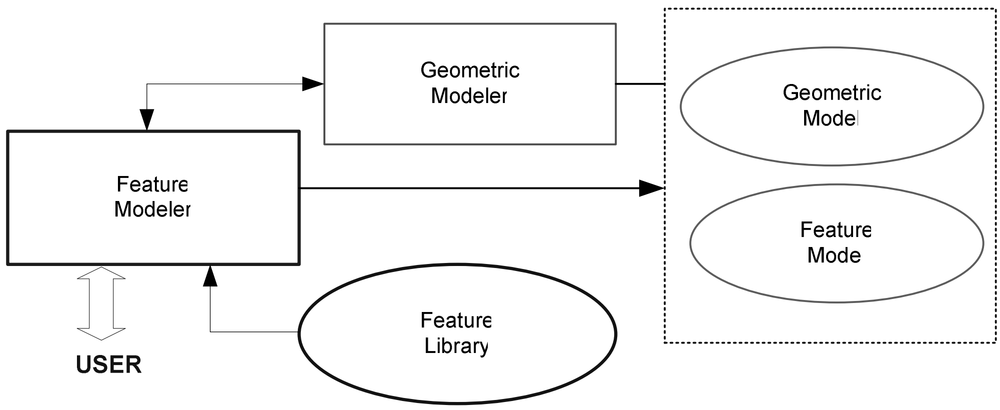

Figure 1. Creating features using the Design by Features approach (Shah and Mantyla, 1995).

In this work the first approach is applied, i.e. Destruction by Machining Features. Some of the researches that were developed in the area of remote design and manufacturing of parts are pointed out below.

2.2. Client/Server Model

In this type of model the data are distributed among a set of processors. According to Hall (1999) and Tourino (2000), the main components of such model are:

- The servers, which provide services for other subsystems.
- The clients, which request services provided by the servers.
- A computer network, which allows the clients to access these services.

Figure 2 shows a manufacturing instance of this model.

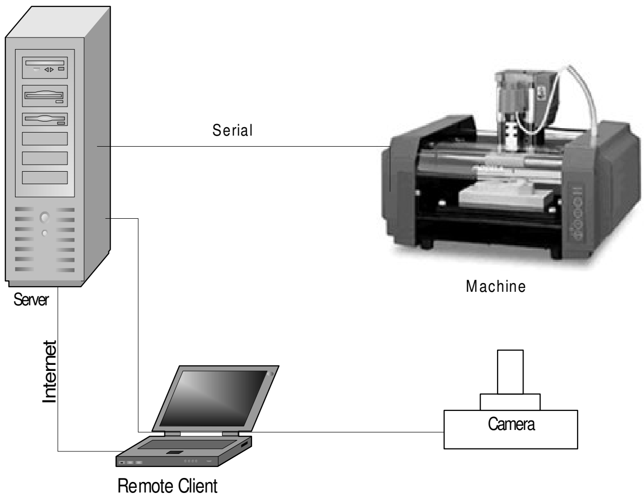

Figure 2. Client/Server manufacturing model

2.3. Related Systems

Smith and Wright (2001) described a distributed manufacturing service called Cybercut, developed at the University of Berkeley (http://cybercut.berkeley.edu), which enables the design of a prismatic part that will be machined using a CAD/CAM system developed in Java in a context of remote manufacture.

Álvares (2005) developed a computer system for the remote manufacture of cylindrical parts in a context of distributed manufacture. The system applied the approach based on Synthesis of Design Features.

The WebSpiff system (Bidarra et al., 2001) is based on a Client/Server architecture, composed of two main elements on the server side: the SPIFF modeling system, which provides all the feature-based modeling functionality, using the ACIS modeling kernel (Corney and Lim, 2001); and the modeling session manager, which manages all the communications between the SPIFF system and the users. The components of the WebSpiff portal (http://www.webspiff.org) provide the initial access to a WebSpiff session for a new client (user), which includes a web server where the part model is made available for download by the other clients who are developing the cooperative design.

Lee et al. (1999) presented the architecture of a network-centered feature-based modeling system, in a distributed design environment, called NetFeature System. The system supports activities of product modeling and cooperative design in a computer network.

