Study on Tool Interference Checking for Complex Surface Machining

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Abstract. In order to solve the problem of complex and low efficiency of tool interference detection algorithm for five axis NC processing of complex surface, new tool interference detection algorithm is proposed based on space three dimensional coordinate system transform principle, the surface points was calculated in tool local coordinate system in the tool projection region to judge whether occurred interference, this method can detect local interference and global interference, it greatly reduce the calculation, and improve the detection efficiency and NC processing efficiency. The calculations of tool axis rotation and angular is given to avoid interference. The feasibility and effectiveness of the proposed method are verified by an example.

Introduction

Complex surfaces have been widely used in all areas of industry, such as automotive, aerospace, shipbuilding, mold and other fields. Five-axis NC machining of curved surface processing brings more flexibility, high efficiency and excellent surface quality [1]. However, the increase in five-axis machining of two rotational degrees of freedom, makes the tool movement more complex, increasing the likelihood of collision and interference between tool and workpiece, allowing for five-axis machining is not fully play its advantages in the practical application [2]. Therefore, the processing capability of interference are important signs of a programming system for NC machining technology [3].

Domestic and foreign scholars have conducted a lot of research on the tool interference. The most common method is the distance method, that is, by calculating the distance between the machined surface and the surface of the tool to determine whether there is interference [4-6]. Cai Yonglin [1] proposed a method to solve the surface to the extreme distance of the tool, the method of projection to the point on the surface of the cutter shaft, and the minimum distance from the surface to the cutter axis, so as to determine the global interference tool. Ahmet[6] proposed a method to determine the detection region and the detection point based on the parameter region, and to determine whether the interference occurred by calculating the maximum inclination angle of the cut point and the detection point. The above algorithm needs to calculate the intersection operation or distance calculation, the computation quantity is big, and the efficiency is low.

In this paper, the principle of spatial three-dimensional coordinate transformation is used to transform the machining surface coordinate system and the tool's local coordinate system to judge whether the interference occurs by judging the position of the detection point on the tool's local coordinate system. Compared with the previous algorithms, this algorithm does not need to perform complicated surface discrete computation or intersection and seek distance calculation, which greatly
reduces the computational complexity, improves the efficiency of NC machining, and can simultaneously detect local interference and global interference.

**Tool Interference Detection**

Free-form surface five-axis machining commonly used tools are spherical tool, flat tool, and ring tool, shown in Fig.1. Because of the normal vector adaptability of the ball-nose tool, the change of the tool posture does not affect the geometrical meshing property between the tool and the machined surface, and the programming and local interference avoidance are simple, so the traditional multi-coordinate machining has extensive Applications. But the ball tool cutting speed is not uniform, processing efficiency is low, accuracy is not high. Flat-bottomed knives and machining surface can be fully in contact with the processing quality and cutting efficiency. Ring tool processing efficiency between the ball tool and flat tool between. Therefore, this paper chooses flat blade as the research object.

**Figure 1. Tool for Five-axis Machining.**

**Principle of Coordinate Transformation**

Set the origin of the coordinate system $T$ of the tool in the center of the bottom of the flat cutter, its coordinates in the workpiece coordinate system $W$ is $(x_0, y_0, z_0)$, the unit coordinate vector $u'_x = (u'_x, u'_y, u'_z)$, $u'_y = (u'_y, u'_x, u'_z)$, $u'_z = (u'_z, u'_x, u'_y)$, as shown in Fig.2(a) below. Assuming that the point $P$ on the surface of the coordinates $(x, y, z)$, it is converted to the tool coordinate system of the point of the coordinates $(x', y', z')$, can be completed by the following two steps. First of all, the coordinate system $W$ translation, so that the origin and the origin of the tool coordinate system $(x_0, y_0, z_0)$ coincidence, the translation matrix is

\[
T = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
x_0 & y_0 & z_0 & 1
\end{bmatrix}
\]

The translation of the coordinate system is shown in Fig.2 (b).
Then use the unit coordinate vector to construct the coordinate rotation matrix $R$, the unit vector $u'_x, u'_y, u'_z$ are transformed to the $X, Y, Z$ axis.

$$R = \begin{bmatrix} u'_{x1} & u'_{y1} & u'_{z1} & 0 \\ u'_{x2} & u'_{y2} & u'_{z2} & 0 \\ u'_{x3} & u'_{y3} & u'_{z3} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Therefore, the coordinate transformation matrix from the workpiece coordinate system $W$ to the tool coordinate system $T$ is

$$C = T \cdot R = \begin{bmatrix} u'_{x1} & u'_{x2} & u'_{x3} & 0 \\ u'_{y1} & u'_{y2} & u'_{y3} & 0 \\ u'_{z1} & u'_{z2} & u'_{z3} & 0 \\ -x_0 & -y_0 & -z_0 & 1 \end{bmatrix}$$

So the transform formula from point $P$ to $P'$ is

$$[x' \ y' \ z' \ 1] = [x \ y \ z \ 1] \cdot C$$

**Tool Interference Detection Algorithm**

Set the tool coordinate system to $T$, the tool axis direction is $Z_T$ axis, the tool direction is $Y_T$ axis, according to the right hand rule to determine the $X_T$ axis, the coordinate system origin is located at the bottom center of the flat bottom tool $O_T$, as shown in Fig.3a. According to the principle of coordinate system transformation, the workpiece coordinate system $W$ is transformed into the tool coordinate system to determine whether the interference occurs. The shaded area shown in Fig.3b is the projection area of the tool in the plane of $X_T Y_T$. It is the area where the interference may occur. When judging the interference, the relationship between the point and the tool in the area can be judged.
When the Eq.1, Eq.2, there is interference; When the Eq.1, the blade and the middle of the arbor and the surface interference; when the type (2), the tool end of the big end and the machining surface interference.

