

SIMULATION OF ULTRA PRECISION DIAMOND TURNING IN VIRTUAL ENVIRONMENT POWER-WALL DEVICE

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Abstract. *In manufacturing there are some products that need, in their production, a precision of micrometer to sub-micrometer for the form accuracy and nanometer for the surface roughness in the range. To deal with this subject, an ultra precision diamond turning was developed. Due to the high accuracy level needed, it is required to do a deep planning of features that include the performance of the machine tools, the quality of the diamond tools, and the properties of the workpiece materials. When the Virtual Environment (VE) is used in a simulation of the process, it is possible to visualize the ultra precision diamond turning, one step before the real machining process. In this paper, the Cave Virtual Environment (CAVE™) was used, a power-wall device composed by 3 wall in passive stereo. CAVE™ provides a high level of immersion and that is very important for successful visualization of the simulated tool-path previously designed. The proposed system will be mainly developed using open-source code libraries, which reduces the project costs.*

Keywords: *Manufacturing, Ultra Precision Turning, CAVE, Virtual Reality, Virtual Environment.*

1. INTRODUCTION

In manufacturing there are some products that need, in their production, a precision of micrometer to sub-micrometer for the form accuracy and nanometer for the surface roughness in the range. By Palma (1995), this process is recognized, compared, such as faster and cheaper method for the surface manufacture with optical quality.

Lee *et al.* (2002) says that ultra precision machining based on single-point diamond turning is a machining process making use of a mono-crystal diamond cutting tool which possesses nano-metric edge sharpness, form reproducibility and wear resistance. Anyway, they are expensive processes. The skill and techniques incurred in the operations of these sophisticated facilities are complex.

The effort used in ultra precision machining planning is a vital step, due to his representation in complexes variables set. According to Lee *et al.* (2007), the ultra precision machining presents especial problems that are not observed in conventional machining.

To helper in ultra precision machining planning, the article goals is the development a visualization tool-path system that allows user to see the final product in Virtual Environment (VE) supposed by a multi-projection devices, using open-source code libraries, which reduces the project costs.

Chapter 2 will introduce multi-projection devices for Virtual Reality in a general and specific approach to the structure used here. Ultra precision machining will be described in Chapter 3. Chapter 4 will explain the development of the system step by step. Finally, conclusion, acknowledgements and references will compose the last chapters.

2. MULTI-PROJECTION DEVICES FOR VIRTUAL REALITY

The first researches in virtual reality appeared in the article by Mr. Ivan E. Sutherland (Sutherland, 1965) entitled "The Ultimate Display," in which he noted that a display device, connected to a digital computer familiarizes the user in a world very different from reality. He studied the computer immersion and simulation in this unreal environment. Schuemie *et al.* (2001) mentions that the factors that differentiate the virtual reality technologies from other visual interfaces are the presence, or the user immersion and interaction with the elements.

According to Cruz-Neira *et al.* (1992) the modern research in virtual reality walks in four different ways, based on visualization displays: the Cathode Ray Tube (CRT), the Head-Mounted Display (HMD), the Binocular Omni-Oriented Monitor (BOOM) and the multi-projection systems like CAVE. The characteristics of each device are divided into two categories: immersion fields and visualization fields.

The immersion fields are divided into: view field, viewpoint, perspective, physical representation of the body and intrusion. And, the visualization fields are presented in: visual acuity, linearity, spatial view, progressive refinement and collaboration.

In another article, Cruz-Neira *et al.* (1993) distinguish virtual reality from other standard graphics developments made in computer based on the following characteristics:

1. Occlusion;
2. Perspective projection;
3. Binocular disparity (stereo projectors);
4. Motion Parallax (head movement);
5. Convergence (visual search field);
6. Accommodation (visual focus, as a reflection of single-lens in the search field);
7. Atmosphere (environment);
8. Lights and shades

The standard graphics developments provide features number 1, 2, 7 and 8, while the virtual reality adds number 3, 4 and 5.

