ORIGINAL ARTICLE

# A web-based virtual CNC turn-milling system

Lida Zhu · Haonan Li · Weili Liang · Wanshan Wang

**Abstract** This paper presents a different web-based virtual turn-milling system, which aims to address the common problems of existed systems. The system has not only economical value, such as shortening product cycle from design to market, but also scientific interest, like proposing a new trajectory planning method. In other words, it helps sellers and buyers better understand products and enables planners and machinists to make decision or verify CNC codes much more accurate and faster. This system is made up of three levels, which is client browser, server, and database, and every level is divided into several specified functions. Among all the functions, turn-milling simulation function is the most crucial part. To enhance the system's features, many sub-function modules are also adopted in simulation functions. Through these modules, the system implements material removal function, tool trajectory planning function, numerical control (NC) code inputting and compiling function, and so on. To realize these functions, the whole machining system is developed by using the network superiority of Java language and Virtual Reality Modeling Language (VRML) technology interaction, which will also lead to smaller data volume. Owing to the transportability of Java language and VRML technology as well as the good understandability of the system, this web-based virtual turn-milling system is also suitable to the dynamic demonstration and machining simulation of other NC machine tools. Some future research directions are given to perfect the system in the end.

**Keywords** Turn-milling · VRML/Java · Web-based CNC system · Dynamic interactive · Virtual machining

L. Zhu (✉) · H. Li · W. Wang
School of Mechanical Engineering and Automation, Northeastern University, Shenyang 110819, China
e-mail: zld1999@gmail.com

W. Liang
Tianjin Tianduan Press Co., Ltd., Tianjin 300142, China

## 1 Introduction

At present, manufacturing enterprises are facing some new challenges, such as shortening product cycles from design to market, finding globally distributed partners, and working with customers. To the best of manufacturing enterprises' competition, this appears to be a necessity to develop and propagandize new products online and get users involved by modern information technology. In fact, most of machine tool enterprise productions are now displayed to customers by static or single form of pictures or texts, lacking either in vividness or in functionality. It results in the consequences that functions and performances as well as the information of products cannot be easily and comprehensively understood by international buyers. This is where virtual reality technology emerges. The VR technology provides a novel way of designing and assembling machine tool, testing CNC machining, and realizes web-based information and machining system [1–3].

There are some scientific research studies on web-based manufacturing system. Xu and Newman [4] have developed a state-of-the-art machining system. They have set a new standard known as STEP-numerical control (NC) and presented web-based NC machining simulations. He and Wu [5] have attempted to give a virtual operating system applied to operation training of manufacturing facility and manufacturing process simulation. Kadir et al. [6] have provided review of existing virtual systems that is clearly a multidisciplinary undertaking which may require employing different types of approaches in one system. Wang et al. [7] have developed an appropriate methodology with open architecture for real-time monitoring and remote control of networked CNC machines and presented a new enabling technology to bring traditional CNC machine tools online with combined monitoring and control capability. Ong et al. [8] have addressed the importance of integrating a virtual manufacturing system with the internet and propose a web-based, scalable, and distributed architecture for developing a platform-independent

virtual machine (VM) system. A prototype web-based virtual CNC milling system has been developed using Virtual Modeling Language and Java. In the simulation of the machining parameters, the prediction of cutting forces, torque, power consumption, and tool life models is implemented using an empirical method.

Besides, comparing with commercial software applications like Unigraphics (UG), web-based manufacturing system has its unique advantages. Its small data volume makes it transmit faster and more convenient through the internet. Moreover, it is a visual and physical 3D model simulation, instead of complicated and abstract NC code generated by UG, which helps laymen easily understand machines [9, 10].

Because of its strengths, some application living examples of web-based manufacturing system were presented. Zheng [11] has developed a web-based machining parameter selection system for agile turning for adequate machine tools, cutters, and cutting parameters for the turning process. The users can also evaluate the machining performance by obtaining the turning force, power consumption, vibration status, and workpiece distortion from this system. Suh et al. [3] have presented methods to represent the motion paths and operation of CNC machine tools on the web. A web-based machine tool technology is presented, including geometric modeling of machine tools, kinematic modeling of machine tools, and implementation on the internet environment. The development system can be used as a teaching aid for NC operation and CAD/CAM in vocational schools and industry where CAD/CAM software is not available. Zhu et al. [12] have developed a 3D dynamic simulation system in the information that demonstrated the platform of digital products based on the web and realized virtual operation machine tool by using the network interactive of Java language and Virtual Reality Modeling Language (VRML) technology. Collaborative modeling is adopted by using the advantages between CAD software and VRML to build quickly the model and optimize the volume of transmission document through the web.

However, most of these systems do hardly visualized the machines' abilities of producing complex parts. The existing methods are lack of the novel data optimization method, which affect on data transmission and simulation efficiency. Cutter trajectory planning has hardly been proposed in the other web-based virtual manufacturing systems. Furthermore, the simple part is only conducted by the exiting material removal algorithm (hidden algorithm). Therefore, the machines' performances are also hardly understood comprehensively and deeply by customers or learners through the web.

This paper presented a powerful web-based manufacturing system in both the economic and academic world. For financial value, it can not only help machine tool enterprise fully exhibit their products' characteristics but also help potential buyers or learners entirely comprehend and visualize what machines they will buy or have already bought. Users can operate online, like drag some operation panels or input a piece of NC codes, to see how the machines respond. Therefore, it will give customers a good understanding of the comprehensive performances of machining process.

Except for its economic value, this system also has its academic interest. A novel data optimization method and material removal algorithm do actualize online and real-time turn-milling simulation in different machining parameters on the web. More importantly, a new trajectory planning method is introduced in this system, which will save planners' time, catching computing bug and shorten product's cycle from design to market. It also offers a case study and theoretical basis for other scientific studies about manufacturing. Besides, by using network superiority of Java language and VRML technology interaction, international buyers can obtain more information and production function of machines. Meanwhile, the product delivery time will be significantly shortened, and the product quality might also be enhanced by this web-based turn-milling parameter selection system.

This paper is divided into four main sections; Sect. 1, entitled "The system architecture and functions," will give detailed architecture of the system and how to realize its own functions. Section 2, "Modeling methods of turn-milling center," will firstly introduce geometric models and motion relationships of turn-milling center and discuss how to optimize models to reduce data volume on the web. Section 3, "Implementation of interactive function of turn-milling system," will respectively realize the functions of motion simulations of machine tool, material removal method, NC code compiling and machining trajectory, and implementation of machining complex part. Finally, in Sect. 4, some conclusions from this study, perspectives of ongoing work, and directions of future research are given.

## 2 The system architecture and functions

### 2.1 System architecture and function modules

From top to bottom, the system is composed of three levels, client browser, database, and server (shown in Fig. 1). The client browser is one of the most crucial part users directly deal with. The browser allows clients to login in, browse various types of machines, observe and operate machines, and launch complex parts of machining simulation. The next part is the server, which is established by VRML, Java applet, and JavaScript. The database is in the bottom, which is made up of machine tool models, controlled parameters, and the user information.

