Development of NC Program Simulation Software Based on AutoCAD Swarm Optimization Algorithm

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Abstract. In order to solve the three main technical problems in the numerical control machining simulation: the establishment of the blank material model, the interpretation and decoding of the NC code and the three-dimensional dynamic machining simulation, the author puts forward the development of numerical control program simulation software based on AutoCAD. Based on the triangle mesh discrete method, the vertex translation algorithm is proposed to calculate the vertex coordinate value of the triangle, which greatly reduces the complexity of the calculation of the triangle function, and draws the blank based on the powerful embedded 3D graphics interface; Based on the interpretation and decoding of NC code features, the tool drive data information is effectively extracted; In the process of tool cutting, the extended DDA arc interpolation algorithm is improved to improve the cutting accuracy. The experimental results show that: Based on the improved algorithm, the machining simulation is carried out, the 3D effect is lifelike, the radial error of the interpolation point is reduced by about 30%, and the machining simulation accuracy is high. It is proved that the numerical control program simulation software based on AutoCAD can meet the needs of actual production and effectively improve the production efficiency and safety of numerical control stamping.

Keywords: NC machining simulation; Triangular mesh discretization method; Extended DDA arc interpolation algorithm.
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1 INTRODUCTION

With the development of science and technology, CNC machine tools are more and more widely used in the machinery manufacturing industry. In the NC machining system, the traditional NC code manual programming is not only inefficient, and it is easy to make mistakes; While the automatic programming using APT language is simple and powerful, however, programmers are required to memorize the language and rules of the system, and it is not easy to find if there is an error [1].

With the development of computer technology and modeling technology, numerical control simulation technology has become an effective method to predict the performance of machining process, product quality and machining efficiency [2]. On the one hand, NC simulation verifies the correctness and rationality of NC code by simulating the removal process of tool, workpiece geometry, machining environment, tool path and material, and avoids the damage of machine tool, fixture and part scrap caused by program error. On the other hand, by simulating the dynamic characteristics of NC machining, the physical simulation model of NC machining is established to predict the machining quality, based on this, some parameters affecting product quality are optimized.

Generally, the NC machining program compiled cannot be directly used in production, especially for important parts, the program must be checked. The traditional inspection method uses the trial cutting method and the machine tool scribing method. Where the program is incorrect, the shape of the part that is cut out is incorrect [3, 4]. It is necessary to modify the procedure and try cutting or scribing again until the procedure is correct. Repeated trial cutting will inevitably result in waste of manpower, material resources and time. In order to check the NC machining program more effectively, the computer can be used for machining simulation. The method is as follows: The computer replaces the CNC machine tool, and the cursor or dynamic tool shape replaces the tool to draw the tool center path graph on the screen to simulate the parts processed by the CNC machine tool.

2 LITERATURE REVIEW

Numerical control machining simulation can overcome various disadvantages of physical trial cutting, it plays an important role in shortening the product development cycle, reducing production costs and improving the market competitiveness of enterprises. The research of NC machining simulation includes geometric simulation and physical simulation. Geometric simulation regards the tool and parts as rigid bodies, without considering the influence of cutting parameters, cutting forces and other factors on the cutting process, in order to verify the correctness of the NC program [5].

The physical simulation regards the tools and parts as elastic bodies, and the main purpose is to eliminate the machining errors caused by cutting deformation on the basis of ensuring the correctness of the NC program. Geometric simulation and physical simulation have developed independently and in parallel, and their respective problems have been exposed. On the one hand, geometric simulation considers the correct procedure, because the physical factors in the cutting process, especially the stress deformation, are not considered. Under certain conditions, the processed parts cannot meet the desired technical requirements. On the other hand, in the mechanical simulation of the cutting process, the cutting quantity that determines the cutting force cannot be accurately given. When the shape of the machined surface and the shape of the blank are complex, it is difficult to obtain accurate dynamic cutting force [6].

Practice has proved that the milling force has a great impact on the work piece, especially for the long and thin work piece, the size and shape accuracy are affected by force deformation, and the calculation of milling force is related to the two parameters of radial cutting width and axial cutting depth, it can be accurately obtained by the geometric simulation system. It can be seen that neither geometric simulation nor physical simulation can accurately describe the machining process. Only by combining the two can the NC machining process be completely and effectively simulated [7, 8].

Xu, Y. et al. proposed an equal volume removal rate machining method for convex and elliptical pistons. A constant volume removal rate machining model has been established. Obtain the instantaneous position parameters of each axis of the CNC piston lathe and convert them into CNC code. Finally, the functional feasibility of this method was verified through simulation processing [9]. Klanfar, M based on three-dimensional photogrammetry, calculate the area weighted average slope on a triangular mesh. Tested CAD models, calibrated physical cones, and actual stacks to evaluate this method and compare it with other commonly used methods: protractors; Cone height diameter [10]. Rafighi, M attempted to study the effect of cutting sound on cutting performance factors. The results of variance analysis indicate that cutting speed and cutting depth have a significant impact on power consumption. However, according to the normalized effect of the normal graph, all machining parameters have a significant impact on cutting sound. [11].

