3D SIMULATION ALGORITHM OF CNC LATHE BASED ON VR TECHNOLOGY

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Abstract - The Virtual Reality (VR) technology was applied to explore the 3D simulation algorithm of computer numerical control (CNC) lathes to understand the current technical levels and utilization of CNC lathes. In addition, based on the 3D models, the virtual prototype of CNC lathe was modeled for simulation. The application of the virtual prototype to CNC lathe, as well as the VR technology, had brought great convenience to the CNC lathe simulation. CNC lathes are important and unignorable to manufacture and production industries. With the arrival of artificial intelligence (AI) era, the technology of CNC lathes would definitely be well-developed under the support of VR and other technologies.

Keywords: VR Technology; CNC Lathe; Simulation Algorithm; Virtual Prototype; 3D Modeling.

1. Introduction

The computer numerical control (CNC) lathe belongs to numerical control machine tools. It is the automatic lathe with the programmed control system. The current CNC lathes vary in models, structures, and shapes. Although the shapes are different, they have the same functional structures.

The bed is the base of a CNC lathe; all the other components are installed on the bed in accordance with the machine tool assembly specifications and perform certain operations in accordance with the numerical control commands [1]. The numerical control machine tools are important manufacturing equipment. They are the foundations of industry and play vital roles in the fields of electricity, power supply, and transportation that are directly involved in the daily lives of people. In addition, numerical control machine tools are also essential in the fields of the National oil industry and military industry. The development of manufacturing is inseparable from the research and development and innovation of numerical control machine tools. In addition, the numerical control equipment is the high-tech working machine tool which is the key equipment for the modernization of the manufacturing industry.

The level of its technology represents the development level of the manufacturing industry of a country. Since the birth of the first numerical control machine tool in the United States in 1952, numerical control machine tools have experienced several key development periods including the era of transistors and printed circuit boards, the era of small-scale integrated circuits and special-purpose functional devices, the era of group control systems, the era of microprocessors, and the era of microprocessors and semiconductor memory. After the 1990s, with the improvement of personal computer (PC) performance, the CNC system has entered the sixth generation of CNC based on PC [2].

CNC lathes are the products of precision technology. Its primary function is to efficiently complete manufacturing tasks under the premise of quality and quantity. With the development of industrial technology, the modern market requires the manufacturers to satisfy the needs of consumers with the shortest production time, the lowest input cost, and the best product quality. The traditional design method proposes solutions through the 2D drawings of product features and technical requirements, which cannot intuitively understand the other problems that may occur in the process of processing and assembly of the product. Practices have shown that various product problems are only manifested in the assembly and trial stages.

Therefore, the traditional design method has increased the product development cycle, brought a high-cost input, and cannot adapt well to the rapidly changing market [3]. Modern virtual engineering technology would solve the above problems. With virtual engineering technology, designers don't have to process each component and part; they only need to build 3D models of components and parts through computer software, virtually assembly these parts, and perform simulation analysis of their designs. Such a design method would timely identify the problems and defects in the designs and correct the designs in real time. Since the 1970s, research on virtual CNC has developed rapidly, including technical breakthroughs from software to hardware.

Therefore, the functions and effects of virtual engineering technology on simulation of CNC lathes were studies to explore the application of Virtual Reality technology in the field of CNC lathe.

2. Methodology

2.1 Virtual Reality

Virtual Reality (VR) technology is a new technology developed in the computer field that integrates various scientific technologies such as computer display technology and simulation technology. It is a technology that can create and interact with the virtual world. It uses a computer to generate a highly simulated virtual environment with the help of professional equipment such as sensor helmets and data gloves, allowing users to enter virtual space and interact and manipulate various objects in the virtual world in real time to obtain visual, tactile and auditory experiences of the environment.

VR technology can be used in various fields such as industry, medicine, aviation, culture, and tourism. In general, VR technology has three main characteristics, i.e. immersion, interactive, and imagination. Immersion refers to the realism of users in a virtual environment. Interactive refers to the operations of users and the feedback of various objects in the virtual environments. Imagination refers to that in addition to the possible real situation, the virtual reality world can provide events that are not present and impossible in the real world, which would greatly expand the scope of human cognition and generate a leap in understanding [4].

It can also be described by three “I”s, as shown in Figure 1 below.

