VIRTUAL ENVIRONMENTS FOR MACHINING PROCESSES SIMULATION: REVIEW ON THE REQUIRED TECHNOLOGIES AND RESEARCH IMPLEMENTATIONS

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Abstract: Currently there is a tendency to integrate Virtual Reality characteristics and production processes models. This tendency is leading to the creation of the next generation simulation systems that will provide quantitative data for the process, increased visualization, fly through and interaction capabilities in a virtual environment. This review aims at clarifying the technologies involved in the development of a virtual environment for machining processes simulation.

Keywords: Virtual Manufacturing, machining simulation

1. INTRODUCTION

The production process simulation is a critical part of the production design process, since it allows the study of process parameters in close to real conditions. The development of computer graphics considerably extended simulation applications capabilities. Virtual Reality initially was only exploited for visualization and interaction between the product and the designers. The development of the computational systems along with the increase of the Virtual Reality functionalities and the integration of production simulation models, significantly extended Virtual Reality capabilities for production processes study.

Virtual Reality based systems focus on the study of specific production processes, such as machining processes and are mainly used as supplementary tools of the simulation system. With the development of techniques for the study of production processes parameters, the available tools for the study of the product have been considerably improved, allowing the development of more accurate and complete virtual models.

The current study is a review in the required technologies for the development of a machining processes simulation virtual environment. The most significant research systems are described. Finally the system developed in the Technical University of Crete for machining processes simulation in a virtual environment is presented.
2. REVIEW ON THE TECHNOLOGIES THAT HAVE BEEN INTEGRATED WITH MACHINING PROCESSES SIMULATION SYSTEMS

2.1. CUTTER PATH DETERMINATION

For the determination of the cutter path from the CAD/CAM system data several methods have been presented [1 - 5]. Methods are diversified according to the cutter geometry and the number of axis of the CNC machine. Methods aim at the determination of the parallel to the geometry trajectory, in which the cutter has to move in order to produce the required shape. In most of the methods the geometry of the part is approximated with mathematical equations from which the offset trajectory is being determined, according to the type and the geometry of the selected cutter.

2.2. THREE DIMENSIONAL GEOMETRICAL MODELS

Solid [6] and surface models are used in contemporary systems for three dimensional geometry definition. These two types of geometry modeling are supported in most CAD systems. Several methods have been presented for geometrical models visualization [7]. In most graphics systems three dimensional geometry is visualized with the use of shaded polygons (usually triangles), which approximate the shape of the geometry.

2.3. WORKPIECE MATERIAL REMOVAL SIMULATION

Workpiece material removal simulation in solid models is determined by defining the sweep volume of the cutter as a three dimensional geometrical model. This geometrical model is being subtracted from the workpiece with the use of Boolean operations to produce the new shape of the workpiece. For sweep volumes calculation the three dimensional model geometry and the cutter trajectory are being mathematically defined [8, 9]. In solid modeling systems [10, 11], surfaces and edges are expressed with mathematical equations and the intersections between the surfaces and the edges of each model are determined. In systems where the three dimensional geometry is defined with polygons, algorithms have been presented for the determination of the section between polygons (polygon clipping algorithms) [12, 13]. These algorithms are used in solid modeling systems for the visualization of the subtracted geometry. Another approach for the implementation of Boolean operations between three dimensional geometries is based in the differentiation and approximation of the model geometry. For the determination of the intersection between geometrical models, the intersection between each elementary geometrical model is determined. The intersecting elementary geometrical models are removed from the geometry. Octree [14] is a geometry differentiation method being used in Boolean operations [15]. Octree is based in the approximation of the three dimensional geometry with elementary cubic volumes and the further subdivision of each volume until the geometry is approximated with adequate accuracy. Marching cubes is a similar to octree method, which was used along with finite elements for material removal simulation in machining [16].

2.4. COLLISION DETECTION

Collision detection between three dimensional geometric models (solids or surfaces) [17] is based on the approximation of the geometry with simple geometry shapes, such as cubes and cylinders, which are more efficient to use in computational systems. The intersection between the approximated geometries is determined. One of the most common methods used for collision detection is octree [18].
2.5. QUANTITATIVE DATA PARAMETERS DETERMINATION IN MACHINING PROCESSES

Production quantitative parameters, such as the machined surface quality, the cutting forces, the required power and the cutter wear, in the product design phase, contribute in the improvement of the machining result appraisal. Prior to the introduction of quantitative data determination tools in the production design processes, empirical or experimental methods were used.