In comparison with traditional stand-alone CNC machine simulation system, this architecture makes the virtual turn-milling system a more exclusive platform. There is no need to install special software on client computers. In addition, the system files' volume is small, so it is convenient to be transmitted through the Internet. This machining simulation system has friendly interfaces, and its home page is given in Fig. 2. It can
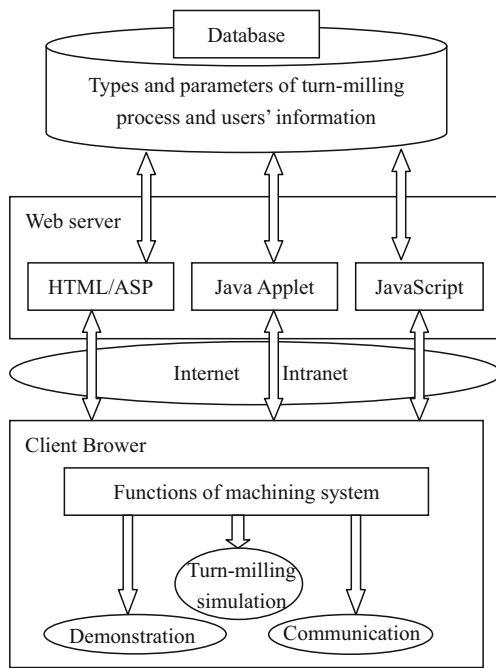
**Fig. 1** Functions and structure of machining system

achieve three functions, which is respectively the motion demonstration function, the information communication function, and the turn-milling simulation function.

The motion demonstration function is the most basic one, whose aim is to help users browse machines' structures and understand every controlled parameter in motion simulation.

The information communication function gives a way to communication between buyers and sellers. Evaluation of alternative, purchase, post-purchase evaluation, and feedback can be easily realized.

The Machining Simulation Function is the core part of this system. Users can select diverse machine tools and cutters, choose difficult turn-milling cutting parameters or input some basic machining conditions, such as the material type and geometric parameters of workpiece and tool or even technical requirement for machining, and then put all of this information into the system and see how the machines perform. The simulation scenes and simple operations will increase customers' understandings of product performances. To enhance simulation function and be close to the real machining environment, many sub-function modules are adopted here, such as NC Code Input and Compiler Module, Blank Preparation Module, Machine and Tool Setting Module, Collision Interference Test Module, and Status Display Module and Stock Removal Module. A brief introduction of every sub-function module is explained as follows:

- The NC Code Input and Compiler Module allow users to input existed NC code or coding on the spot. After input, users can also check and debug NC code. Modification or compile is also accessible.

- The Blank Preparation Module is employed to do parametric design and discretization process, which influence the initial shapes of the blank and material removal algorithm.
- Machine and Tool Setting Module is adopted to set machine movement parameters, such as fast moving speed and spindle speed. It also includes parameter settings of turning tools and milling cutters in the tool magazine.
- The Collision Interference Test Module is used to detect collision, interference, and overcut between cutting tools, workpieces, and fixtures.
- The Status Display Module includes information display of the machine (such as spindle speed, and cutting tool types and tool position) and NC code execution display.
- The Stock Removal Module shows the removal process simulation from the blanks to parts. The realization of this sub-function is the core part of this system. During material removal, in order to distinguish processed and unprocessed parts, it changes the processed part colors.

2.2 Function realization of dynamic interactivities in the system

The machining system embeds VRML plug-ins, JavaScript, and Java applets by using HTML. In this system, VRML is used to create the virtual NC machining environment; JavaScript and Java applets are used to provide simulations and handle all the information on the web. JavaScript and Java applet can communicate by using their internal interface, and Java applet can communicate with VRML by using the External Authoring Interface (EAI) [13, 14]. EAI has two major functions: The first one is the input parameter by using VRML, and then the scene and the gesture of product are changed in different parameters. The second is to monitor changes in VRML and inform the corresponding actions. JavaScript is a web scripting language that can be integrated with HTML and Java to deal with complex issues, which cannot make a communication with VRML directly. It has to communicate with VRML through Java applet which plays the role of communication information. The realization of interactive function between VRML and Java/JavaScript is shown in Fig. 3.

Since it is an important issue of machining modeling in simulation system, the file size of machining model needs to be minimized, and the discretization of machining model can be communicated with Java applet on the web. Taking advantages of powerful modeling capabilities and small data volume, this machining system combines strengths of Unigraphics software (UG) and VRML technology in this machining system. Therefore, machining models of machine tool are created by UG and then converted it into VRML file, which communicates with Java applet and is transmitted on the internet, and VRML is used to create the virtual NC machining environment. Motion function and machining simulation are realized by using Java applet/

**Fig. 2** Home page of machining system

JavaScript. For the client, the plug-in "Cortvrml" should be installed to navigate the VRML files. The plug-in is about 1 MB and can be easily downloaded from the official website. For the server, Microsoft VM and jdk 1.3 should be installed, and then the system environment variable for the standard package of VRML is needed. The settings are expressed as follows:

```
path=c:\jdk1.3\bin // storage path for the
procedure call in compiling process
classpath=;C:\Program
Files\jdk1.3.1\lib\dt.jar; // for the
procedure call of other classes
C:\Program Files\jdk1.3.1\tools.jar
C:\Program Files\Common
Files\ParallelGraphics\
Cortona\classes.zip; // packet into zip file
C:\Program Files\Common
Files\ParallelGraphics\
Cortona \ corteai.zip // packet into zip
file in the installation directory
import vrml.external.Browser; // for the
browser interface
import vrml.external.Node; //for the node
interface
import vrml.external.field.*; //for the
field interface
```

## 3 Modeling methods of turn-milling center

### 3.1 Structure and motion models

The turn-milling center consists of many parts, such as bed, headstock, tool, and workpiece. All these parts have their own movements, which are composed of translation of $X$-axis, translation of $Y$-axis, translation of $Z$-axis, rotation of $B$-axis and $C$-axis [15]. The subordination relationship and movement chain of mechanical components and functions are shown in Fig. 4, and they are the reference and foundation for motion simulation and NC machining system. For example, fixture components are assembled into turn-milling center based on position relation, but motion components have to consider the motion relationship to control motion and machining.

### 3.2 Co-modeling and data optimization of machine tool

There are some different commercial software, such as UG, Pro/E, SolidWorks, and CATIA. Machining models and complex parts are created by most of commercial software in the way of users need. But, they do not communicate with Java applet and are not suitable to transmit data on the web, in which 3D model volume is large, especially the model of

**Fig. 3** The function realization of interactivity
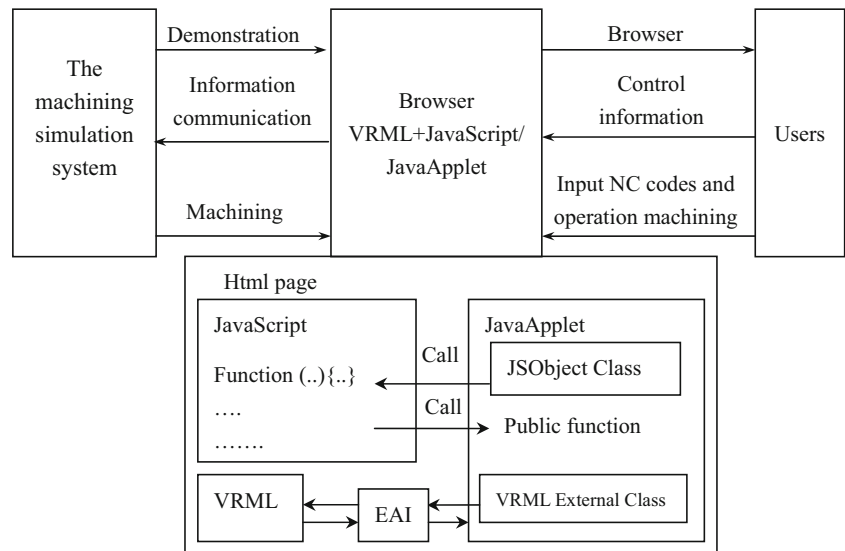


machine tool, so it is difficult to use as a machining model by using CAD software in real manufacturing process on the web. It is difficult to model the complicated parts by VRML. The advantages of VRML and CAD are combined into virtual machining system. Therefore, every components and parts of machine tool are created by using UG software and then assembled the turn-milling center and converted into VRML file to communicate with Java applet by using the External Authoring Interface.