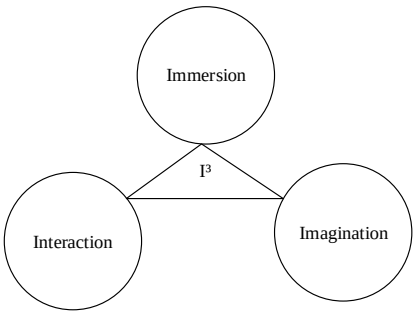

Figure 1: The 3I nature of virtual reality technology

2.2 Virtual Reality technology

The virtual engineering technology refers to the in-depth and comprehensive analysis and simulation of the performance of the product by using the virtual environment of the computer to the maximum extent before the product is put into production. It is possible to find out possible problems in early stages and propose the optimization plans by adjusting the data of all parties, which would avoid the occurrence of repeated works due to errors, thereby improving the quality of the product and the success rate of the development process

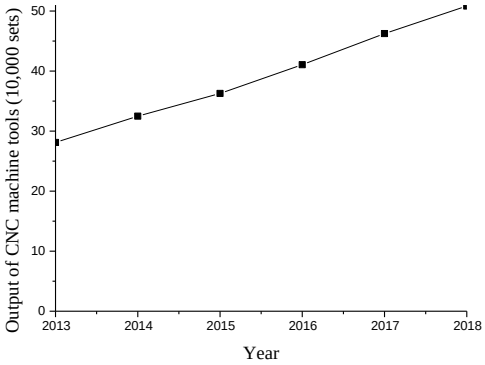

Figure 2: Growth trend chart of CNC machine tool production from 2013 to 2018 in China

The virtual product model established by computer technology records the geometric parameters and spatial topology information of the product entity, which has the same physical information as the material model. Therefore, the application of various loads to the model would simulate possible situations to obtain the quantitative assessment results of the product performance. The simulation system simulates the actual lathe machining parts, allowing the operator to visually observe the machining process on the computer and detect errors at any time to avoid dangers [5]. Therefore, the system is required to have functions such as programming, operation, and machining process simulation. The operation process should be consistent with the actual lathe, and the animation of the machining process should be realistic and real-time.

Figure 2 is a trend chart showing the growth of CNC machine tools from 2013 to 2018 in China. It can be seen from the data that the output of CNC machine tools in China is increasing every year.

In terms of the current situations of CNC lathes, such as various types, complex structures, and lack of flexibility in static modeling, the VR technology is selected to study the 3D simulation algorithm of CNC lathes.

2.3 Prototype modeling and simulation

First, a virtual prototype of a CNC lathe needs to be established. The basis of the virtual prototype is to build a 3D model, and the subsequent simulation work can be carried out on the basis of the 3D model. Modeling is the process of building a digital 3D model based on various information characteristics of the product, such as design dimensions, structure, materials, and machining processes.

The modeling process is complex, in addition to the details of each component, the mutual driving relationship between them should also be considered.

Then, modeling software such as Pro/Engineer is applied to build a complete 3D model. The first task of building a virtual prototype is to create virtual parts. The appearance of virtual parts does not look different from real objects. It includes not only external features such as color, material, surface texture, and decoration but also the intrinsic features such as mass, the center of gravity, and moment of inertia for accurate simulation of simulation calculations. At present, the mature 3D design software commonly used in the market includes Pro/E, SolidWorks, UG, CATIA, etc.

The software allows to build a 3D model of the parameterized CNC lathe components and parts; therefore, the assembly relationship in the real situation is simulated, each component and part is virtually assembled, and the design of the components and parts is judged according to the assembly condition. If it is unreasonable, the parameters can be re-inspected in real time. If it is reasonable, the next step can be carried out, i.e. the simulation software and analysis software are used to analyze the performance and dynamics of the CNC lathe [6]. In the virtual environment, the 3D model of the CNC lathe can also be analyzed through human engineering.