3. INTEGRATED CAD/CAPP/CAM SYSTEM

The methodology for the development of this integrated CAD/CAPP/CAM system is based on the Destruction by Machining Features approach, with the purpose of allowing the integration of the design activities (CAD), process planning (CAPP) and manufacturing (CAM). The system applies the Client/Server computer model, in a context of remote manufacturing using the Internet as the communication means.

Through the CAD module, the remote user can design a part based on features. Then, the CAPP module receives information from the CAD module, adds information related to the manufacturing process (available machine, chosen material, machining parameters, among others), and generates the process plan. Finally, the CAM module is responsible for generating the HPGL code for machining the part at the rapid prototyping milling machine.

The system was structured using the approach based on the IDEF (Integration DEFinition) methodology (http://www.idef.com), which is a graphical approach for describing systems (Michel, 2002). In a IDEF0 diagram, the system a whole is decomposed in activities, and these activities are then decomposed into sub-activities, for a better detailing of the system. The IDEF0 diagram (on the zero level) of the integrated system is shown in Fig. 3, where the input requirements and the outputs of the system can be seen among other things. Figure 4 shows the integrated system on level one in an IDEF0 diagram, where the three modules can be seen.

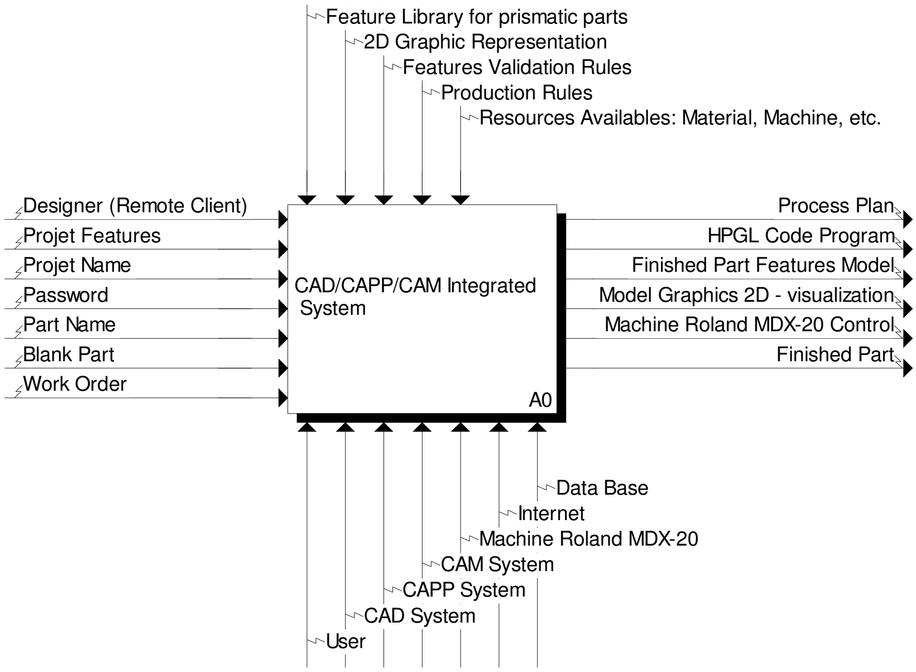

Figure 3. IDEF0 diagram, level 0 of the integrated system.