From Table 1, the more complex the geometry part is, the larger the file size is. The more complex the assemble components are, the larger the file sizes are. Therefore, co-modeling and data optimization of machine tool are realized by using UG and VRML, which provides machining model for machining trajectory planning and NC code verification on the web. If a workpiece of complex geometry is machined, it is necessary to optimize the model files with the large data model and more cutters and some kinds of cutting parameters. Taking an example, variable pitch and variable depth screw, the file size of machining model, and more NC codes need to be optimized in the end section.

The file volumes of machine tool have to be reduced to transmit fast data in machining process on the web. There are three methods to optimize the document during the design process: Firstly, design optimization, no rendering is needed in the inner surface of the parts; secondly, text optimization, delete the notes, indent and extra spaces as well as optimize data, such as 0.8 for 0.800000; finally, components optimization, reduce the resolution of images of the part which does not affect the movements. The UG model file is about 11 MB, while it is about just 181 KB after converted into VRML file and optimization. The assembly relations between parts are lost when the model is converted into VRML, so we have to regroup the chips and rename

them to facilitate program design. The coordinates in the VRML file should be updated for assembly and machining. Table 1 shows the comparison with file format and optimization. There are 16 parts in UG files and then 10,000 pieces and bodies in VRML, so the relation of pieces is complex. Cosmo Worlds software can help to make some groups to recognize parts in turn-milling center as shown in Fig. 5. Some planes and bodies are packed into groups, which will save a lot of times and reduce volume data. At the same time, the motion group can be renamed in whole machine, such as x_move and y_rotate. The position and orientation of plane and body can be adjusted in the world coordinate. Therefore, the co-modeling and data optimization will provide foundation and reference for the motion, transmission, and NC machining simulation.

## 4 Implementation of interactive function of turn-milling system

### 4.1 The implementation of the turn-milling center movement

The VRML file (.wrl) and Java file (.class) are designed in the same page of an HTML to achieve the interactivities between VRML and Java. The movements are carried out by interpolation nodes, including "Position Interpolator" and "Orientation Interpolator." Taking the $X$-axis movement of tool holder as example, information transmission through the web is realized in Fig. 6.

The tool and tool holder nodes are packed as "x_move," then the node names are obtained through the command "browser. getNode," and the data is

**Fig. 4** Subordination and movement relationship among components
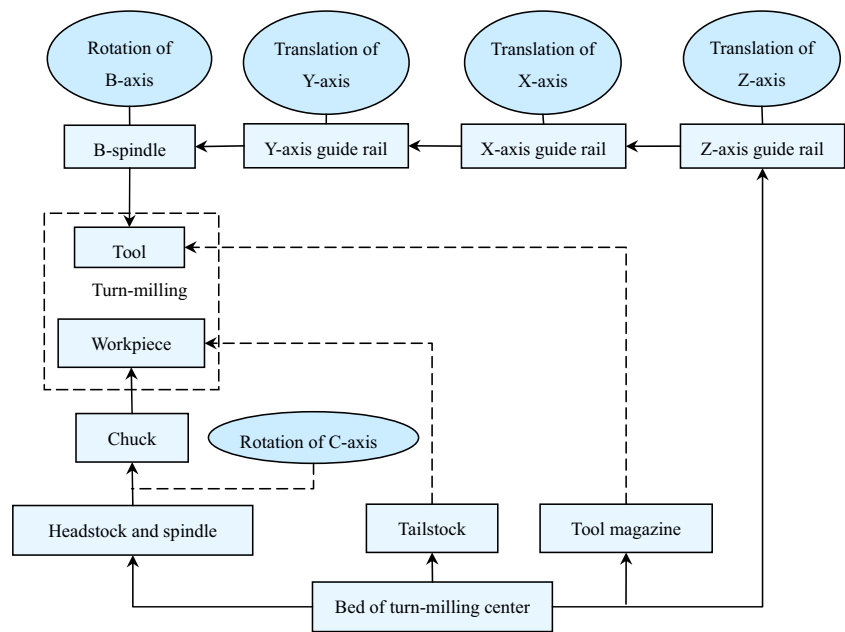


changed by the control bar; finally, the data to the file is transferred through the command "setValue." The process is expressed as follows:

```
s=(Node)(browser.getNode("x_move")); //
Definite the node name
EventInSFVec3f x_move1=s.getEventIn
("translation"); // Translation value
```

```
value1[ 2] = (float)((float)(scrbar[ 1] .g-
etValue())-80); //Set a new data value
x_move1.setValue(value1); //Input the
new translation, such as X direction
DEF x_moveP PositionInterpolator { // Po-
sition interpolator in X direction
Key[ 0, 1]
```

**Table 1** Compare with files and optimization

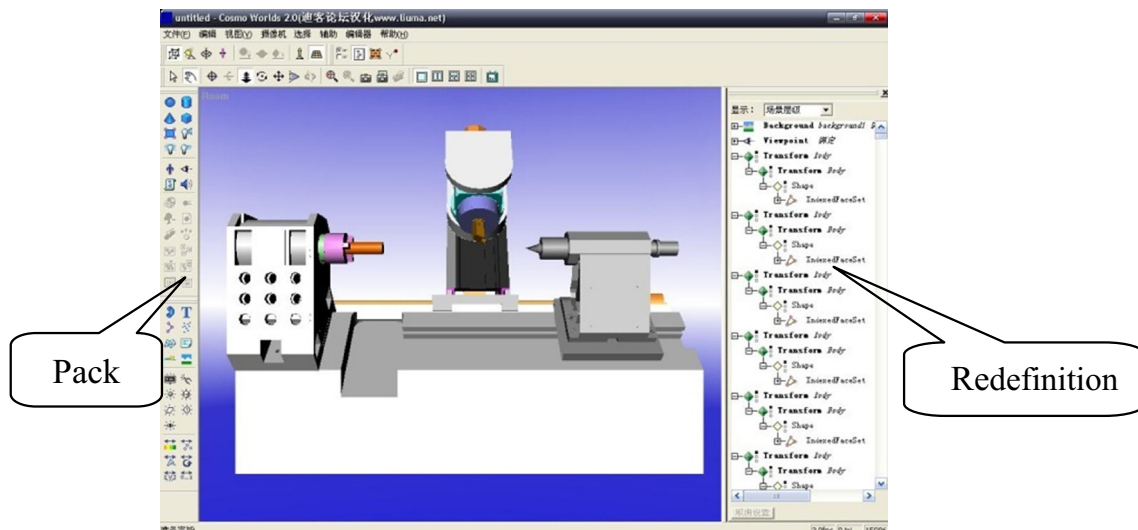| Format (Kb) / Kinds of model | | Drawing | UG | VRML | VrmlPad2.1 compressed VRML | Optimized VRML |
|---|---|---|---|---|---|---|
| | | | .prt | .wrl | .wrl | .wrl |
| Part | Simple geometry | | 136 | 18 | 1.52 | 1.49 |
| | | | 184 | 23 | 1.61 | 1.57 |
| | | | 223 | 29 | 1.69 | 1.61 |
| | | | 251 | 32 | 1.71 | 1.66 |
| | | | 267 | 35 | 1.73 | 1.67 |
| | complex geometry | | 338 | 42 | 1.81 | 1.78 |
| Assemble components | models of machine tool | | 11002 | 1811 | 216 | 191 |

