

PROCEDURE FOR THE IMPLEMENTATION OF A VIRTUAL CNC LATHE

Antonio Valerio Netto

Universidade de São Paulo – ICMC/USP
Av. Trabalhador São Carlense, 400 13560-241 - São Carlos – São Paulo – Brasil
avnetto@sc.usp.br

Anésio Tarcisio Anitelle

debis humaita IT Services Latin America Ltda.
Alameda Campinas, 1070 - CEP01404-002 - São Paulo – São Paulo – Brasil
tarcisio.anitelle@debis-humaita.com.br

Abstract: The paper presents a work executed in the virtual prototyping area. It is described as a procedure for the implementation of a CNC (Computerized Numeric Command) lathe prototype using software for virtual environment development. This procedures focus mainly on the interlocking system (functionality) and geometric model (physical design) of the lathe. Consequently, this work aims at checking the potential and limitations of this graphic interface tool, considering the complexity of the data required for product prototyping in manufacturing or assembly.

Keywords: Virtual Reality, Virtual Prototyping, Simulation, Training and Marketing.

1. Introduction

Companies, in a global context, need to look for higher competitiveness levels to face new competitors, causing a total remodeling of productive systems, from the replacement of obsolete and low productivity equipment with more modern and productive ones; layout restructuring of plants and existing transportation flows at the shop floor; production planning and control, up to the need of higher labor qualification, so as to improve the product quality, reduce production lead time and scrap waste (Valerio Netto et al., 1998).

Aiming at finding new ways to reach this organizational improvement in companies and providing modernization of their productive system through more modern equipment and expert labor, the use of virtual reality-based software is proposed for the simulation of equipment, employee training, production planning validation, plant layout, and product prototype viewing (Ressler, 1997).

It is important to point out that a number of authors report the use of virtual reality in training and education, thus proving the efficiency of using this technology for such purpose (Rosenblum, 1995). Other researchers (Wittenberg, 1995; Kirner, 1996) present studies where results of training obtained with the use of virtual reality are clearly superior to those obtained with the support of conventional systems.

For some researchers, one of the most important areas of project automation using resource of virtual reality is virtual prototyping (Leston, 1996). Several among them explain in their works the justification for the use of virtual prototyping, mainly in the automotive area (Dvorak, 1997). There are also works that report the perspectives of the virtual prototyping in the market, advanced techniques of product modeling using this new resource, and some examples of industrial application. (Rix et al., 1995).

Even having the entertaining area as a leverage to the interest of the great public for virtual reality, most innovating technology still comes from areas committed to the professional usage.

With a sophisticated software for virtual reality environment development it is possible to model machinery, vehicles, and devices, aiming at simulating the hardware's actual behavior. This will save money and development cycles, and will allow to perform training sessions and validation with the help of the virtual product (Valerio Netto et al., 1999).

Finally, the advance in research in the virtual reality area is increasingly providing powerful hardware and software tools such as: lighter and more resourceful helmets, gloves and goggles. This is causing greater interest from different segments of the industry and an increasing number of users and applications all over the world.

Virtual prototyping is an important step towards the efficient development of the final product. Based on geometry information and project topology, on the results of simulation obtained by modeling tools combined with kinematics' calculations, material, tolerance and other available information on the product, it will be possible to generate computerized prototypes for realistic presentations, reducing costs with real prototypes and availability time for tests. In addition, it will allow the interaction of the product even in the early stages of development. (Rix et al., 1995).

The main advantages of virtual prototyping for industrial processes are:

- Time reduction: the time parameter today is one of the most important factors for the industry. *Time-to-market* is the marketing key that makes the difference among competitors.
- Cost reduction: virtual prototypes can reduce the need to execute a number of physical prototypes. This enables a reduction of development time and human work employed in the project. There is also a reduction in the quantity of tools and materials employed in the execution of the physical prototype. The results of the virtual prototype more quickly are obtained and, therefore, allow a feedback to the project, before production costs are established.
- Quality improvement: the application of different alternatives to a project can be more quickly performed, allowing an improvement in the validation of the appropriate solutions that comply with the parameters specified by the client at a lower cost.

2. General view of the practical project

The project consists in the development of a procedure for the implementation of a CNC (Computerized Numeric Command) lathe prototype using virtual reality and focusing mainly on its interlocking system (functionality) and its geometric model (physical design).