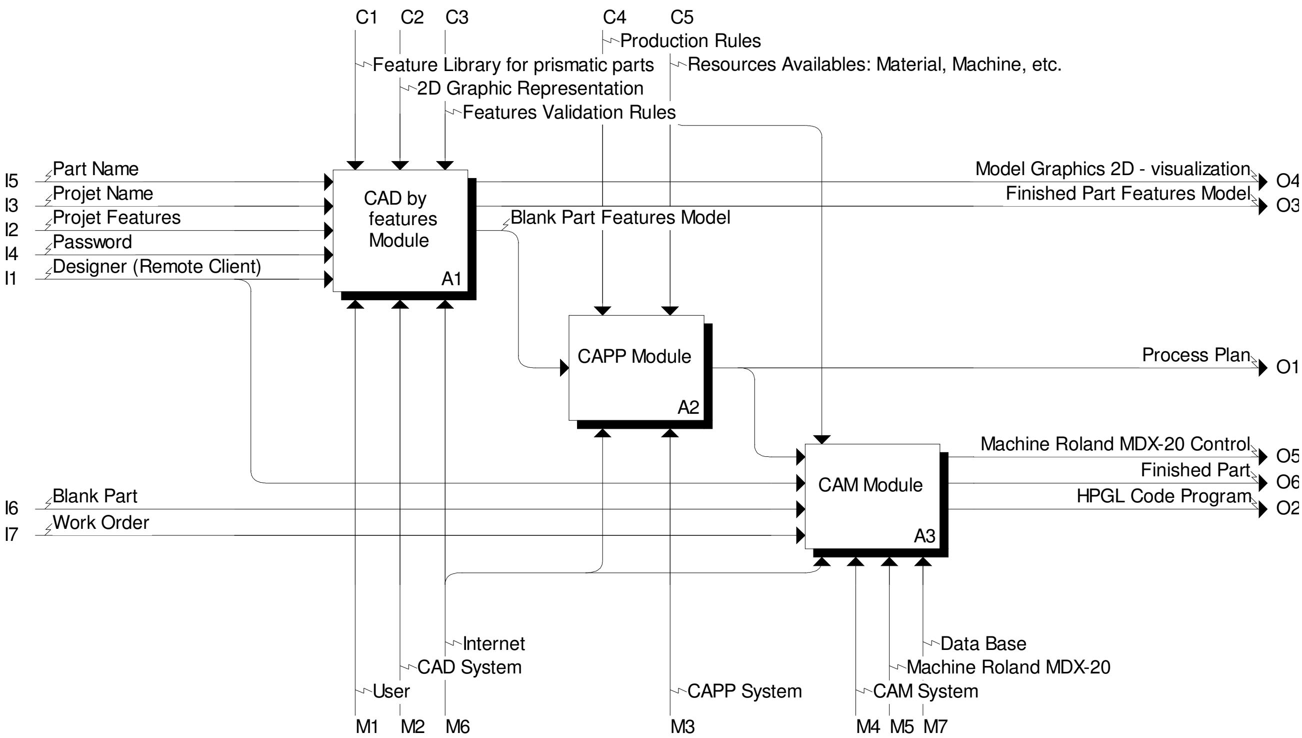

Figure 4. Integrated CAD/CAPP/CAM system in IDEF0, level 1.

3.1. CAD Module

As can be seen in Fig. 4, the outputs of the CAD module are: the feature-based model of the finished part, and the geometric model or 2D visualization. In order to achieve that, the CAD module carries it out in three stages:

(a) Generation of the part model utilizing the library of features:

The part model should be generated using the feature library provided by the system. The system requires that the dimensions of the workpiece are specified, from which the finished part will be obtained.

Since this system was developed using object-oriented programming techniques, in this CAD system the raw material is an object that contains an array called "faces", in which there are six objects called Faces, which correspond to each of the six faces of a box, as can be seen in Fig. 5.

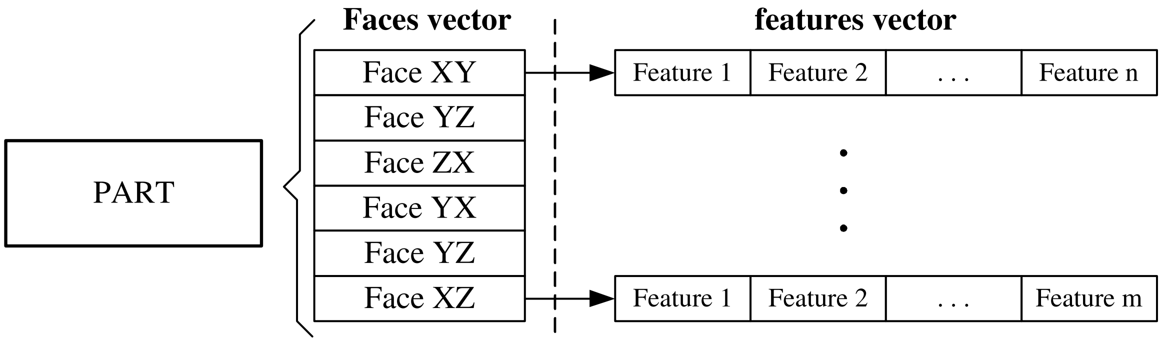

Figure 5. Block decomposed into Face arrays.

Each one of these Face objects has an array called "features", which is empty at the moment when a new part is created (since no features have been created yet). But when the remote user adds features to the model, each feature will be added to this array.