**Fig. 5** Turn-milling center in Cosmo World environment

```
KeyValue[ 0 0-80, 0 0 36,]} // movement by
the Interpolation node
x_move1.setValue(value1); // Set posi-
tion in X direction
Taking Z direction as example to explain
movement control is realized and shown in
Fig. 7.
z_move=(Node) (browser.getNode
("z_move")); //Definite the node name
EventInSFVec3f z_move1=(EventInSFVec3f)
z_move.getEventIn ("translation"); //
Translation value
value1 [2]=(float) ((float) (scrbar
[1].getValue ())-220); //Set a new data
value
z_move1.setValue (value1); //Input the
new translation
z_move node is received from Applet posi-
tion information by Position Interpolator
as follows:
DEF z_moveP PositionInterpolator { // Po-
sition interpolator in X direction
Key[ 0, 1]
KeyValue[ 0 0-220, 0 0 75,] // Set position
in X direction
  }
```

The motion of turn-milling center is demonstrated by the adjusting different parameters on control panel, as shown in Fig. 8. The workspace is gained, and the interference is easily discovered in motion process.
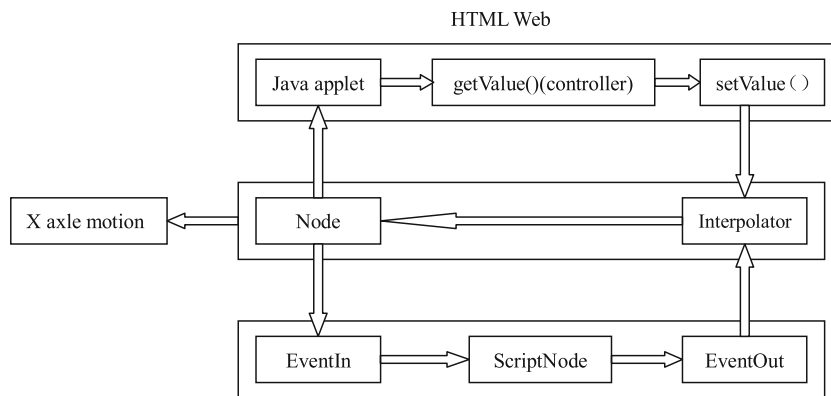
## 4.2 Material removal of workpiece

The simulation of real-time material removal of workpiece is the most important part of the machining simulation. Users understand easily the machining process by the lively simulation of material removal of the workpiece [16, 17].

### 4.2.1 Wire frame model

The material removal is realized by the Boolean operation between the blank and cutting tools, and the Boolean operation includes intersection, union, and subtraction. The basis for the three kinds of operation is the vertex on original surface and a series of new points operated by intersection operation. So, it is necessary for those points to make the three kinds of operation. As a result, the model in this system is built in the form of the grid. The wire frame model and schematic diagram of the Boolean operation are shown in Fig. 9. In order to simplify modeling process and increase simulation speed, free surface of workpiece could be built by the ElevationGrid node in the VRML. This node shows the same rectangular grid in different height. Through a lot of different height values, various geometric shapes are described. Every height value on the grid updates in time with the value of the Script node changed. X dimension and Z dimension indicate the number of meshes on $x$ and $z$ direction. X-spacing and Y-spacing indicate the distance between adjacent vertexes respectively. The value of X-spacing and Y-spacing is smaller, and the precision of workpiece surface is higher. Material removal is essential for the updating of the Y dimension value according to the position of the tool. In the VRML file of virtual machine, workpiece and tool position are read by the Script nodes as EventIn fields. At the same time, the instantaneous value is transmitted to an external Script procedure (Java class file). Using this external Script procedure, we can calculate the height value in time and use the value to present the workpiece geometry. The height value is then returned to the Script nodes in VRML files of virtual machine, through ROUTE command, connected to the ElevationGrid nodes. The height value

**Fig. 6** Information transmission
through the web



of the ElevationGrid nodes describes of geometric shape of the workpiece surface, with the dynamic position of workpiece and tool that changed passively.

### 4.2.2 Material removal algorithm

Boolean operation includes intersection, union, and subtraction. The basis for the three kinds of operation is the vertex on original surface and a series of new points operated by intersection operation. So, it is necessary for those points to make the three kinds of operation using cuboid as an example. Assuming that there are two bodies A and B, subtract operation is shown in Fig. 8. Making the Boolean operation between the scanning spaces form by tool movement and the part, the Wire frame model of the part is changed timely and new parts are generated. The essence of this process is not the material removal but updates the coordinate value of the points of the workpiece surface. Milling cutter envelope surface is divided

into the sphere and cylinder. All points of the part wire frame are traversed, and the height value of every point is calculated, which is compared with the coordinate value of the points on the tool wire frame. If the height value is larger than the coordinate value, the height value is replaced by the coordinate value in order to realize the cutting effect in Fig. 10.

There is ElevationGrid node in the VRML which can be used directly, so workpiece and tool can be described by the ElevationGrid node in the VRML to determine how many points on the X and Y direction are needed to describe the workpiece which can be calculated as follows:

$$\begin{cases} \Delta x = \dfrac{X}{k_x} \\ \Delta y = \dfrac{Y}{k_y} \\ \Delta z = \dfrac{Z}{k_z} \end{cases} \tag{1}$$

where $k_x$, $k_y$, and $k_z$ are respectively the required number of points on the X direction, Y direction, and Z direction. $X$ is the length of