An interlocking system is understood as a system that detects conditions out of the predefined work area or improper sequences, and aborts the action in course, or starts the necessary corrective actions (Dombrowski et al., 1991).

The proposed interlocking is triggered as the equipment is used, that is, when the CNC door is opened during a machining operation, or when there is an error caused by the NC (Numeric Command) program, for instance. This allows the user to check which was the procedure adopted by the machine, depending on the failure that caused the errors. Many interlocking operations are triggered when a part is being machined. This way, the project has also the viewing and interaction of this process functionality, as well as the exchange of existing tools in the lathe tool holder and the animation of the scrap and cooling liquid appearance and withdrawal. However, there are interlocking operations for those situations where failures occur due to hardware problems. It is the case of the failures: spindle brakes, electrical energy feeding and hydraulic and pneumatic systems of the lathe. For these cases an interlocking flaws generator was proposed.

Besides helping in the development of a prototype of the equipment, this project also allows the training of operators to handle this machine without tools weariness and raw material employed, without the risks of labor accidents and, also, with the possibility of training several operator simultaneously without increasing final costs.

The project used a mouse as navigation and interaction device with the virtual environment, and as viewing device a 17' display monitor (Cathode Ray Tube) helped by a graphic board that allows acceleration in the synthesis of polygon images.

With regard to the feeling of presence, this work may be classified as non-immersive. It is also possible to state that the project allows a session of interactive virtual reality, that is, it provides a user-guided exploration through the 3D environment and existing virtual entities in this environment will respond and will react in accordance with the participant's actions.

The model developed by Lobão (1995) was used for the implementation of the interlocking in the CNC lathe. This model has had its interlocking modules simulated and validated by logical diagrams and Petri Nets.

In the figure 1 a general vision of the CNC lathe is shown in subject.

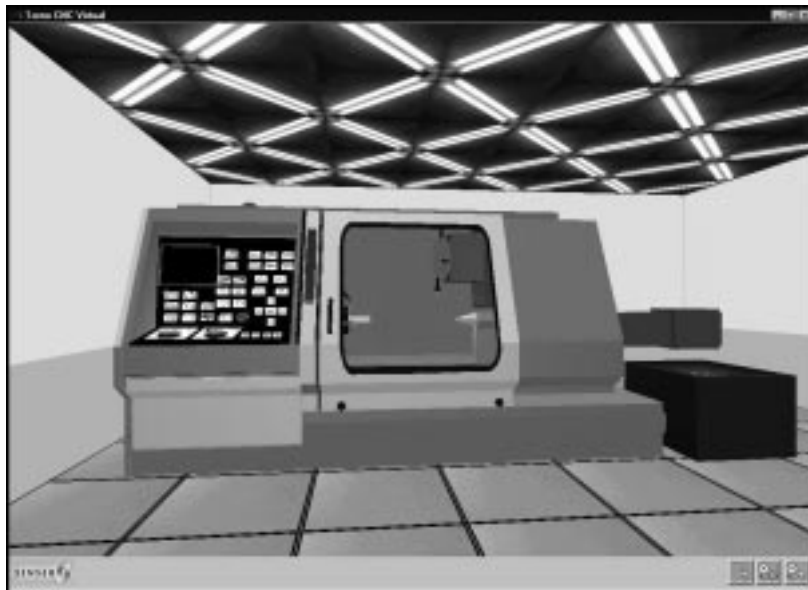


Figure 1: General vision of the CNC virtual lathe.

3. Procedures for the CNC lathe implementation

Basically, this procedure is divided into two different groups that occur in parallel with the beginning of the work, but that converge at the moment of the implementation of the logical project characteristics (Interlocking). The first group refers to the graphic/geometric development stages of the project that are further detailed in the subsequent items. The second group deals with the system validation and functionality simulation using for that some modeling tool such as the Petri Nets.

Later, with most stages of the first group finished, it is possible to execute the last stage of the second group that concerns the implementation of the functional project characteristics. In the case of the lathe, the functional characteristics are understood as the opening and closing of the feeding door, the tool-holder cart's X and Z-axes, the turret lathe, the spindle, and the counterpoint motions. As well as, the animation of the cooling liquid, the scrap remover, the buttons and displays in the lathe control panel, etc.

This way, the proposed procedure for the execution of the lathe in a virtual environment can be depicted in figure 2.