The author has developed numerical control program simulation software based on AutoCAD. Based on 3D solid modeling technology, on the computer screen, the tool movement, tool path and work piece material removal process generated under the control of NC program are displayed, and the visual simulation of NC machining process is realized. Different from the previous NC machining process simulation system, this simulation system performs the graphic display of the machining process and the collision and interference inspection between objects at the same time; it is mainly used to extract the key geometric information required for quality prediction and analysis. Then the surface roughness is calculated by the prediction model of surface processing quality. In this way, after the simulation is completed, the 3D solid model of the "cutting" part can be obtained, and the machining size and surface roughness of the part can be observed, thus realizing the visualization of the simulation results.

3 METHODS

3.1 Overall Structure of Simulation Software

The purpose of NC machining simulation is to use the working principle of computer graphics to dynamically simulate the whole machining process, so as to check the correctness of NC code. NC machining simulation generally adopts 3D simulation technology; NC code gets tool drive information through lexical inspection, interpretation and decoding. Under the action of the tool drive information, the tool scanning volume cuts the material off the surface of the machined part. Until all NC codes are executed and the simulation is finished [12].
According to the above description, the overall structure of the NC machining simulation system is shown in Figure 1, including the following main functional modules:

3.1.1 Blank modeling

The triangular mesh discretization method is adopted, under the condition of satisfying the discrete precision, the coordinate information of the discrete points on the whole blank surface is calculated, and the triangular mesh model of the blank bar is drawn by using this information.

3.1.2 NC code interpretation and decoding

Read the NC code text file, perform lexical and grammatical analysis, and extract the information driving tool movement and relevant auxiliary function information for storage.

3.1.3 Simulation of turning process

Read the stored drive information, perform linear interpolation and circular interpolation calculation on the data points, make the data points denser, and use 3D animation technology to realize the process of part material removal in dynamic machining.

3.2 Design and Implementation of NC Lathe Machining Simulation

3.2.1 Blank modeling

Because of the strong adaptability of triangular mesh discretization in representing complex 3D models, it is often used for blank modeling. According to the symmetrical characteristics of the revolving body of the shaft type blank, the author uses the vertex translation algorithm to calculate the mesh vertex coordinates, that is, calculates a group of vertex data, and uses the vertex translation algorithm to obtain the next group of vertex data based on this group of data.

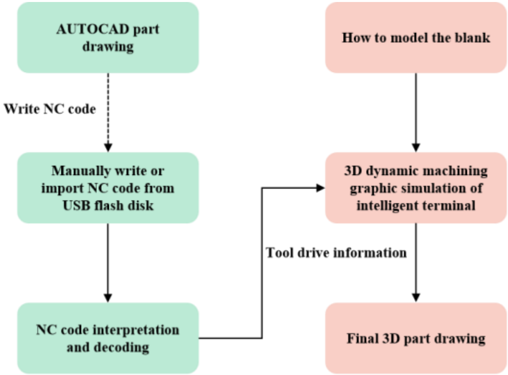

Figure 1: General structure of NC lathe machining simulation system.

The triangular mesh discretization method is used to discretize the blank bar along the axial and radial directions, and the discretization according to the accuracy range of 0.01~0.1mm can meet the machining simulation requirements [13]. The detailed steps are as follows:

3.2.1.1 Step 1 Triangulate the blank and bar

Divide the blank bar with length L and radius R into m small cylindrical slices in axial direction, n equal parts along the radial direction; it is connected into a three-piece mesh model according to certain rules.

3.2.1.2 Step 2 Use the translation algorithm to calculate the triangle vertex coordinates

Calculate the vertex coordinate value of the ith small cylinder
For vertex Vertex [i,j] , $(i \leqslant m, j \leqslant n)$, the coordinate value is

$$\begin{cases} x_{i,j} = i \times d \times scale \\ y_{i,j} = R \times scale \times \cos(2\pi \times j/n) \\ z_{i,j} = -R \times scale \times \sin(2\pi \times j/n) \end{cases} \tag{3.1}$$

Where $d = L/m$, scale is a conversion ratio between the actual size of the blank and the virtual space size of the software.
Translate the vertex along the axis d to get the coordinate value of the vertex of the $i+1$ small cylinder.
When drawing the blank model, the coordinate axis is taken as the symmetry axis, so the vertex $[i+1, j]$ is obtained after translation, with coordinates:

$$\begin{cases} x_{i+1,j} = x_{i,j} + d \\ y_{i+1,j} = y_{i+1,j} \\ z_{i,j} = z_{i,j} \end{cases} \tag{3.2}$$

For the whole blank model, just calculate the vertex coordinate value of a small cylinder mesh, and then you can get all the vertex coordinate values of the whole blank model through the translation algorithm, so as to avoid the complex trigonometric function calculation of each vertex and greatly improve the efficiency of the algorithm.

3.2.1.3 Step 3 Draw the blank model

The mesh vertex data is obtained from the above steps, and the information such as texture is added, and the blank model is drawn on the terminal by calling the interface function [14].

