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RESEARCH ARTICLE

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Kinematic simulation of a parallel NC machine tool in the manufacturing process

Abstract Aimed at enhancing the research status of parallel machine tools, this paper introduces the structure of a 6-SPS parallel machine tool and explains the application significance of the kinematic simulation of the manufacturing process. The simulation software was developed in Microsoft Visual C++6.0 using OpenGL API functions. The data flows are presented. Finally, a simulation application of odd leaf hyperboloid is performed before the manufacturing process; the kinematic simulation demonstrates the rationale of trace planning and the feasibility of manufacturing instruction.

Keywords kinematic simulation, parallel NC machine tool, manufacturing process, trace planning

1 Introduction

Parallel NC machine tool, also known as varied-axis NC machine tool, virtual spindle machine tool, and parallel robot, is a novel nonlinear tool based on nonlinear Stewart mechanisms and differs from traditional linear tools. In the past decades, the tool has received a great deal of attention from many researchers, and its development and applications have achieved many improvements [1, 2]. During this period, the kinematic simulation system of parallel NC machine tools has also been developed as a practical tool and plays a great role in parallel machine tool design and research.

Kinematic simulation has now been applied in many aspects of tool design; for example, it can explore the dimensional target and search the terminal edge; it can also check the validity of trace planning. Furthermore, the safety of the wholly produced unit can be ensured by real-time checking of the collision and interference of the NC machine tool [3].

There are many articles on the development of a simulation system. Most of these are constructed on an existing simulation system, which makes the application quickly, but also brings some problems: huge development investment and infeasible application in free from feature object trace planning simulation. In allusion to parallel NC machine tool application, this paper introduces a development method of kinematic simulation using OpenGL API functions with MS Visual C++ [4].

2 The structure of a 6-SPS parallel NC machine tool

As shown in Fig. 1, $O-XYZ$ is a static coordinate of the base platform and $P'-X'Y'Z'$ is a mobile coordinate of the mobile platform. According to the reverse kinematic model:

$$I_j = P + P_j A - B_j \tag{1}$$

where I_j is the vector of leg direction, P is the vector from the origin point of the mobile coordinate to the origin point of the static coordinate. P_j is the vector from the center point of the mobile platform sphere joint to the origin point of the mobile coordinate. B_j is the vector from the origin point of the static platform to the center point of the universe joint. A is the transformation matrix, also called direction cosine matrix.

In the past decades, Stewart platform research has received a great deal of attention and has been applied in a wide variety of equipment, such as flight simulators, parallel robot manipulators, machine tools, six-degrees-of-freedom coordinate measuring devices. In practical terms, the 6-SPS parallel NC machine tool is based on the Stewart platform and has some potentially advantageous points, such as simpler structure, higher

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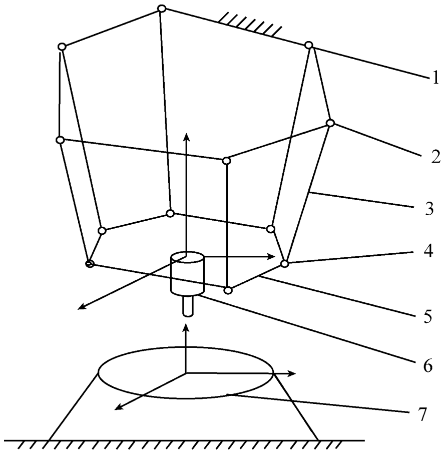
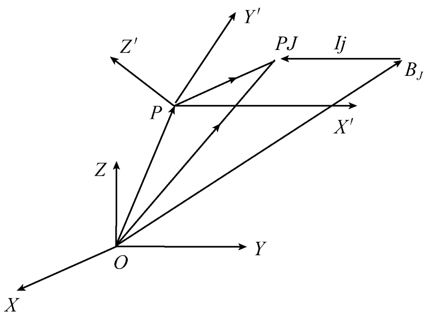
stiffness, heavier loading ability, more stable kinematic properties.