\[
\begin{align*}
\{ x_t^2 + y_t^2 &\leq (d / 2)^2 \\
0 &\leq z_t \leq L_d 
\}
\end{align*}
\]

(1)

\[
\begin{align*}
(d / 2)^2 &\leq x_t^2 + y_t^2 \leq (D / 2)^2 \\
L_d &\leq z_t \leq L_{d0}
\end{align*}
\]

(2)

It can be seen from the above equation, the interference check, just calculate the tool projection area of the surface coordinates of the value, without the need to get the distance and other complex operations, greatly improving the tool path planning efficiency.

**Interference Avoidance**

For flat-bottomed cutter machining, generally avoid cutter interference by lifting and rotating tool shaft, cutter axis rotation refers to the place with a tool plane contact for the fulcrum, the tool rotation of Angle, the cutter cut into parts The surface is no longer part of the gnawing surface. The principle of interference avoidance is that it cannot generate new interference in the process of interference avoidance. Therefore, the process of interference avoidance is an iterative process, and interference avoidance should be done after interference to ensure that no new interference will occur. When the tool axis is rotated, the tool may interfere with the other parts of the surface to generate new local interference or global interference. Therefore, the tool needs to be adjusted to make the tool swing in the plane perpendicular to the plane of the pendulum, angle. If the tool posture cannot be found after repeated iterations, it means that the interference cannot be avoided by rotating the tool axis. If the tool size is not appropriate, the tool is to be lifted and the tool can be lifted in the direction of the tool axis. The cut contact is recorded, and the unfinished surface portion is machined with a small diameter cutter in a future make-up. The lift amount and the tool axis rotation angle are calculated according to the maximum depth of the cut surface of the tool. The calculation procedure is as follows.

**Rotary Tool Axis Mode**

**Curvature Interference Avoidance.** As shown in Fig.3, when the curvature interference occurs, the effective cutting radius of the tool is larger than the curvature radius of the curved surface of the tool cutting point, that is, \( R_s > \rho \), to avoid interference must be made \( R_s < \rho \). From geometric relations, we know
\[ R_e = \frac{1 + \sin^2 \alpha}{2 \sin \alpha} \cdot r < \rho \] (3)

\( \alpha \) is the inclination of the tool in the cutting direction, and \( r \) is the tool radius. Solving for Eq.3 gives \( \alpha \), where \( \alpha \) is the angle at which the tool axis needs to be rotated.

**Tool Bottom Interference Avoidance.** Assuming that the maximum point of interference at the bottom of the tool is \( P_m \), and the coordinate of \( Z \) in the local coordinate system is \( Z_m \), as shown in Fig.4, the distance from \( P_m \) to the tool contact point \( P_c \) is \( d \), to avoid interference the tool must rotate at an angle \( \theta \) in the feed direction.

\[ \theta = \arcsin\left( \frac{z_m}{d} \right) \] (4)

**Global Interference Avoidance.** Avoiding Global Interference, generally, the rotary cutter axis is used. Since global interference can occur in any direction, it is necessary to determine the direction of rotation before rotating the tool axis. Firstly, the interference of the curved surface is projected onto the \( X_rOY_r \) plane of the local coordinate system, and the closest point \( P_m \) is found out from the origin point. Then the vector \( \overrightarrow{P_mO} \) is the direction of the tool rotation, as shown in Fig.4. To make a line \( l \) through the cutting point \( P_c \), perpendicular to \( \overrightarrow{P_mO} \), the line \( l \) is the tool rotation axis. The rotation angle is calculated from the following formula, where \( L \) is the distance from the maximum interference point to the tool edge, and \( d \) is the distance from the maximum interference point to the cutting point.

\[ \theta = \arcsin\left( \frac{L}{d} \right) \] (5)

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**Tool Lift Mode**

In the case of interference by lift-up, the maximum amount of tool lift along the tool axis should be calculated. Assume that there are no interference points when the interference occurs, calculate the amount of lift for each interference point, and find the maximum lift amount, that is, the amount of lift to avoid interference. Assuming interference as shown in Fig.5, the surface equation has been transformed into the tool coordinate system, the interference point interference is to calculate the surface of each interference point to the tool surface distance, find the maximum distance is the maximum required Interference.
Example Verification

In order to verify the correctness of the proposed algorithm, the algorithm is simulated and verified. In this paper, we use the algorithm to check the tool path of the curved surface and adjust the tool attitude to avoid interference. Cutting tool and parts have been machined surface when the interference is checked, as shown in Fig.6 (a), the method is used in this paper to check and adjust the tool attitude to avoid interference, as shown in Fig.6 (b). It can be seen that the tool interference is avoided by interference check and adjustment of the tool posture.

Conclusion

This paper use the space transformation principle of three-dimensional coordinates, transform complex surfaces to the tool coordinate system, to detect tool interference of five axis NC machining
of complex surface, avoid the complicated intersection and distance calculation, improve the efficiency of tool path planning. In order to avoid the occurrence of interference, the rotation axis and rotation angle of tool posture adjustment are given for different interference forms. It can be seen that the interference detection and the avoidance algorithm of this method are relatively simple, which is beneficial to improve the efficiency of NC machining. Finally, an example is given to show that the proposed method can accurately detect the tool interference during the five-axis NC machining process and avoid the interference.

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