Finally, after the 3D model of the CNC lathe is established, it can be used for finite element analysis, as well as the kinematics and dynamics simulation, and servo control system simulation. The appropriate dynamic simulation software is selected to simulate the feeding system of the CNC lathe. Many software provides environments that can directly establish geometric models and perform simulation work, such as ADAMS software. In terms of 3D models built in other software, as long as the model is transformed into a format that can be recognized in ADAMS software, it can be imported into ADAMS software for simulation. A core problem of the simulation system is a dynamic simulation of the machining process. The servo control system is the most important component to determine the performance of the CNC lathe; therefore, its simulation work is especially important. In terms of the simulation of the servo control system of CNC lathe, the common MATLAB software can be applied. The software is flexible, simple, and extensible. The SIMULINK module can be used to analyze linear/nonlinear and discrete control systems.

The simulation system needs to meet the following requirements:

First, the processing process of the simulation system is exactly the same as the real processing process.

Second, the processing of the simulation system needs to have a machining accuracy no less than the actual machining center.

Third, the actual processing code can be parsed and run in the simulation system, and the running result is exactly the same as the code running in the real machining center.

In the development of the simulation system, the hardware part mainly completes the model and UI construction of each component, and the software mainly completes the logic construction behind. The specific logic implementation needs analyzing and sorting the functions of the numerical control system. The code interpretation module is an important piece in the whole simulation system, which is also a very difficult piece. Therefore, many studies have kept the code interpretation secret so that the existing data is relatively small and the numerical control codes used by different systems is not the same. Therefore, the entire interpretation module needs to design and develop algorithms independently after summarizing the characteristics of the numerical control codes.

The analysis module of the numerical control code is the lowest level module of the whole CNC simulation system, and its performance would directly affect the efficiency of the subsequent compilation module and the performance of the entire CNC simulation system.

The key technologies for dynamic simulation of the entire simulation system are collision detection and cutting algorithms. The collision detection is mainly used to prevent the interference of objects and perform dangerous operations. The cutting algorithm is used to achieve the result of the whole simulation processing, which is the focus of dynamic simulation. The efficiency of the algorithm would directly affect the final simulation effect.

The modeling of the workpieces is the key to the simulation of CNC lathe; the modeling should not only accurately represent the shape of the model but also realize the real-time display of the machining process. At present, commonly used geometric modeling techniques include solid modeling techniques, discrete thinking-based modeling techniques, and feature modeling techniques [7].

Solid modeling is applied to define some basic voxels, which are constructed by various set operations of basic voxels. Discrete modeling is used to discrete the surface of a part into a series of points with a certain precision, and these points are used to express the original surface. These discrete points need to be globally searched to form a workpiece model. The height values of these points are calculated and stored, and the simulation process is the process of constantly modifying the height values of these points.

3. Results and Discussion

The schematic diagram of the process of first using discrete modeling to simulate machining is shown in Figure 3 below:

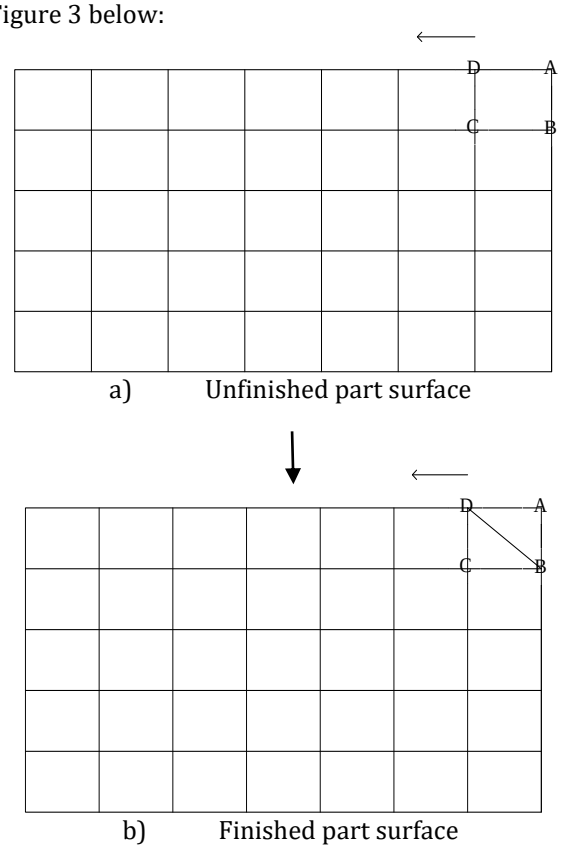

Figure 3: The schematic diagram of discrete modeling

The processed condition is shown in Figure 3a. The tool moves from right to left. First, point A is cut. Then, point A changes in the coordinate value and becomes point B, as shown in the figure. When point D hasn't been cut by the tool, its coordinate value remains still; since the surface is continuous, it becomes the boundary between point B and point D, as shown in Figure 3b, which constitutes the boundary of the newly generated surface. The surface of the processed virtual part would always have such problems, resulting in errors in the simulation results.