2.1 Multi-projection devices

Multi-projection Devices based on CAVE, have a set of features that allow the user to deeply interact with the virtual reality.

According to the authors, the CAVE was developed to be a tool for scientific visualization. Another purpose would be the theater of virtual reality, where scientists would design the criterion of exposure.

The objectives pursued with the development of the first CAVE included:

1. The desire for color images of high resolution and a peripheral vision without geometric distortion;
2. Less sensitivity to head rotation, inducing errors;
3. The ability to merge Virtual Reality with real devices;
4. The need to guide and teach through artificial worlds;
5. The desire to connect supercomputers in networks and data sources for consecutive refinements.

The first CAVE was developed at Electronic Visualization Laboratory at the University of Illinois in Chicago and presented at SIGGRAPH in 1992, as described in CRUZ-NEIRA *et al.* (1992).

2.2 Multi-user Laboratory of Immersive Visualization

This section will describe the Multi-user Laboratory of Immersive Visualization by means of its hardware and software constitution.

2.2.1 Hardware

The Multi-user Laboratory of Immersive Visualization (MLIV) of the University of São Paulo (USP), located in São Carlos-SP, has a multi-projection device for virtual reality based on CAVE. This device consists of three projection screens with dimensions: 3.2 x 2.4 meters (front wall), 2.4 x 2.4 meters (right wall) and 3.2 x 2.4 meters (floor).

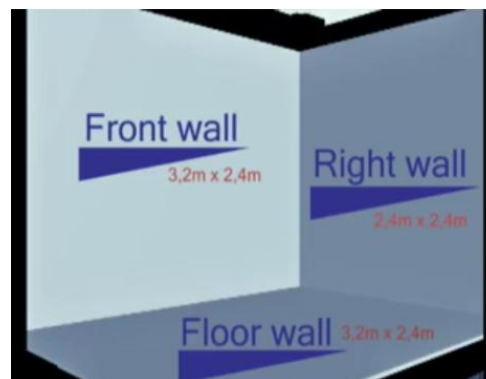


Figure 1 – Multi-projection walls dimension.

For each projection screen there are two Christie DS +60/DW30/Matrix 3000 projectors, a computer with a Nvidia Quadro FX4500 video card and 4GB of RAM. Each computer is connected to the projectors through DVI cables. There is a main computer where one can access or control the three computers responsible for the screens. The mounted system allows the passive stereo visualization mode, where each projector is responsible for the image visualization of one of the user's eye.

The images for the right and left eyes are projected superimposed on the screen so that the use of stereoscopic glasses enables the feeling of immersion in any virtual environments. The stereoscopic glasses used in MLIV are INFITEC filters. This type of system allows the immersion of multiple users within a virtual environment, as long as each user wears a pair of stereoscopic glasses.

2.2.2 Software

The operating system used on all computers of MLIV is Microsoft Windows XP Professional. For the modeling of virtual objects and scenes are used, among others, Blender Software version 2.48a and the OpenGL libraries for C++. The programming platform used is the Visual C++ 2005 Express Edition along with VR Juggler 2.2.1 to enable the provision of virtual environments in the multi-projection system. The VR Juggler software allows the use of tools that facilitate and enhance the development of virtual worlds for multi-projection. To import the 3D models and create the scene graph, OpenSG 1.6.0 has been used.

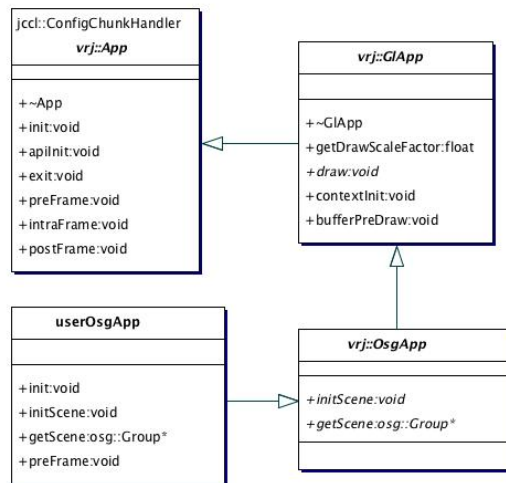


Figure 2 –VR Juggler and OpenSG classes relation.