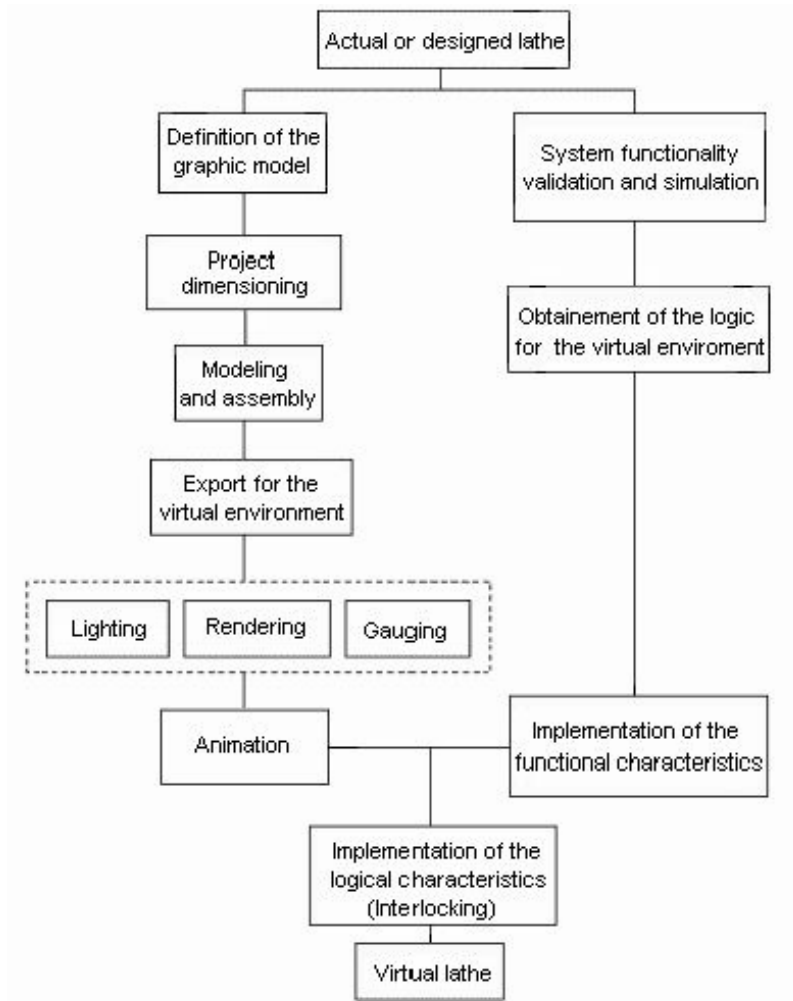


Figure 2: Procedure adopted for the lathe creation (Valerio Netto, 1998).

3.1 Definition of the graphic model and project dimensioning

The model, that is, the lathe format and configuration, was defined in accordance with its purpose. In this case, this project does not allow the user to explore the interior of the machine tool. Thus, the modeling of internal non-visible parts was not necessary. Many details such as bolts, junctions and external details without functional action were suppressed so as to limit the number of model faces, thus increasing the processing speed in the virtual environment.

Two Traub lathe models were chosen to serve as a graphic model, a TND360 and a TNA480 (Traubomatic, 1993). A hybrid of both lathes was created using the external appearance of the TND360 and the machining system of the TNA480, where the tool-holder cart moves on the X and Y axes, not hindering the view of the machining.

It was decided to work in this project with a 1:1 scale, being the modeling environment unit equivalent to one millimeter, thus avoiding the calculation of the scaled model dimensions. Regarding the number of decimal digits, these can also be configured in the software. In this case, we worked with 4 decimal digits.

A sketch of the lathe was drawn, not only to show its form, but to allow the independent handling of functional parts of the lathe in the virtual environment, as at the moment of the project the functions that each element would perform in the virtual system were already known. This way,

it was possible to show which parts of the machine should be separately modeled. In this case they were: turret lathe, tool-holder cart, access door, all the buttons, the spindle, the nuts and the counterpoint. Except for those mentioned above, all of the other parts were melted in just one. The scale employed in the sketch was 1:10 both from the front and side point of view that showed only a body section including the lathe door. This information was sufficient to begin the modeling and assembling process.

3.2 Modeling and assembly

Modeling was started by creating a 2D picture representing the side view of the lathe, from which the body, the door and panel module (to which buttons, keys and display were later added) were extruded. This process presents some advantages, such as the guaranty that all the objects created from the same environment would perfectly fit, and always having the center coincident with the side view, as the extrusion process is performed on the x axis, from the same picture for all the above mentioned objects.