The library of features supports the creation of holes, steps, slots, and rectangular pockets, which are features usually found in mechanical parts. The creation of a new feature implies the specification of its parameters. For instance, for a hole it is necessary to input its position in space, as well as its radius, depth, and face on which it will lie.

(b) Validation of the part

In a second stage, the part should be validated. The CAD module has tools that aid the designer in creating a part that can be manufactured, and some validation rules were implemented taking into account the available cutting tool, the available machine, and the order of precedence of the created features. Some of these rules are as follows:

- A feature that is not located within the limits of the face is not considered as being valid.
- The depth of a feature must not be greater than the maximum depth of the workpiece, otherwise the cutting tool could collide with the machine table.
- The user will no be allowed to create a feature that cannot be machined with the available cutting tool, e.g. a hole with a diameter smaller than the diameter of the cutting tool cannot be created.
- It is not allowed to create features on faces that cannot be used for fixturing.

(c) Graphical modeler

Finally, in the last stage the graphical modeler checks the arrays of the faces. If some face contains features, its graphical representation will be generated, and shown to the remote user. Figure 6 shows a part modeled in this system.

On the left-hand side of the figure, the geometric model of the part is presented, whereas on the right-hand side the feature model is shown, containing the created features on each face.

3.2. CAPP Module

The activities carried out by the CAPP module are described in this section.

(a) Mapping of features into workingsteps

In this system, a workingstep (STEP-NC, 2000) contains all the data related to the geometry of the feature, besides containing other data that are useful for manufacturing, such as the axial depth of cut, radial depth of cut, and the cutting tool trajectories.

With the information about the available cutting tool, the power of the machine spindle, and the workpiece material, the maximum material removal rate can be determined, and from it the axial depth of cut (a_p) is calculated.

The maximum radial depth of cut (a_e) is considered as being equal to the tool diameter, since, in order to machine a slot, the cutting tool must engage with its whole diameter.

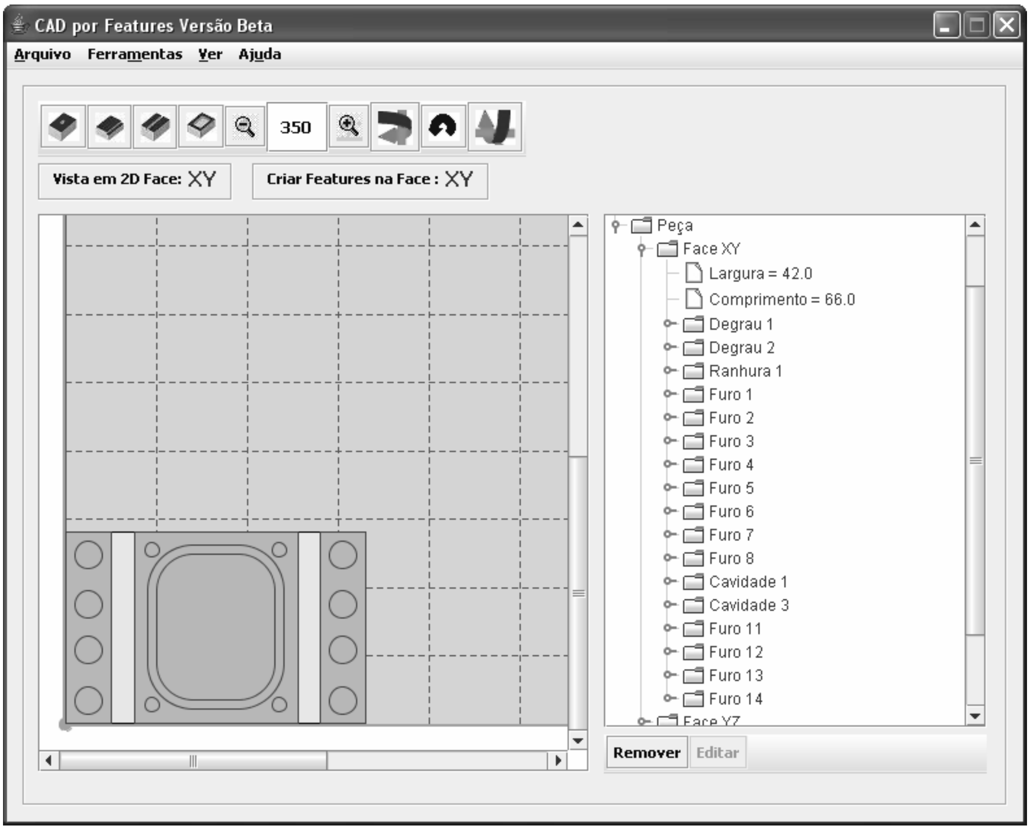

Figure 6. Modeled part in the CAD module.