3. ULTRA PRECISION MACHINING

Similar to the electronics industry, there is an increasing demand for the production of smaller mechanical parts. There are applications examples of these components in aviation, aerospace, medical and telecommunications fields (Coelho and Arai, 2006).

Also according to the authors, in most of cases, it can be observed that the usual machining process are adapted to a displacement of 1 µm, or less. The main differences are:

- Thermal stability: Realize the sizes are compact and isolated and the environment is thermally controlled with control of air purity;
- Extra precision of spin and guides: The rotating shaft is precise with linear guides with hydrostatic or balloon principles;
- Extra precision of rotative and linear position: The engines and special encoders have typically 64 Mpulse/rev and 1nm, linearly.

The turning with diamond is the process that utilizes a special single-crystal diamond tool in an ultra precision machine, especially designed to produce surface complements under controlled machine conditions, tool and environment. All components must be built addressing the maximum global rigidity, i.e., minimal deflexion of tool on part (Palma, 1995).

Initially, the ultra precision machining used diamond tools. But, it was not recommended in all ferrous materials, so other tools have been used and are, still been development (Coelho and Arai, 2006).

In figure , Taniguchi (1983) presents the dimensions evolution of each machining method , normal, precision and ultra precision.

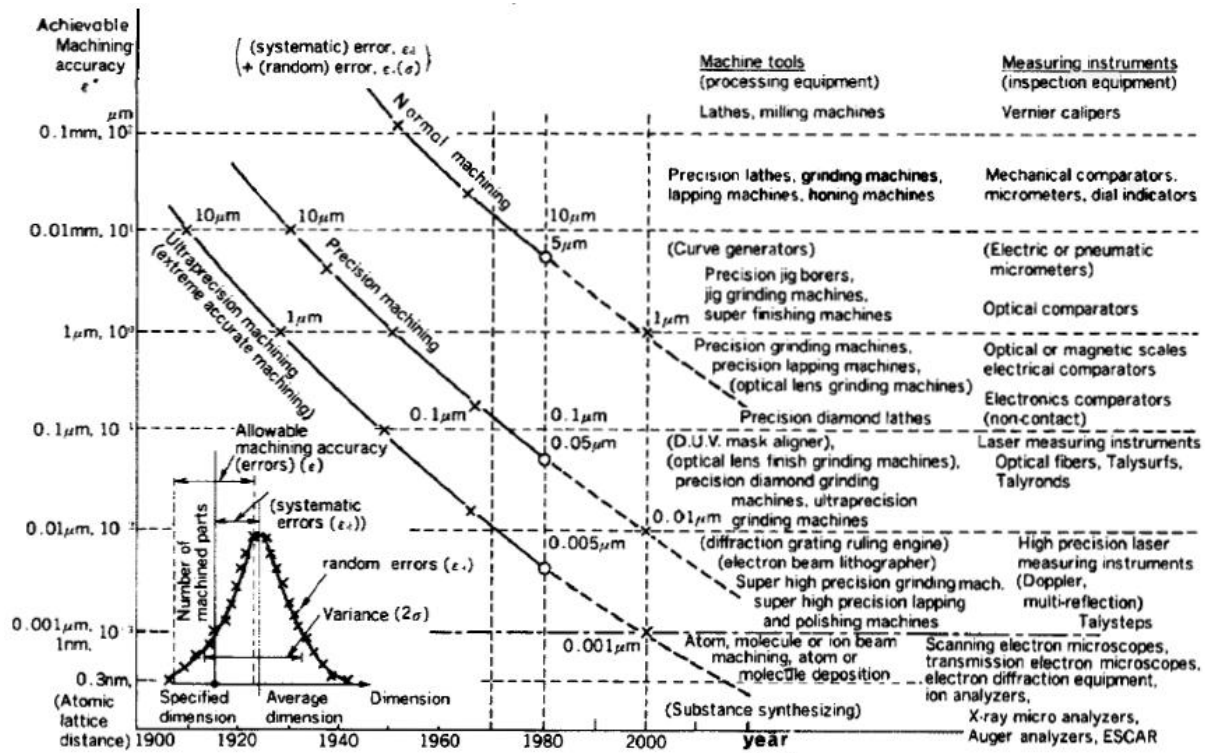


Figure 3– Evolution of machining process

On table 1, (Pramanik *et al.*, 2008) the experiments were carried out with the machining conditions and the cutting tools.

Table 1. Machining Conditions

Types of Diamond tool	Depth of cut (μm)	Feed rate (μm/rev)	Spindle speed (rpm)	Phosphorus content (% w/w)	Crystal orientation at rake face	Crystal orientation at flank face
Artificial	2	10	1000	10-11	{100}	{100}
Natural	2	10	1000	10-11	{100}	{100}
Artificial	2	10	1000	10-11	{110}	{100}

For Delvin, 1986, the generated optical surface by ultra precision machining could be classified as: flat, which involve a simple set up of machine and are characterized by a big volume of production; spherical, which it is characterized by a simple process of machining; and aspheric, this last is divided by ellipse, parabola or hyperbola, and they have several ways to specify the path of the tool.

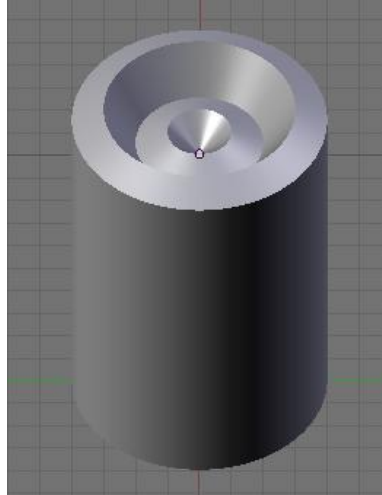
4. ULTRA PRECISION VIEWING OF TOOL PATH