Then, the created objects were assembled using the alignment tool available in the 3Dstudio MAX which allows to align objects in any of the axes (x, y, z) using as reference the maximum or minimum point of the object on the chosen vector, the pivot or its geometric center. From the geometric figure sector that defined the window opening, an ellipse was extruded, thus forming the sealing rubber of the window pane. As the window pane should have total transparency, to allow the machining viewing, it was suppressed in the modeling.

Following, the spindle and counterpoint were created, basically made up of cylinders. After creating those cylinders, through a side view it was possible to align those objects on the x and y axes using the alignment tool. The cart that moves the counterpoint was created from the figure that determines its side sector through the extrusion process, and the counterpoint axis was created from a solid. This creation process in stages allowed many objects to be created exactly in the spot they should be placed, for instance, the counterpoint cart and its axis.

From this point on, the lathe model began to show a certain complexity, making it difficult to model the next steps. To overcome this difficulty, 3Dstudio MAX viewing tools were used, allowing to hide or freeze graphic objects. This facilitated the creation of the tool-holder cart and the turret.

The tool-holder cart was created through the same process as the counterpoint cart, since the turret lathe was initially created from a cylinder segmented in two halves. This enabled the middle segment radius to be longer than the end radius, allowing that the internal portion of the turret lathe, where the tools are located, to have a smaller radius than the portion that is connected to the tool-holder cart.

The 3DStudio MAX allows the objects to be linked with each other through an hierarchy. This way it was possible to test the geometric functionality of the lathe even before it was sent to the virtual environment. For instance, the turret lathe was linked with the cart that moves along the y-axis, and later linked with the cart that moves along the x-axis. Moving then the cart along the x-axis, the cart on the y-axis and the turret lathe are solidary with their movements. When only the cart on the y-axis was moved, only the turret lather followed its movements. The same test was applied to the spindle and the lathe door, as both have other objects that follow their movements.

Finally, the cutting tools, the tablets/chips and holders (later assembled on the turret lathe using the alignment tool) were modeled.

3.3 Exporting to the virtual environment

The World Up[®] software (Sense8, 1996) features a resource to import geometry from other programs designated as *resource browser*. The use of this resource allowed to import all the objects at the same time, maintaining each one of them as an independent part. And, at the moment when the importing is performed, it is possible to change the scale of the objects through a multiplication factor. In the case of this work, all the objects were multiplied by a factor 4, thus changing the scale from 1:1 to 4:1 because the lathe was too small in the virtual environment, thus compromising the navigation.

The virtual environment software has also an object hierarchy, which is assembled in the *scene graph browser*. It is a cascading list with multiple levels, that is, it is possible to place an object “within” another, so that an object responds to scaling and translation operations performed over its parent (object within which it is found in the list).

3.4 Lighting, Rendering, Checking and Animations

In a virtual environment, the elements must be lighted to appear. The lathe has “internal” parts, such as the chamber where the machining is performed, and just one light source was not enough to have all parts lighted. Therefore, besides the room light which is the universal standard lighting, three more directional light sources were created: one above the lathe body (lighting all the exterior portion, including the panel), another light inside the machining chamber (lighting the part, the counterpoint, the tool-holder and the spindle), and another lighting the back of the lathe.

Rendering is the application of material on the objects that define their plastic aspect such as color, texture and shining, besides the application of bitmaps that are stick to the objects (Elliott & Miller, 1995).

All graphic objects were transferred to the World Up[®] MODELER to receive the materials and brought back to the World Up[®]. This operation is simple. It is just a matter of selecting an object and choosing *Edit Geometry* in the *Object* menu. In the MODELER there is a very simple material editor allowing to choose the basic material color that reacts to directional light, and the color of the shining. It is also possible to define the material transparence level and choose a bitmap to be stuck to the object. The sticking options are: on faces, on level surfaces, cylindrical or spherical. It is also possible to adjust the bitmap positioning and scaling on the object.

The objects subjected to the rendering process were the buttons, the display panels and the doors. The bitmaps of the buttons were created in the Windows 95 Paint and the ones from the doors and panels were created in the Photoshop 4.

As for the gauging, it was the process through which the limit of movement of the lathe’s mobile parts was checked in terms of virtual space. The values in (x, y, z) which the objects would reach their maximum and minimum course were defined, such as the door and the tool-holder. Later, this data was used to program the behavior of those objects in a virtual environment.