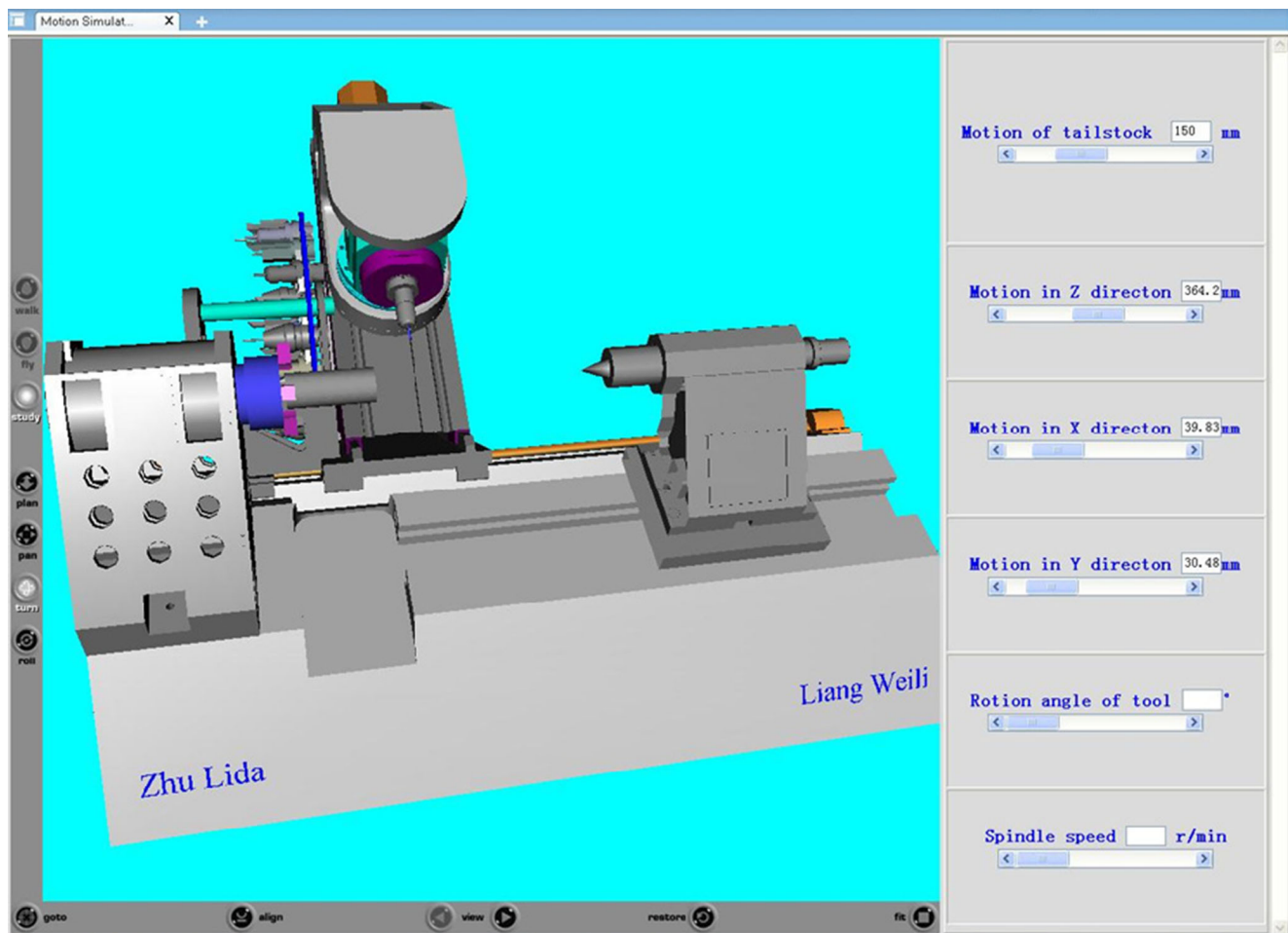**Fig. 7** Movement control of the tool in Z direction
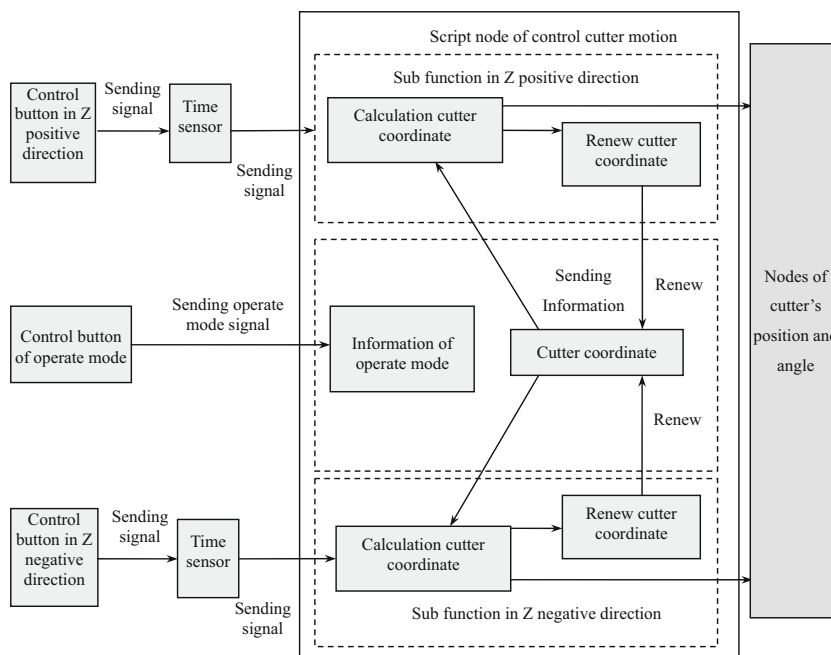
**Fig. 8** Motion process of turn-milling center

workpiece, *Y* is the perimeter of workpiece, and *Z* is the height of workpiece. $\Delta$x, $\Delta$y, and $\Delta$z are respectively the distance between the two vertices in X, Y, and Z direction. The smaller the $\Delta$x, $\Delta y$, and $\Delta$z are, the more discrete accurate the workpiece is. Consequently, the more system memory is required.

The projection points of cutting tool and workpiece in coordinate are obtained and compared to the value of target point of workpiece with the value of tool, and then the value of target point is updated. The algorithm of material removed is shown in Fig. 11. The workpiece material is removed in motion space of tool by the Boolean calculation, in which various coordinate points of workpiece are changed to form new model.

Display() function and cut() function are defined as follows:

```
function Display(){
c=C.angle; //Obtained information of cut-
ter coordinate
i f ( c > p a i 2 )          { c = c -
Math.floor(c/pai2)*pai2;} // Set angle
if(a1>0){cut(a3,a1,c);}
......
```

```
}
function cut(y,z,c){
N0=Math.round(z/length); // // The value
of length in Z direction
if(N0>0)
{
for(k=1;k<3;k++)  {
N1=Math.round((pai2*100-100*c)/pai2)+
100*(N0+k-1-1);//Counting
for(N=N1;N<N1+2;N++)
{
si=Math.sin(belta); //sin function
co=Math.cos(belta); // cos function
if(po.y(N)/co>=y||po.x(N)/si>=y)    //
comparison position  {
if(y>0)
{
po.y(N)=y*co; //Cutting
Co.Blue(N)=1; // Playing up
......
}
```

**Fig. 9** Wire Frame Model of tool and workpiece



Workpiece                    tool
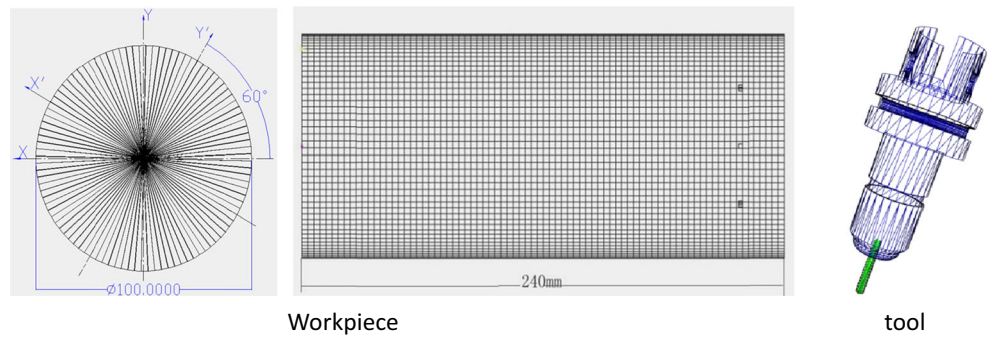
```
else
  { po.y(N)=0,po.x(N)=0;} // Cut off
  }
  }
  }}}
```

4.3 NC code compiling and generation path

The NC code complier is embedded in the control module of motion and codes that are saved as text files. A temporary data buffer that is created reads the information of NC machining of program segment in sequence as processing instructions in compilation process. The flow chart of the NC code interpreter is shown in Fig. 12. The detailed steps are expressed as follows:

Step 1.  Read the code file: the character string is stored into variable, and then the grammar of all codes is checked. Users can modify codes based on error information and then compile the NC code again.
Step 2.  A piece of NC codes and the status of relevant machine tool will be read in code file, including kinds of movement and coordinates of cutter.
Step 3.  NC codes are transformed to simulate the movement by the relevant sub-function of control section in this module.
Step 4.  The codes grogram will return to step 2 until all NC nodes have been read.