(b) Determining the trajectories of the cutting tools for each type of feature

For each type of feature there is a type of movement:

- In the case of a hole, the movement is initially linear in the radial direction, and then circular, as shown in Fig. 7.
- In the case of a slot, the condition is similar to a step, and the adopted strategy is a zigzag, as shown in Fig. 8.
- In the case of a rectangular pocket, the movements are divided into linear and circular portions, as shown in Fig. 9.

Equation (1) shows the range of the linear movement, and if the current radius is greater than L_1, then the mixed region has been reached, and the interpolation points of the four circular arcs should be calculated.

Equation (2) represents the portion in which the tool should interpolate the circular arc of the pocket.

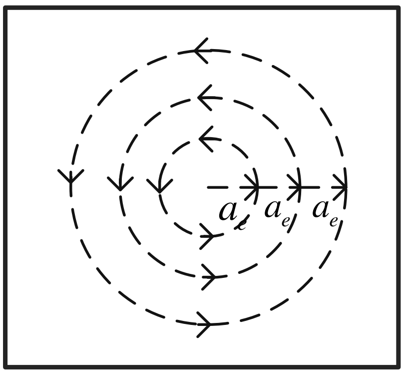

Figure 7. Movement strategy for the hole.

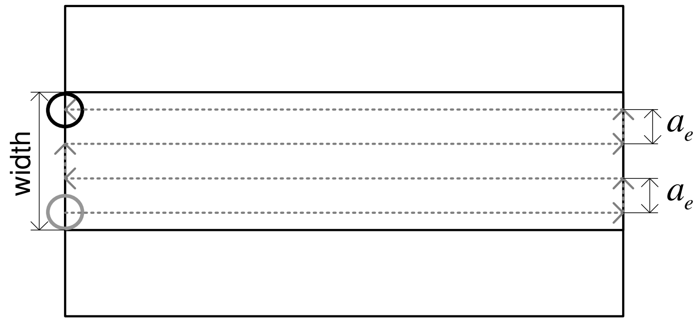

Figure 8. Movement strategy for the step and slot.

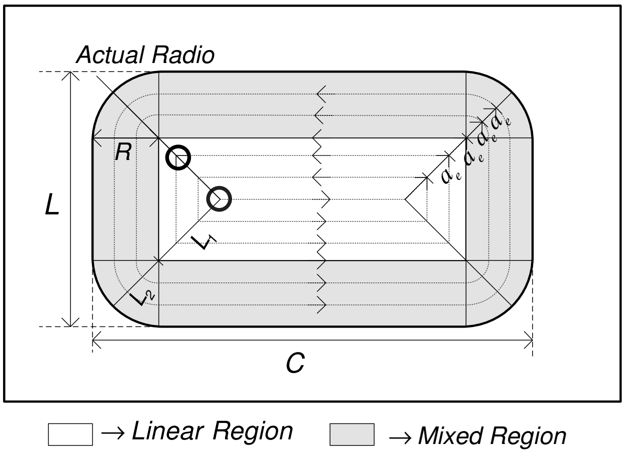

Figure 9: Movement strategy for the rectangular pocket.

where:

$$L_1 = \left(\frac{L}{2} - R \right) \times \sqrt{2} \quad (1)$$

$$L_2 = R \quad (2)$$

In that way, the points where the cutting tool will pass are calculated, and for each of the created features these points are stored in an array of movement points.

All these data are added to the feature information for creating a workingstep, as shown in Fig. 10.

(c) Creating groups of workingsteps.

Once all useful manufacturing information is added to the workingstep, the CAPP module groups the workingsteps by layer. In other words, the workingsteps that have the Z coordinate closer to the originating surface will be machined first, and so on. An example is shown in Fig. 11, where a part with one step and three holes is presented. The step has position Z = 0, and the Z position of the holes correspond to the depth of the step. In this case, two groups of workingsteps will be formed, one of them with a single workingstep (the step), and the other with three features (the three holes), since they share the same Z coordinate. Figure 12 shows a diagram illustrating how the workingsteps of this example part were grouped.