Animations in the World Up[®] are created through programming, that is, the change of properties of graphic objects on the time vector. In the project, some objects were created so as to represent the movement of the cooling liquid and scrap production. The created objects are small squares representing the instances of the scrap and cooler dynamics in space. These instances were divided in groups, so that it was possible to create the representation of those elements’ movement just by sequentially enabling and disabling these groups.

4. Implementation of the model features

With the purpose of supporting the development of the virtual environment, the first lathe prototype was created to get acquainted with the programming techniques of the avatar, trigger and virtual lathing.

Trigger is a technique that enables the handling of buttons and triggers/drivers in the virtual environment.

With regard to the avatar, when one is navigating on the virtual environment created by the *software* World Up®, it is possible to pass through all the solid objects that make up this environment. In this case, there is the programming technique which prevents this from occurring.

This technique disables the camera motion link with the mouse. When navigating on a virtual environment using the mouse, what happens is the following: There is a virtual camera that follows all the movements made by the mouse. The motion link is the object class of the World Up® responsible for the connection.

Thus, it is possible to detect the collision of this cube when one is navigating among other objects on the virtual environment. By means of the programming in *BasicScript*, the solid with which one navigates (in this case, the cube), designated as “AvatarBody”, is always expelled to the position immediately before the position where there is a collision, thus preventing from crossing over the solids that make up the virtual environment. These *scripts* also prevent the occurrence of rotations on the camera axis (rolling), keeping the virtual horizon always in the horizontal position.

When a dowel is under a machining process in a real lathe, it takes a different shape at each machining step, and at the end of the process the result is a part totally distinct from the initial one.

It was very difficult to make this process feasible on the virtual environment in real time and also in accordance with the lathe’s CN programming due to the fact that every virtual geometry is made up of three basic elements: vertexes, segments and polygons. In the event of changing any feature of the virtual object, it is necessary to handle all of these elements, simultaneously.

This way, several consecutive side-by-side cylinders were created, so that the whole set appeared as a sole cylinder. This way it would be possible to manipulate the dowel body. With this new situation, the idea was that it would be much simpler to change only the radii of each and every cylinder, instead of changing them vertex by vertex, since the machining of one part by the lathe is only able to configure simetric changes on its longitudinal axis.

By using small cubes coupled very next to the tool’s surface, it was possible to make the lathing process similar to the real one. The collision or not among the cubes of a certain tool with some of the cylinders that make up the dowel is checked by means of the *BasicScript* programming. In affirmative case, the radius of the touched cylinder decreases as the tool forwards towards its longitudinal axis. The detail is that the cylinders’ thickness define the lathing resolution as well as the thickness of the cubes responsible for the collision detection.

In order to insert the CN program in the virtual environment an Excel spreadsheet was used. By means of a data sharing system named ODBC 32 *bits* of Microsoft®, this software exchanges information with the virtual environment editor. The procedure is simple: The user accesses an Excel spreadsheet where there is a table with several columns, each one specified for a CN programming command. A example CN program was created with the purpose of showing this procedure.

4.1 Virtual part’s reference

The graphic model of the CNC lathe was made from a source point (0,0,0) defined by virtual environment itself. This source point is located inside the tool cart. This is the so-called **machine’s**

zero point, and it is the actual point that allows the part's reference for the execution of the CN program.

By using an interpolation of points, two equations [1] and [2] were obtained, which will be later used in the programming of the CN program compiler in the virtual lathe.

$x = -2.X + 410$ [1], that is, for an X value expressed in the CN program, the tool advance an X value of the virtual machine.

$z = -6,75.Z - 2895$ [2], that is, for an Z value expressed in the CN program, the tool advance a Z value of the virtual machine.

Equations [1] and [2] were used in the programming of the CN program compiler in the virtual lathe.

Figure 3 shows the inner space for the machining, emphasizing the spindle together with the example part at left; the tool cart at the highest center, and at the right the counterpoint.