(a)



(b)

Fig. 1 Six-SPS structure and vector sketch. **a** 6-SPS parallel NC tool sketch **b** 1. Static piatform 2. Universal joint 3. leg 4. sphere joint 5. main spindle 6. mobile platform 7. base platform

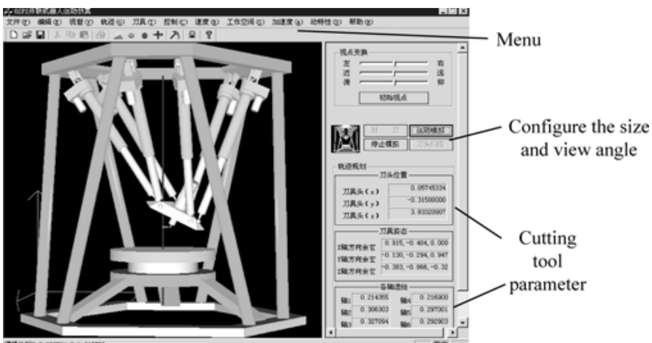


Fig. 2 The main interface of the simulation system

3 The significance of manufacturing simulation

The movement of the 6-SPS parallel NC machine tool is confined by its own structural characteristics:

The length of each leg confines the pose and position.

The swing angle limit of the sphere subsidiary ream.

The interference between the legs

Therefore, the cutting tool of parallel machine tools must be placed inside a certain working space. However, when manufacturing a complicated free from surface part, it is difficult to determine whether the cutting tool is safely placed inside the working space and whether the manufacturing code is inaccurate, incomplete, or unreasonable. Code validation, including format checks, completeness checks, reasonableness checks, and limit checks, must be performed by a simulation system before the manufacturing process begins. The manufacturing process is simulated to ensure that the NC program is error-free and capable of performing its intended trace. Obviously, all of these processes have practical significance to the manufacture of parallel machine tools.

4 The design of the simulation software Principle

The simulation software was developed in MS Visual C++ using OpenGL API functions running under Windows 2000. According to the principle of modular design, the system development uses object-oriented programming techniques to ensure system structure modularization and discreteness. To ensure the robustness and reproducibility of the system, all core modules use the Component Object Model and data communication between system modules is based on the Communication Component Interface. The input source of trace planning simulation is the cutting tool pose file, which includes the Cartesian coordinates of the cutting tool point and the normal vector of the cutting tool bar. The simulation is performed according to a linear pattern and time linearity. Under the circumstances that the simulation process does not go beyond any confined condition, the trace plan file will produce the file of the extension quantity of those legs that is required by the practical uses.

The main interface of the simulation system is shown in Fig. 2. Some main function options are listed, such as track programming, simulation, and elongation of the extension legs, etc. The main view frame is a three-dimensional (3D) substantial model of the parallel machine tool. On the right area of the main view frame, three subframes are placed from top to bottom, which are used respectively to control the visual angle for observation and to show the parameter of the knife's pose position and the extension quantity of those legs. The module of the manufacturing process simulation system is shown in Fig. 3. Two core modules are the Trace Plan Programming module and the Manufacturing Process Simulation module. The former uses the trace plan file to produce the corresponding cutting tool position file; the latter inputs the cutting tool position file to simulate the manufacturing process.

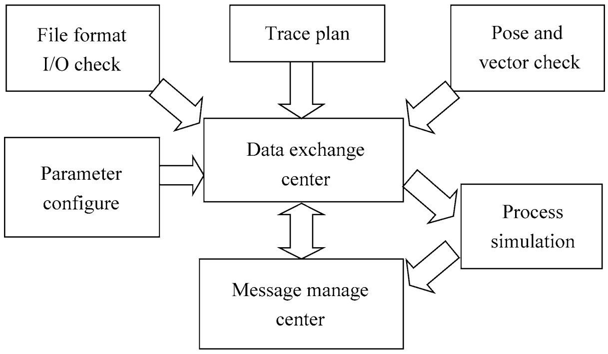


Fig. 3 The structure of 6-SPS parallel NC machine tool manufacturing process simulation system

When the kinematic simulation performs the initialization, the File Format module opens the trace plan file and checks the file data, then configures the system data; after checking the validity of the tool trace data, the system begins to perform the manufacturing process kinematic simulation according to the cutting tool trace file. During this process, the system only checks the safety of the working space. As soon as the confined condition exists, the corresponding judgment function and action are activated. So a warning is given automatically to inform the user what happened and what error occurred.