In the last stage of the CAPP module, the machining sequence is determined. The criterion used in this case is that the cutting tool should move along a minimum distance. For example, for the part in Fig. 11, since on layer 1 there is only one workingstep (related to the step), then it is clear that this step will have to be machined first. However, it is necessary to determine which corner will be machined first, and this is done by calculating the distances of the possible starting points for machining as shown in Fig. 13. After completing the machining of the step, and assuming that the cutting tool stopped at the point indicated in Fig. 13, again the distances from the current position of the cutting tool to the possible machining starting points of the other features are calculated.

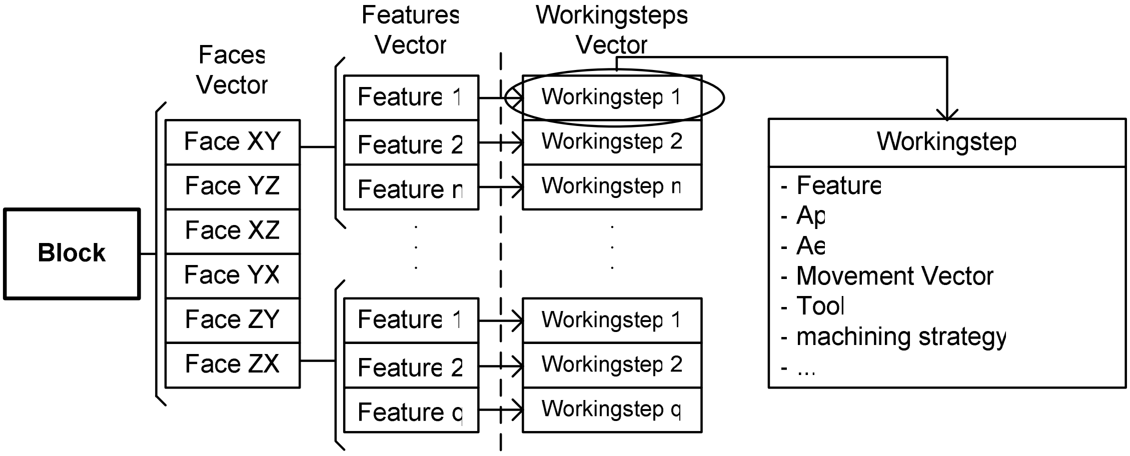

Figure 10. Mapping features into workingsteps

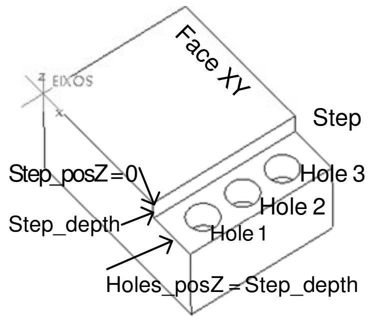

Figure 11. Example part with features on two layers.

3.3. CAM Module

This module is responsible for generating the HPGL code, which will be sent to the rapid prototyping milling machine. The used commands are:

- IN: to start rotating the spindle,
- Z: to move to a certain absolute position,
- H: to send the cutting tool to the machine zero.

The points of the movement array of each workingstep are used for the generation of the HPGL code. Once the code is generated, it is sent to the machine through the serial port.

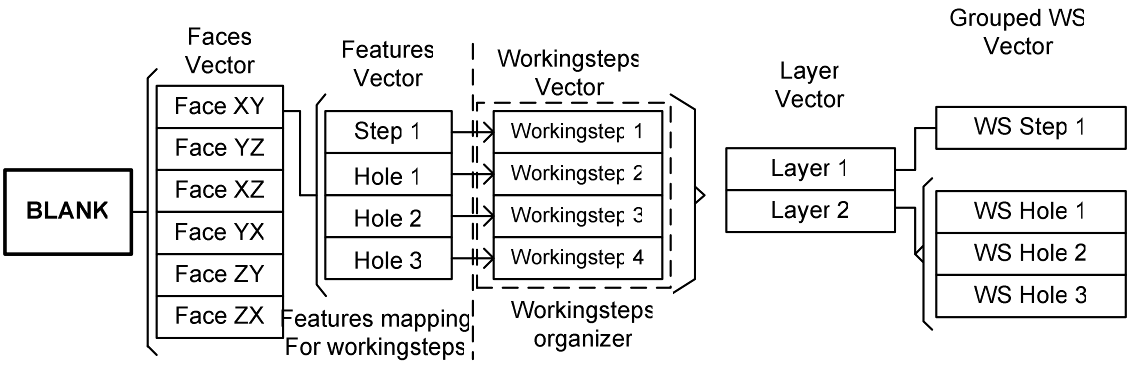

Figure 12. Organization of the workingsteps by layers.