The tool path generation in ultra precision machining is done by a graphic application called Blender 3d and a computer programming language Python, which can be acquired for free. In order to enable more features in the 3D modeling tool, an API written in Python, was provided. This language enables fast learning and the scripts can be developed in an easy and controlled way, wich makes the code robust and extensible.

By the Blender API, which was developed in Python, 3D objects can be created with functions and classes. Thus, it is possible to create forms, animations and behaviors through scripts, and it is possible to get information from the user

through graphic interfaces and to export the generated document in the required format, such as X3D and VRML. The advantage of generating objects by script is that customization is done in a practical way. Moreover, in this method, the error in manual modeling can be avoided and the generation of complex objects becomes more objective.

In order to simulate a machining part, the vertices of this part profile must be initially created as seen in figure 4 , it would be placed the points of profile in figure 5.



Picture 4 – Desired part



Figure 5 – Points of the profile

A revolution surface is generated from the profile, by rotating the vertices by 360° at the part axis, which a considerable level of details. Other vertices were generated with their position on (1), with v varying from 0 to 360° according to the level of detail, by analogy with the position in Y.

$$X = X_{\text{profile}} \cdot \sin(v) \tag{1}$$

Simultaneously to its generation, two vertices that are consecutively generated from a point n from profile and two vertices that are consecutively generated from a point $(n+1)$ from profile will create the part faces. The algorithm can be seen in Figure 8.

The height (z) of the part is correspondent to every simulated step (x), so that the steps generated from the part can be consistent with the real steps in a real machine. This way the possible errors can be effectively analyzed. The height is found on universal equation of optical (2). This way, every x generated is corresponding to height generated by tool path on machine.

$$Z = \frac{CX^2}{1 + \sqrt{1 - (K+1)C^2 X^2}} + A_1 X + A_2 X^2 + A_3 X^3 + \dots + A_{13} X^{13} + A_{14} X^{14} \quad (2)$$

As an example an illustration was used. The data used were: the starting and final steps ranging between $x=0$ and $x=90$, the constant of deformation aspheric ($A_1 \dots A_{14}$) equal to 0, the conical constant K is equal to -1 and the radio of curvature is equal to 8, the profile, as seen in Figure 6, and the surface, as seen in Figure 7, were calculated. In order to have a view of the generated surface, the height on every point was decreased by a thousand times.