According to feature modeling, the component is considered to be an entity that consists of a series of basic features based on certain rules, which can completely describe the information of the component, not only including the geometric information that expresses the shape of the part but also containing the topological information of the position of the component, as well as the manufacturing information. It makes the components have unified information models throughout the whole process of design and manufacturing, which greatly improves the design efficiency of the components and makes the simulation more realistic.

The method avoids the complex Boolean operations; in addition, the features are searched at first for modeling, followed by feature triangle processing, which effectively avoids the disadvantages of common discrete modeling that requires triangular processing of the entire part. Besides, the display speed is improved and processed.

The shape of the components is relatively accurate without errors occurred in discrete modeling.

Through the above analysis, the feature modeling technology has been selected to realize the establishment of the workpiece model in the system, and the feature dynamic operation has been applied to simulate the processing process of component parts.

The component description structure of the lathe structure assembled on the bed body is (taking the X axis as an example):

```
COMPONET "X" {
COMPTYPE "Translation"
CONNECT "Base"
ORIGIN (0,0,0) ROTATION (0,0,0)
SUBSYSTEM_ID "1"
ASSEMBLY {}
}
```

In terms of the unit component parts that make up the machine tool components, since the specific structural shape parameters have their own structural descriptions, such as size parameters, origin, etc., the corresponding description structure examples are as follows:

```
Cylinder object (CylinderObj)
CYLINDER {
RADIUS 15
HEIGHT 5000
TOLERANCE 0.3
ORIGIN (0,0,0) ROTATION (0,0,0)
}
}Cone object (ConeObj)
CONE {
BOTTOM_RADIUS 45
TOP_RADIUS 120
HEIGHT 120
TOLERANCE 0.1
ORIGIN (0,0,0) ROTATION (0,0,0)
}

Block object (BlockObj)
BLOCK {
LENGTHS (5000,2000,750)
ORIGIN (0,0,0) ROTATION (0,0,0)
}

Sweep object (SweepObj)
SWEEP {
PTS {(0,0) (10,5) (15,25) (15,125) (-5,125)}
PTS {(-5,5) (0,0)}
ZLIMITS (-20,0)
```

```
ORIGIN (5,0,2.5)
}

Sor object (SorObj)
SOR {
PTS {(0,0) (20,0) (25,5) (25,35) (0,35)}
}

Stl object (StlObj)
STL_FILE "aerh 1000.stl" Outward MILLIMETER {
ORIGIN (0,0,0) ROTATION (0,0,0)
}
```

The virtual lathe is the mapping of the real CNC lathe in the virtual environment. The above methods have introduced the application of VR technology to 3D simulation of CNC lathe from several perspectives, such as the construction environment, the material modeling, and virtual assembly, the ergonomics analysis, and other applications (finite element analysis, kinematics simulation and servo control system simulation).

It can be seen that the method is expected to be better used for teaching training and processing guidance.

4. Conclusion

With the continuous advancement of computer technology, the work and application of CNC lathes begin to develop in the direction of flexibility and intelligence, which puts forward new requirements for the simulation technology of CNC lathes.

The VR combination simulation technology has received more attention because of its vivid graphics rendering environment, realistic production animation, and the new human-computer interaction mode compared with traditional simulation methods. Based on the related theories of VR technology, virtual prototype technology, and 3D model establishment, detailed and profound research on the simulation technology and the application of design knowledge of CNC lathe was proposed; in addition, the characteristics and application of virtual prototype technology to CNC lathe was introduced.

However, the whole system is still not comprehensive enough; thus, in the subsequent development, more in-depth development can be carried out to make the whole system more perfect.

The important role of CNC lathe in production and manufacture determines that its industrial design must not be ignored.

With the development of modern technology, the era of artificial intelligence has arrived. The technology related to CNC lathe based on VR technology would continuously achieve breakthroughs and innovations in the current environment to better benefit mankind.

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