In NC machining, the cutter trajectory could be obtained by the simulation of tool path, which checkout the machining
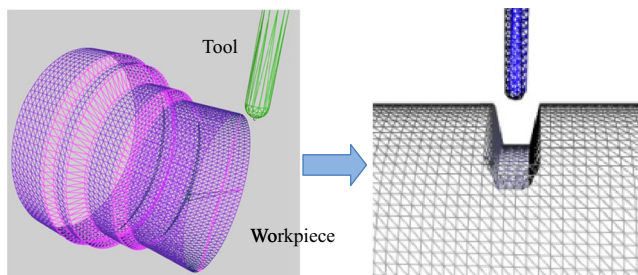
requirements by the NC code programs to save time and cost in machining process. Generation trajectory in milling process is shown in Fig. 13. Using JavaScript technology, this system can simulate web-based tool trajectory, which significantly reduces cost. Machining trajectory is consisted of a series of key points. These points are detected by Track() function 200 ms a time. Function Track() is defined as follows:

```
function Track(){
trackN+=1;
M.Nodes("BraceMove").Fields("rot").x=
(Y.y)*1.1547*Math.cos(C.angle)*1.15;
// Trajectory is generated based on tool
  coordinates
M.Nodes("BraceMove").Fields("i")=
trackN; // The i th point
timer4=setTimeout("Track()",200); //
  Tools and workpieces information
  }
```

BraceMove node would generate an array of the points passed by the function of Track(). Finally, trajectory could be generated by extrusion. Since the tool and workpiece are rotating simultaneously, so the rotation angles of tool and
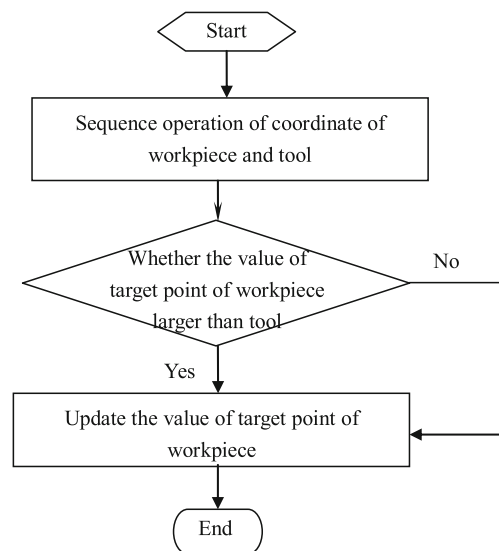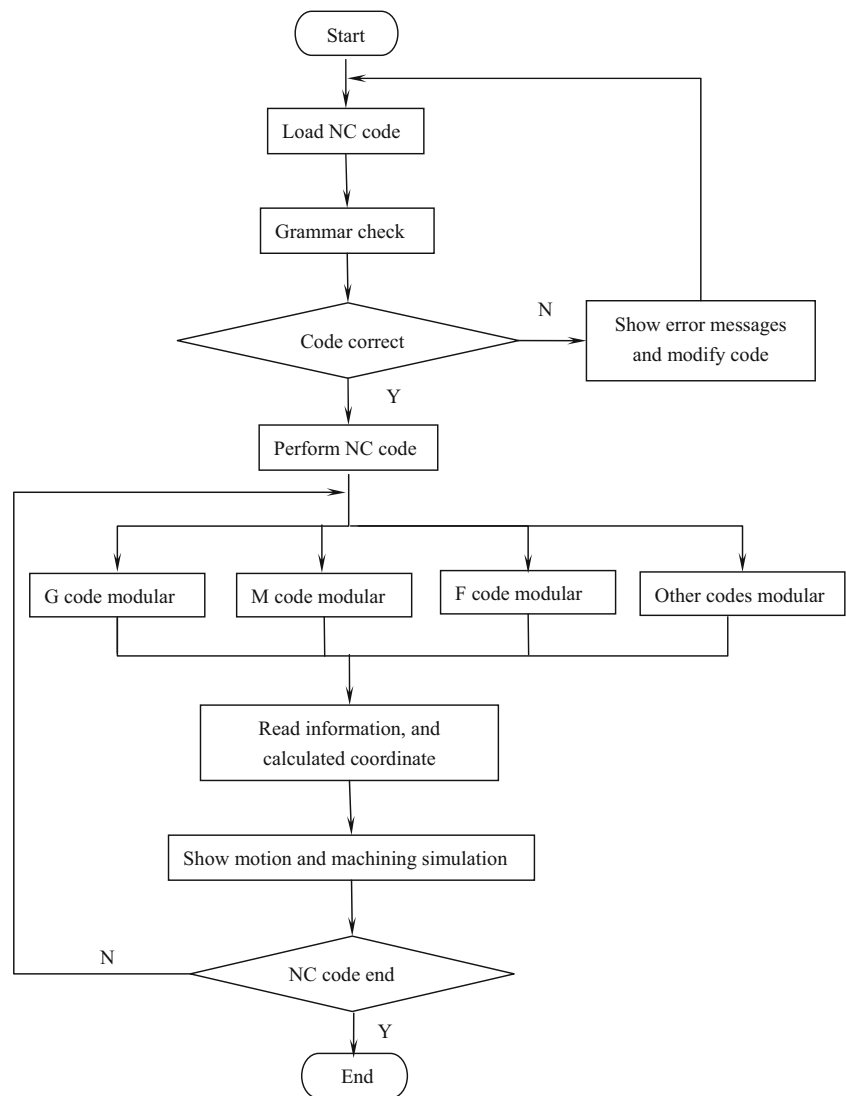


**Fig. 10** Boolean operation between tool and workpiece



**Fig. 11** Flow chart of material removal

workpiece should be adjusted to get the reasonable trajectory. BraceMove is defined as follows:

```
DEF BraceMove Script{
eventIn SFVec3f   rot //Input node in
JavaScript
eventIn SFInt32  i //The i th input node in
JavaScript
field MFVec3f  transResult []
field SFNode  NodeResult  USE ResultBrace
url "vrmlscript:
function rot(value){
transResult[ i][ 0] =value[ 0] ; // X-axis"
displacement ......
NodeResult.set_spine=transResult; //
Passed to the node of trajectory
  } "
  }
```

In order to avoid overlapping machining trajectory and workpiece surface, the scale of the trajectory's displacement value expanded 1.15 times. Machining path of camshaft is shown in Fig. 14. Machining trajectory will assist engineers to make machining trajectory generate processing program that is transmitted to the machine for machining in the actual
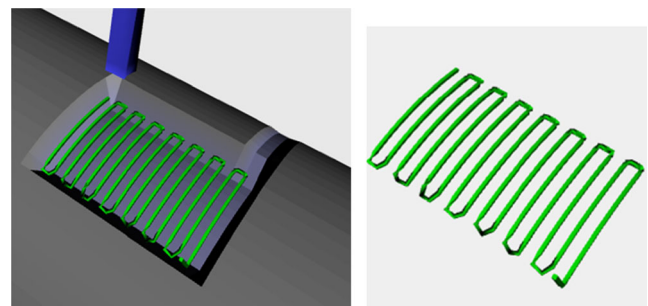


**Fig. 13** Generation trajectory in milling process

processing and especially provided a reference for machining complex surface.

### 4.4 Implementation of CNC turn-milling simulation system

Interpretation and implementation of NC codes are of great importance for machining simulation. The simulation contains three modules: the model display module, the NC codes input module, and the motion control module. NC codes interpreter is embedded in the control module, including lexical analysis, syntax analysis, and code conversion. In the system, users input some basic machining conditions such as the type and geometric parameters of tool and workpiece and machining technical requirement, such as turning-spindle speed, milling-spindle speed, feed rate, and geometry and dimension of workpiece. Machining trajectory planning and NC codes verification provide foundation and reference for the real manufacturing process. The file size of machining variable pitch and variable depth screw and more NC codes need to be planned and optimized by manufacturing engineer according to the user's requirement, such as geometry shape and dimension of screw. Therefore, manufacturing engineer provides cutting parameters, types, and material of cutters in NC codes to users.