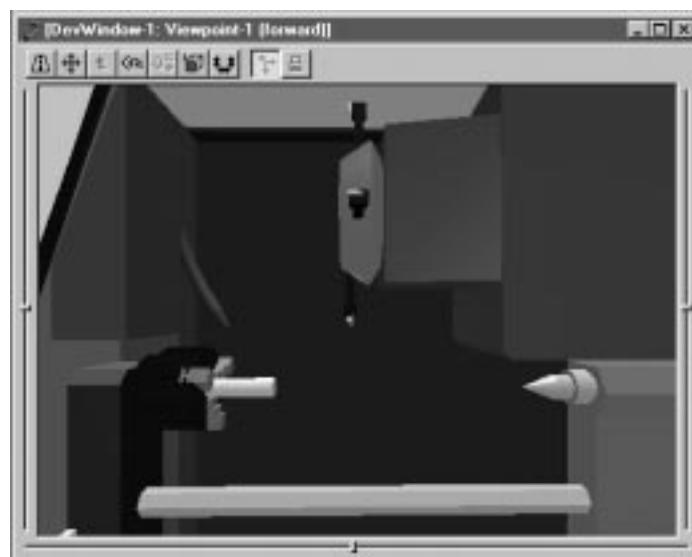


Figure 3: Inner space of the virtual lathe (Valerio Netto, 1998).

4.2 Failure Generator

The virtual lathe is a model created in a tridimensional graphic environment. As it strictly follows a programming, that is, a *script*, its functioning is perfect and never fails. Failures occur in a real lathe due to the influence of the external environment, such as: electric power peaks, highly polluted air, human failure, and also due to internal failures (fatigue of parts and tools, lack of fluid, etc.).

In order to check the functioning of the Interlocking System with regard to the malfunction of the machine tool, a failure generator was created in virtual environment. This generator consists in the use of buttons, externally allocated to the rendering screen of the virtual environment (figure 4).

By means of these buttons one is able to change the value of the initialization variables in the programming of the virtual prototype, thus generating a failure when executing a simulation of this virtual lathe.

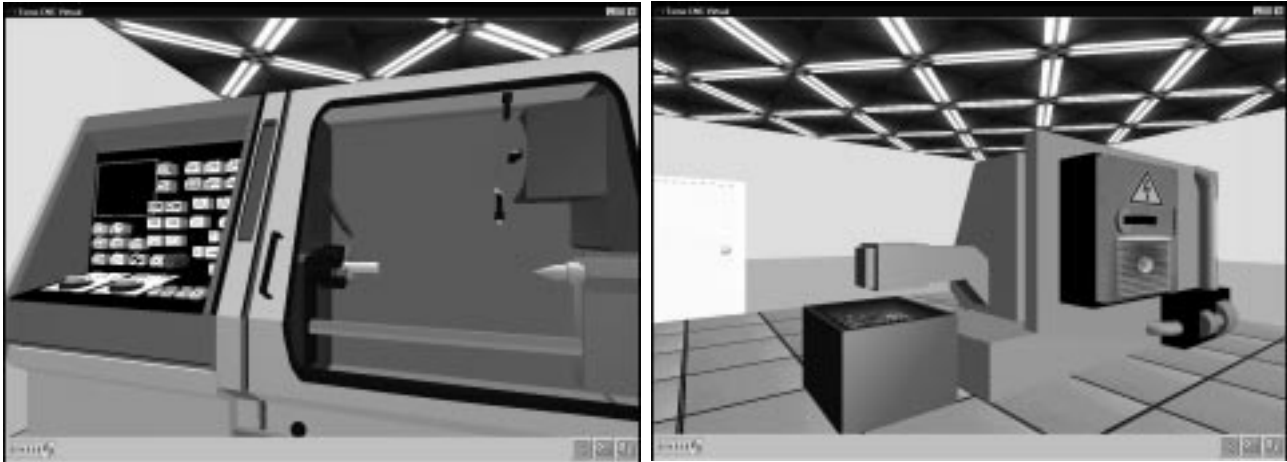


Figure 4: General view of the CNC lathe (front and rear) with the failure generator buttons (right lower edge).

5. Conclusions

This project can be initially employed in three different areas. The virtual lathe can be used for the training of operators in industries or for the students at schools, for the realization of the product marketing, offering the virtual lathe for the potential clients to handle it, thus enabling a better interaction and product knowledge by the purchaser, prior to its acquisition. Finally, it can be used for the product development support using virtual reality resources, the so-called virtual prototyping which, in the case of studies for mechanical engineering, it is the area with the most relevant approach.

With regard to the proposed interlocking (functionality) system, the greatest difficulty was to obtain the algorithms and flowcharts, since these information representation forms follow a pattern of sequential logics, whilst the model in Petri Networks handles data on a parallel basis, getting very close to the Ladder language used in the programming of industrial PLC's.