In order to simulate the practical manufacturing process, the parameter of a virtual 3D object must be identical with the parameter of the practical parallel machine tool. All of these data are queried by the system and are configured in the Parameter Configuration module. These data represent the practical size of 6-SPS, such as the absolute coordinate value of six universal joint centers on the static platform, the coordinate value of the six sphere joint centers on the mobile platform in the mobile reference frame, the initial length of the leg, the diameter and the length of the cutting tool bar, and the sphere ream radius, etc.

The function of the Pose and Vector Check module is to check the validity of the trace data and determine whether the cutting tool pose is inside the working space. The relationship between the coordinates of the cutting tool point and the direction cosine of the normal vector is governed by Eq. 1. According to this law, the parameters of the mobile platform, including the coordinates of the six spherical joint centers, are calculated. Then the lengths of the six legs are calculated. The data flow chart is shown in Fig. 4.

The input source of the Manufacturing Process Simulation module is the cutting tool trace file; this file includes information about the position (X, Y, Z) and pose (a, b, c) of the cutting tool, where X, Y, Z are the position coordinates of the cutting tool point and a, b, c the pose which can be written in the form of three direction cosines. The system loads these data into a data buffer and then exchanges the double display buffer, so the manufacturing process can be displayed dynamically. The data flow chart is shown in Fig. 5.

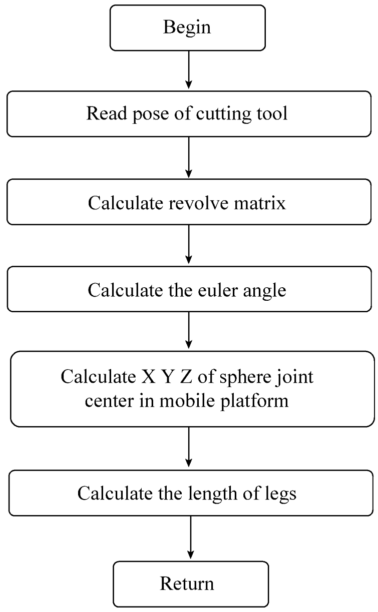


Fig. 4 Data flow of the pose and vector check module

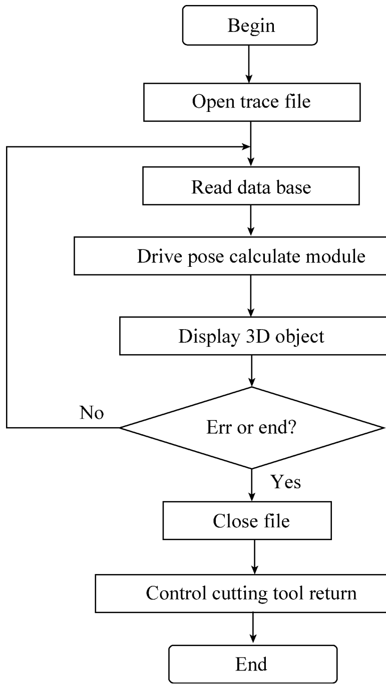


Fig. 5 The flow of kinematic simulation

The control file, also called the practical manufacturing control (PMC) file, is the NC code driver file. In general, the trace file is a temporary middle file that contains information about trace planning. After checking the pose and vector of the trace file, the validity and correctness can be ensured. After the kinematic simulation is performed, the rationality of trace planning can be confirmed. However, practical manufacturing requires the PMC file. According to the control requirements of the parallel machine tool, the File Format I/O Check module produces the consistent

PMC file with the trace file. The data flow of the resulting PMC file is shown in Fig. 6, where *rfile* is the state parameter.