Taking the variable pitch and variable depth screw as example, the pitch and depth of screw are variable, so multiaxis linkage has to be conducted in turn-milling process. Interface and variable pitch and variable depth screw machining simulation are displayed in Fig. 15, such as part display and CNC turn-milling process. The NC codes are verified in turn-milling system based on programs of machining experiments, which are input into virtual turn-milling system by text file based on simple modification, and then machining trajectory of variable pitch and variable depth screw is obtained in process planning. Part of program is defined as follows:

```
function c_round(){ // Rotation of C-axis
zi=zi+1;
if(zi<Num*T)  // Comparison of number
{
M.Nodes ("lingjianandqiapan").Fields
("rotation").angle+=pai2/Num/T;// Rota-
tion of workpiece
```
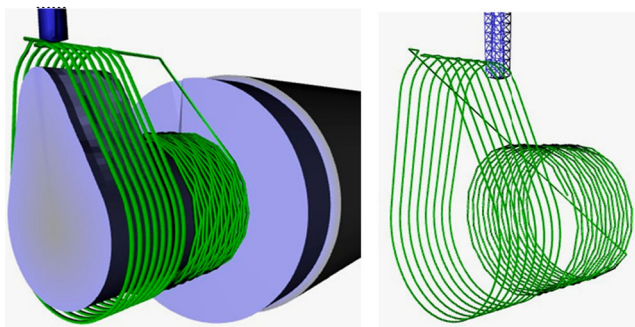


**Fig. 14** Machining trajectory of camshaft

```
deltac=deltac-Math.floor(deltac/
(pai2/axisN))*(pai2/axisN); //Real-time
angle
M.Nodes("y_move").Fields("translatio-
n").y=axisy/2*Math.sin(deltaN)/
Math.sin(deltac+deltaN)/2*1.732; // Feed
rate of cutter
M.Nodes("y_move").Fields("translatio-
n").x=-y/2; // Set relation of movement in
x and y direction
......
timer=setTimeout("c_round()",10); // Set
time of rotation of C-axis
}
else
{ clear Timeout(timer),i=i+1,NC();} //
Clear time record
}
```

In order to the accurate real-time calculation of workpiece material removal, motion components, etc., a lot of computer resources have to be consumed in display, transmission, and the simulation process. So, the accurate simulation process on a low performance computer will reduce the speed of graphics and simulation efficiency. With the increased speed of graphics display and simulation, the geometric accuracy will be reduced. The relationship between machining accuracy and graphic display speed is shown in Fig. 16. It is difficult to find the balance point between speed and geometric accuracy simulation, but it can adjust the relationship between geometric accuracy and the graphical display frame rate from 20 fps (frame per second) to 100 fps. With the increase of the amount of calculation, the frame rate should be reduced to improve the geometric accuracy.

### 4.5 The evaluation of economic and academic value for turn-milling system

This turn-milling simulation system can save manufacturing time because errors will be eliminated before manufactures instead of errors that happened in the process. Also, process planners get machining trajectory planning and NC code verification much faster. In fact, this is only a piece of saved time. It can be seen in Fig. 17 that it also helps to save time from design to manufacture if there are some design mistakes, from manufacture to experiment if there are some manufacture wrong, from experiment to sale if there are some bad unthought-of experiment result and so on. Another benefit this system brings is that machinists and planners can do their works much easier because the CNC code the system provides facilitates process decision. Besides, machining trajectory
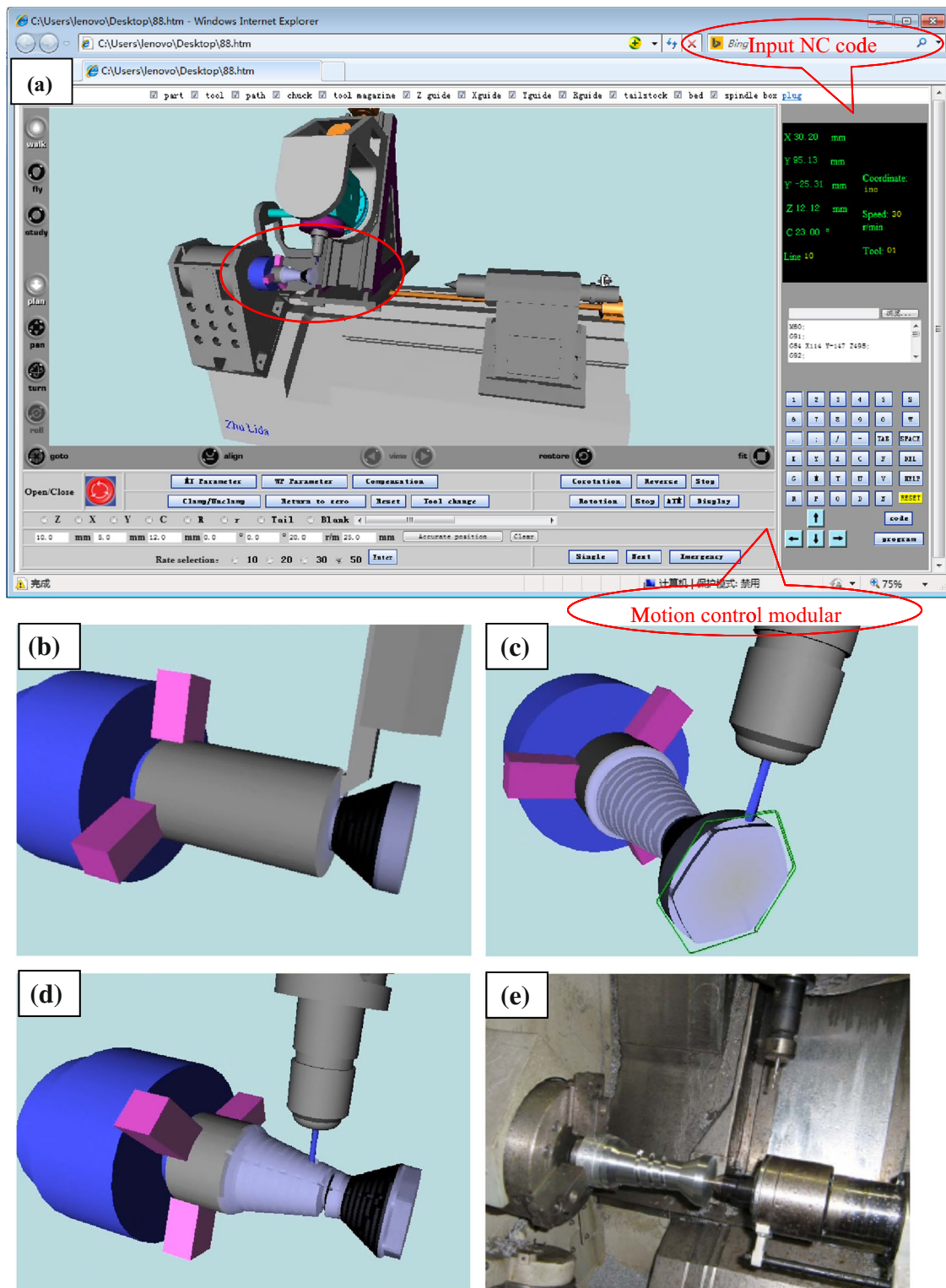
(a) The interface of simulation system (b) Turning conical surface (c) Milling six corners surface (d) zoom image of variable

pitch and depth screw (e) variable pitch and depth screw in experiment

Fig. 15 Variable pitch and variable depth screw in turn-milling simulation and experiment. a The interface of simulation system. b Turning conical surface. c Milling six corners surface. d Zoom image of variable pitch and depth screw. e Variable pitch and depth screw in experiment

planning and NC code verification provide foundation and reference for manufacturing engineer.