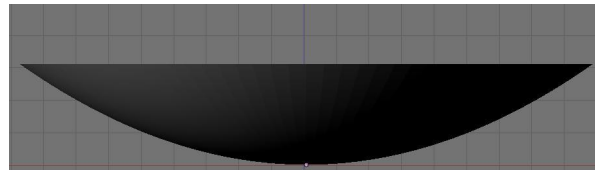


Image 6 – Profile of the example

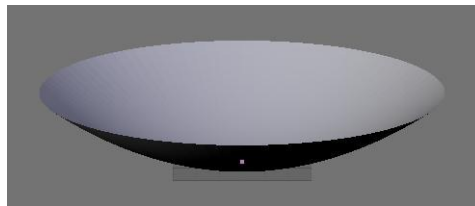


Image 7 – Surface of the example

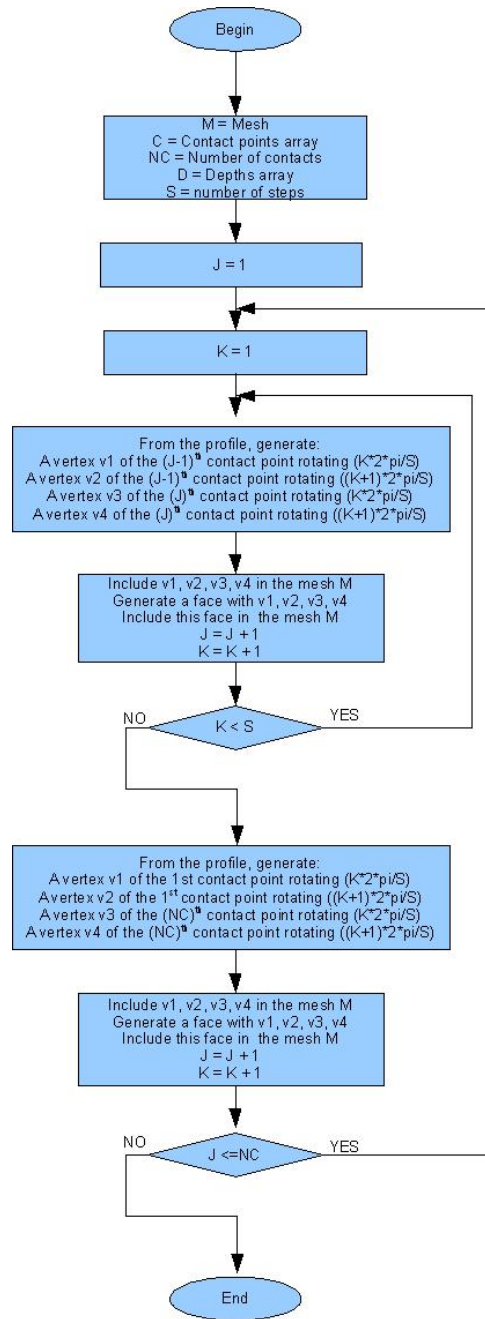


Figure 8 – Algorithm for generating the surface

Finally, Figure 9 illustrates the visualization of the simulated part model generated, originally developed in virtual reality.



Figure 9 – Visualization of the example

5. CONCLUSION

This work could meet the expectations of developing a system to visualize a simulated tool path in ultra precision machining in virtual environments, supported by multi-projection devices. This level of immersion is an important element to the success of the physical model building stage, because the user has a better detail perception of the virtual tridimensional objects before it is actually built. The offered system was developed upon open-source libraries which reduced the project costs.

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