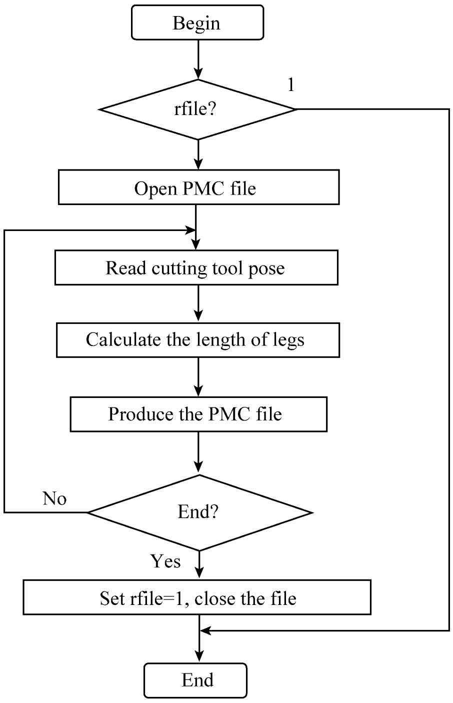


Fig. 6 Data flow of the produced PMC file

The Trace Plan module is the core module in the manufacturing process kinematic simulation. When the surface of practical parts is selected, this module produces the cutting tool trace plan file. The steps in the configuration are as follows: choose the trace type; input the parameter.

Set the trace order, such as parallel line mode, borderline mode, and so on.

After all the required parameter values are configured, the Trace Plan module figures out the discrete points coordinate value of the special surface according to the requirements of interpolation precision and Eq. 1. These data are written into the trace file using a particular data format shown in Fig. 7.

```
10.0000,-2.2500,-3.0000,0.5572,0.0760,0.8269
10.0000,-1.1480,-1.5306,0.6568,0.2148,0.7228
10.0000,-0.0459,-0.0612,0.7070,0.4152,0.5724
10.0000,1.0561,1.4082,0.6639,0.6190,0.4196
10.0000,2.1582,2.8776,0.5659,0.7635,0.3113
10.3567,1.5647,-3.0000,0.2355,0.5700,0.7872
9.3114,2.4708,-1.5306,0.1911,0.7284,0.6580
8.2661,3.3770,-0.0612,0.1012,0.8480,0.5202
7.2207,4.2831,1.4082,0.0039,0.9146,0.4044
6.1754,5.1893,2.8776,0.0986,0.9423,0.3200
8.3498,3.9955,-3.0000,0.0975,0.7148,0.6925
6.7733,4.5609,-1.5306,0.1715,0.7946,0.5824
5.1967,5.1264,-0.0612,0.2579,0.8437,0.4708
```

Fig. 7 Cutting tool trace file

5 simulation of odd leaf hyperboloid

Odd leaf hyperboloid is a kind of typical complicated surface; its equation is:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z^2}{c^2}=1 \tag{2}$$

where a=10, b=6, c=8.

The steps in the simulation are as follows: configure the trace type and input the needed parameters, such as velocity, interpolation periods, and length of the cutting tool bar. Then click on the menu of Trace/Create file to produce the trace file, as shown in Fig. 9. After checking the file validity, click the button to begin the manufacturing process simulation. The system gets the data from the buffer at the same time and displays the position, pose, and length of the legs. If the trace file has an error, the system checks it and displays a message to indicate the error type and position.

6 Conclusions

In general, the kinematic control of the parallel machine tool is more complex because of the nonlinear relationship. In order to maintain the safety of the manufacturing process, the Mac control code must be checked by the simulation system before the practical manufacturing begins; furthermore, the rationality of the trace file is confirmed by the simulation system.

In the manufacturing process simulation application of odd-leaf hyperboloid, if the trace file has an error, the system can find this error to avoid any malfunction. This application demonstrates the practical value of the simulation system.

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