CAM systems are the most common machining simulation tools, but they are unable to provide quantitative data for the machining process. Quantitative data are determined in different systems that employ mainly analytic or numerical methods. Antoniadis et al. [19] presented a numerical method for quantitative data determination (cutting forces and surface roughness) in milling processes with ball end cutting tools. The method is based in workpiece modeling by linear segments that decrease their height at the interaction point with the cutter cutting edge. Engin et al. [20, 21] proposed a generalized mathematical model for predicting cutting forces, vibrations, dimensional surface finish and stability lobes in milling. The model is based in the mathematical modeling of the cutter with helical flutes defined in a parametric volume. Liu et al. [22] developed a model for the determination of peripheral milling dynamic parameters. The geometry and kinematics of the cutter are considered for the determination of the machined surface, from which surface roughness is being calculated.

Several analytical methods have been presented for surface roughness parameters determination in milling processes. These methods are considering the cutting speed, the feed, the depth of cut and vibrations as parameters and employ mathematical equations, such as the multiple regression equation [23] for the determination of the surface roughness parameters. Tseng et al. [24] state that in conventional metal removal processes an exact prediction of surface roughness is difficult to achieve, due to the stochastic nature of the machining processes and they propose the use of a data mining technique for predicting acceptable machined parts, rather than focusing on the calculation of precise surface roughness values.

For the calculation of the cutting forces in milling, research is focused on different processes parameters, such as the determination of the cutting forces equation coefficients [25] and the chip thickness [26]. Generic mathematical approaches have also been presented [27-30]. These models focus on processes in different machining surfaces types, such as inclined surfaces [28] or freeform surfaces [29]. Additionally, models employing visualization technologies, such as solid modeling tools [31], for the determination of the intersection between the cutter and the workpiece have been presented. Moreover, models have been presented for the study of specific cutting conditions, such as the vibrations between the cutter and the workpiece [30].

2.6. VIRTUAL ENVIRONMENT SYSTEMS FOR MACHINING PROCESSES SIMULATION

Virtual environments have been used for the study of different machining processes parameters, such as the design, modeling and implementation of production plans, aiming at errors detection in the executed operations [32-34], the determination of quantitative data, such as the machined surface roughness [35] and the cutting forces [36-38], training in machining processes [33, 39-41], calculation of the cutter swept volume [42, 43], in order to determine the intersection between the cutter and the workpiece and the visualization of the process, exploited in the determination of the process kinematics [44] and the simulation of the chip removal [45].

3. TECHNICAL UNIVERSITY OF CRETE MACHINING PROCESSES SIMULATION SYSTEM

CAD lab from the Technical University of Crete developed a virtual machine shop environment with the use of a commercial Virtual Reality platform. In the environment a
A three-axis CNC milling machine is simulated. In figure 1 the structure of the developed model for machining simulation and in figure 2 the developed virtual environment for milling processes simulation is shown.

![Figure 1: Model for the development of a machining processes simulation system.](image)

![Figure 2: Machining processes simulation virtual environment.](image)

The user can fly through the virtual environment, interact with all the objects and manually manipulate the CNC machine. For the execution of a machining process, the user has to select the workpiece and cutter from the corresponding data table. The G code program is being read from its file and the CNC machine realistically executes the defined machining process. During the machining process simulation, workpiece material removal is being visualized when the cutter intersects the workpiece and data related to the process are being visualized. Moreover, information like the G code command simulated in the CNC machine, feed, spindle speed and cutter trajectory are being visualized in a data table. When the simulation is completed, the user is able to select the surface roughness measurement area in the equivalent virtual environment data table and hence acquire quantitative data for surface roughness parameters and the measurement area topomorphy.

4. CONCLUSIONS

Evaluating the applications described above, the use of virtual environments for simulating industrial applications shows adequate maturity, none the less not all the existing problems and restrictions have been confronted. It should be noted though that the integration of graphics technology with simulation models composes a powerful tool for the designers. Nevertheless applications development remains a time-consuming and difficult process.

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