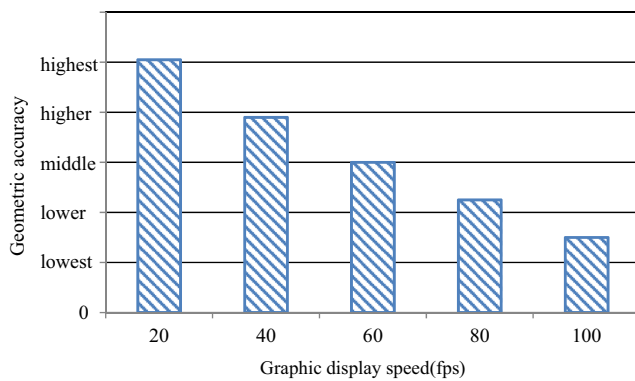In this module, turn-milling simulation system is provided to turn-milling process based on users

**Fig. 16** Relationship between graphics display rate and geometric accuracy

controlling the operational panel and inputting NC code to realize deep interaction. The platform of information communication and dynamic motion demonstration is provided for users based on the web. In a word, for the customers, it can deepen understanding of the machine product, and for the enterprises, it can accelerate the marketization and informatization of products. This method of NC machining simulation is not dependent on the expensive commercial software, and since the size of the system files is small, it can be transferred on the network conveniently. Therefore, the method is suitable to research other productions on the web, reducing manufacturing time and making it easier to make NC code and technical plan for machinist and planner decisions to obtain the CNC code for a particular piece-work based on modify and verification. The virtual system can help customers to get involved in a machining piece work with the process planner directly. The comprehensive performance of machining process and dynamic demonstration of machine tool is deeply understood by users controlling the operational panel and inputting NC code in this web-based system. For process planner, machining trajectory planning and NC code verification will provide foundation and reference before machining experiment. Therefore, the product delivery-time significantly can shorten, and the product quality can enhance by web-based turn-milling parameter selection system.

## 5 Conclusion and future work

This paper presents a web-based virtual turn-milling system by using network superiority of Java language and VRML technology interaction. This system can help users and process planners obtain more information and production functions in the global area. It is composed of three main functions, which is machining simulation function, movement demonstration of turn-milling center function, and information communication functions. Among the three main functions, the first one is the core part of this system. It can realize real-time simulation and has the advantages of CAD software and VRML. Therefore, the data volume of this system is in small size and can be transmitted conveniently though the web. The machining simulation function includes three main issues, which is the implementation of material removal, machining trajectory planning, and NC code compiling. They are explained respectively in detail. Therefore, this system can greatly shorten the product life cycle cost, enhance the product quality, and decrease the product lead-time.

There are still many flaws in this system, which are also further researched in direction for machining system. One is about machining accuracy and efficiency. Because of its significance in manufacture, machining accuracy and efficiency will be considered and optimized to improve and perfect the machining system. And, another is about physical simulation. Since focusing on geometric simulation in this system, physical simulation will be realized in further, such as cutting force and heat, chatter stability, and machining quality. Besides, since the virtual turn-milling system works online, the graphics information and data codes will be calculated magnanimous, in which the model files and NC codes are optimized to improve graphics display, reduce calculation, process simulation velocity, and transmit speed of information on the internet.

**Fig. 17** Product life cycle
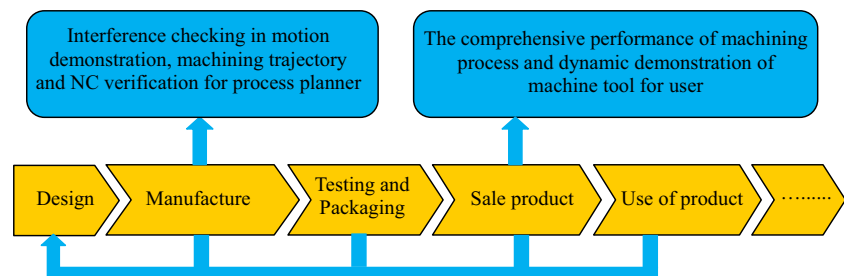
## 6 Part of NC code

```
M60;
G91;
G54 X114 Y-147 Z495;
G92;
M06 T01;
G92;
M03 S3000;
G01 V3;
G01 Y-2;
G01 Z25;
G01 Y-25 Z45;
G01 Y20 Z100;
G01 Y7 Z10;
G92;
M06 T10;
G92;
G00 Z300;
G00 Y-150;
G01 Y-20;
M05;
M46;
G01 V20;
G01 Z3;
……
G01 S360 D100 N6;
G01 Z3;
G01 S360 D100 N6;
G01 Z3;
M47;
M03 S300;
G00 Y5;
G00 Z70;
G01 V3;
G01 Y-38;
G01 V3;
M46;
G01 Y20 Z65;
M47;
G00 Y30;
G00 Z-150;
END;
```

## References

1. Ong SK, Mannan MA (2004) Virtual reality simulations and animations in a web-based interactive manufacturing engineering module. Comput Educ 43:361–382
2. Yang H, Xue D (2003) Recent research on developing web-based manufacturing systems: a review. Int J Prod Res 41(15):3601–3629
3. Suh S, Seo Y, Lee S (2003) Modelling and implementation of internet-based virtual machine tools. Int J Adv Manuf Tech 21(7): 516–522
4. Xu XW, Newman ST (2006) Making CNC machine tools more open, interoperable and intelligent-a review of the technologies. Comput Ind 57:141–152
5. He HW, Wu YM (2009) Web-based virtual operating of CNC milling machine tools. Comput Ind 60:686–697
6. Kadir AA, Xu X, Hammerle E (2010) Virtual machine tools and virtual machining-a technological review. Robot Cim-int Manuf 10: 1–14
7. Wang LH, Orban P, Cunningham A (2004) Remote real-time CNC machining for web-based manufacturing. Robot Cim-int Manuf 20: 563–571
8. Ong SK, Jiang L, Nee AYC (2002) An Internet-based virtual CNC milling system. Int J Manuf Tech 20:20–30
9. Newman ST, Nassehi A (2007) Universal manufacturing platform for CNC machining. Ann CIRP 56(1):459–561
10. Newman ST, Nassehi A, Xu XW (2008) Strategic advantages of interoperability for global manufacturing using CNC technology. Robot Cim-int Manuf 24:699–708
11. Zheng L (2008) A web-based machining parameter selection system for life cycle cost reduction and product quality enhancement. Comput Ind 59:254–261
12. Zhu LD, Liang WL, Dong SG (2009) Research of dynamic simulation system for NC machine tool based on web. Comput Integ Manuf Syst 5:954–958 (In Chinese)
13. Jiang P, He QH, Wang Y (2008) Research on interactive virtual assembly technology based on VRML and JAVA. Mech Res Appl 21(6):96–99
14. Soori M, Arezoo B, Habibi M (2013) Dimensional and geometrical errors of three-axis CNC milling machines in a virtual machining system. Comput Aided Des 45:1306–1313
15. Zhu LD, Li HN, Wang WS (2013) Research on rotary surface topography by orthogonal turn-milling. Int J Adv Manuf Technol 69:2279–2292
16. Qin SF, Harrison R, West AA (2004) Development of a novel 3D simulation modeling system for distributed manufacturing. Comput Ind 54:69–81
17. Tsai WH, Chou WC (2011) An effectiveness evaluation model for the web-based marketing of the airline industry. Expert Syst Appl 38: 15499–15516