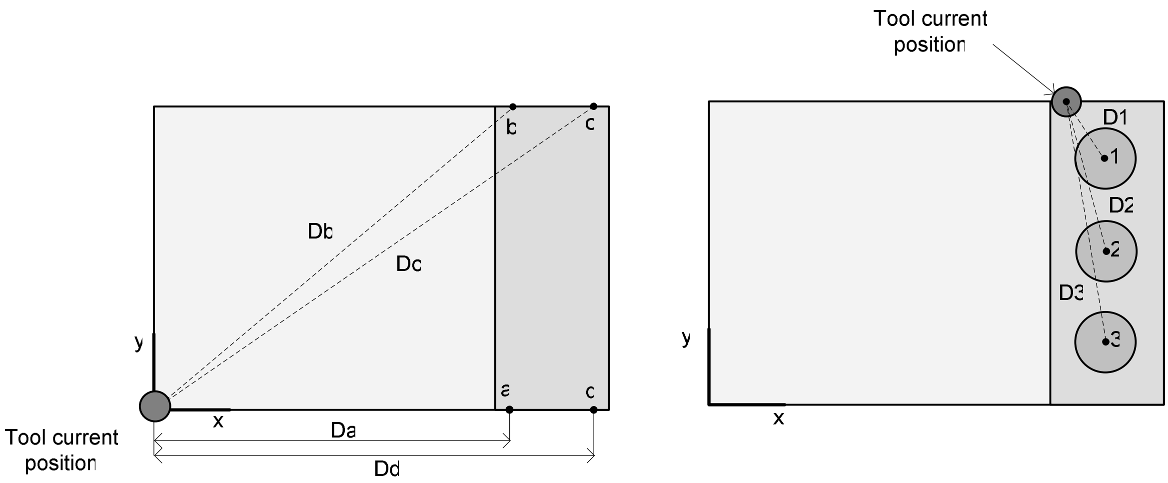

Figure 13. Minimum distance criterion.

4. RESULTS

The system is available for use in the Internet in the address http://grima.ufsc.br/~jticona/CAD, through which the remote user can input manufacturing orders. Thereafter, the manufacturing operations are generated by the CAPP module, and finally the HPGL code generated by the CAM module for the manufacture of the part can be sent to the machine.

The part modeled in Fig. 6 was machined using this integrated CAD/CAPP/CAM system, and the machined part is shown in Fig. 14.

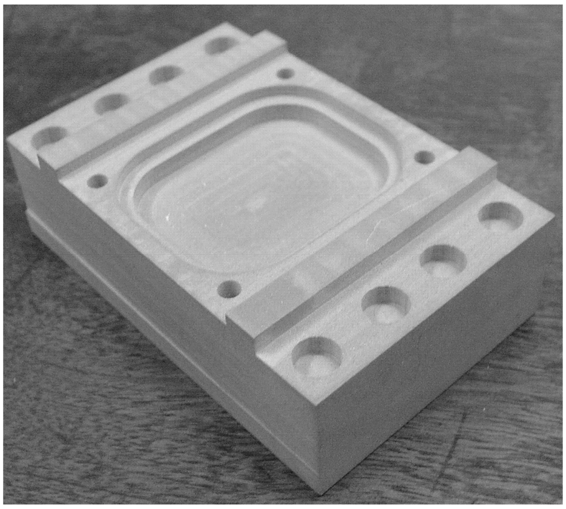

Figure 14. Manufactured part.

5. CONCLUSIONS

This research work contributes to the development of integrated manufacturing systems, and uses the Internet as a communication means, enabling the remote manufacture of prismatic parts. It provides appropriate techniques for developing future systems, and the use of the Java language allows the independence of platform of the remote user.

The application of the feature-based design approach is very important, since in this way it was possible to integrate the CAD, CAPP and CAM modules, because the information about the features are explicitly available for all the modules.

As a future work, it is intended to include more features in the library, such as protrusions, general pockets, and general slots.

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