In the case of the geometric model (physical design) the major problem was detected in what concerns the *rendering* speed of the virtual environment. The higher the number of graphic objects placed in this environment, the slower was the updating of the graphic model. This can be noticed when the spindle is on; its visual rotation speed is much slower than the desired original. This slowness also hinders the user's interactive navigation and the shift of mobile objects (door, back center, etc.) in the virtual environment. This way, it is important to emphasize that for environments with a high number of objects a graphic accelerator board with a higher performance is necessary.

A positive issue with regard to the software for virtual environment development used in the project is that its form of functional routine execution is much similar to the parallelism that an interlocking of a machine tool requires, that is, the environment allows the execution of several procedures at the same time, including the continuous checking of several machine conditions for further decision making.

A negative issue pointed out in the project was the lack of a "second hand" for it is a limiting condition to work in a machine tool only with the *mouse* to manipulate the buttons and the dowel. In this case, the limitations ranged from pressing two buttons at the same time, as in the case of the speed driver of the tool cart, which requires pressing the speed and steering buttons simultaneously, and when placing the machined part out of its niche, what requires both hands to perform such

procedure. The suggestion to proceed with the project would be the use data gloves for a simulation that could be closest to the desired reality (Valerio Netto, 1998).

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7. References

- DOMBROWSKI, R. et al. (1991). “Separation of interlocking and regulatory control in programmable electronic systems”, *ISA Transactions*, pp. 19-25, vol.30, n.4.
- DVORAK, P. (1997). Engineering puts virtual reality to work, *Machine Design*, pp. 69-73, February.
- ELLIOTT, S. D. & Miller, P. L. (1995). *3D Studio 4.0 técnicas avançadas*, Ed. Berkeley, São Paulo.
- HANCOCK, D. (1995). Viewpoint: virtual reality in search of middle ground, *IEEE Spectrum*, 32(1):68, Janeiro.
- KIRNER, C. (1996). *Apostila do ciclo de palestras de realidade virtual*, Atividade do Projeto AVVIC- CNPq (Protem - CC - fase III) - DC/UFSCar, São Carlos, pp. 1-10, Outubro.
- LATTA, J. N. & OBERG, D. J. (1994). A conceptual virtual reality model, *IEEE Computer Graphics & Applications*, pp. 23-29, Janeiro.
- LESTON, J. (1996). Virtual reality: the it perspective, *Computer Bulletin*, pp. 12-13, June.
- LOBÃO, E. C. (1995). *Intertravamento de máquinas-ferramenta: proposta de roteiro para projeto em ambiente de manufatura flexível*, Dissertação (mestrado), EESC-USP, São Carlos-SP, 175 Pp., Fev.
- RESSLER, S. (1997). *Virtual reality for manufacturing - case studies*, National Institute of Standards and Technology. <http://www.nist.gov/itl/div894/ovrt/projects/mfg/mfgVRcases.html> (Setembro).
- RIX, J. et al. (1995). *Virtual prototyping - virtual environments and the product design process*, IFIP Chapman & Hall, 348 Pp.
- ROSEMBLUM, L. J. (1995). Mission visualization for planning and training, *IEEE Computer Graphics and Application*, pp. 12-14, September.
- SENSE8 (1996). *Customer applications: information management and analysis*, Sense8 corporation, <http://www.sense8.com/> (Setembro).
- TRAUBOMATIC. (1993). *Manual de programação e operação de tornos automáticos*, Traubomatic indústria e comércio Ltda., 240 Pp..

VALERIO NETTO, A. et al. (1999). As novas perspectivas da engenharia com a utilização de ambientes em realidade virtual, *Revista MÁQUINAS & METAIS*, n. 397, pp. 72- 85, Ed. Aranda,- São Paulo – SP, Fevereiro.

VALERIO NETTO, A. (1998). *Prototipação de um torno CNC utilizando realidade virtual*. São Carlos, 1998. 131p. Dissertação (Mestrado) – EESC, Universidade de São Paulo.

VALERIO NETTO, A. et al. (1998). Realidade virtual e suas aplicações na área de manufatura, treinamento e desenvolvimento de produto, *Revista GESTÃO & PRODUÇÃO*, v. 5, n. 2, pp. 104-116, São Carlos - SP, Agosto.

WITTEMBERG, G. (1995). Training with virtual reality, *Assembly Automation*, pp. 12-14, v.15, n. 3.