3.2.2 NC code interpretation and decoding

In the actual turning process, the NC code cannot be directly used for NC lathe processing, and the actual parts can only be processed after being interpreted and translated into instructions that can be recognized by the NC machining system. In the lathe simulation system, it is also necessary to interpret and decode the NC code to dynamically simulate the machining process of parts. The main task of NC code interpretation and decoding is to extract the tool motion path information, feed speed, and auxiliary functions contained in the NC program, and interpret and translate them into the data processing format that can be recognized by the simulation processing module. NC code usually goes through lexical analysis, interpretation and decoding. Finally, the motion driving information of the tool is extracted from it. The detailed steps are as follows:

3.2.2.1 Step 1 Lexical and grammatical analysis

Open the NC program code stored in *. txt format through the FileInputStream file input stream, based on the regular expression syntax rules, the whole code is traversed for lexical analysis and syntax to detect whether there are errors, if there are errors, the error location is prompted for modification[15].

3.2.2.2 Step 2 Process the branch module

Use readLine to read one line of program segments, and use substring to intercept modal function words. Enter the corresponding function word branch processing module according to different function words.

3.2.2.3 Step 3 Extract tool drive information for interpretation and decoding

After entering the branch processing module, for the G function word module, further judge what kind of G function word (such as G00, G01, etc.), and then extract the coordinate information and explain the decoding; For auxiliary function words such as F and M, the data information in the function words is directly extracted for interpretation and decoding[16].

3.2.2.4 Step 4 Judge whether the process is completed

Judge whether the NC program has finished reading and processing, after processing, convert the above stored data information into a predefined format and send it to the simulation module as tool drive information, otherwise, return to step 2 to continue reading the next line for processing.

3.2.3 Simulation of turning process

In NC turning, the data information provided by NC code cannot fully meet the requirements of lathe machining simulation. In order to dynamically simulate the machining process of the part, the coordinate data provided by the NC code must be interpolated. Using the known coordinate information, several interpolation points that meet the requirements of machining simulation are calculated.
The detailed algorithm steps are as follows:

3.2.3.1 Step 1 Perform another interpolation at the intersection E and calculate its coordinate value.

The straight-line OB intersects the arc at E, making the interpolation point $\mathrm{A_i}$ coordinate (x_i, y_i), according to the triangle $\triangle OPA_i$ and $\triangle OEF$ side and angle relationship, there is the coordinate of E point:

$$\begin{cases} x_E = R\sin\beta \\ y_E = R\cos\beta' \end{cases} \quad \beta=\alpha+\theta \tag{3.3}$$

Expand it to get the coordinates of E point:

$$\begin{cases} x_E = x_i\cos\theta + y_i\sin\theta \\ y_E = y_i\cos\theta - x_i\sin\theta \end{cases} \tag{3.4}$$

3.2.3.2 Step 2 Calculate the A'_{i+1} coordinate increments Δx and Δy of the interpolation point from point E.

According to the relationship between the two sampling interpolation points, the $A'_{i+1}(x_{i+1}, y_{i+1})$ coordinate increments Δx and Δy are:

$$\begin{cases}\Delta x = x_{i+1} - x_i = l\cos\,\beta \\ \Delta y = y_{i+1} - y_i = -l\sin\,\beta\end{cases} \tag{3.5}$$

Where l is the distance from point A_i to point A'_{i+1}. Combined with the coordinates of point E, we can get that Δx and Δy are expressed as E:

$$\begin{cases}\Delta x = \frac{l}{R} y_E \\ \Delta y = -\frac{l}{R} x_E\end{cases} \tag{3.6}$$

3.2.3.3 Step 3 Calculates the A'_{i+1} coordinate value of the next sampling interpolation point.

First, expand the coordinate increment values Δx and Δy. When θ is very small, in step 1, $\sin\,\theta \approx \theta, \cos\,\theta \approx 1 - \frac{\theta^2}{2}$ can be set and substituted into formula (4), when $l << R$, $l = V\lambda_t, \lambda_d = \frac{V}{R}\lambda_t, \theta \approx \frac{l}{2R}$ can be obtained by combining formula (3.4) and formula (3.6):

$$\begin{cases}\Delta x = \lambda_d\left(\left(1 - \frac{{\lambda_d}^2}{8}\right) y_i - \frac{\lambda_d}{2} x_i\right) \\ \Delta y = -\lambda_d\left(\left(1 - \frac{\lambda_d^2}{8}\right) x_i + \frac{\lambda_d}{2} y_i\right)\end{cases} \tag{3.7}$$

Secondly, after obtaining the values of Δx and Δy, the values of coordinate positions x_{i+1} and y_{i+1} that the tool should reach in this sampling period can be calculated, namely:

$$\begin{cases}x_{i+1} = x_i + \Delta x \\ y_{i+1} = y_i + \Delta y\end{cases} \tag{3.8}$$

At the same time, due to λ_d is a fixed value, which can be calculated in advance to avoid recalculation for each interpolation to achieve the optimization algorithm effect. The overall dynamic machining simulation flow is shown in Figure 2.

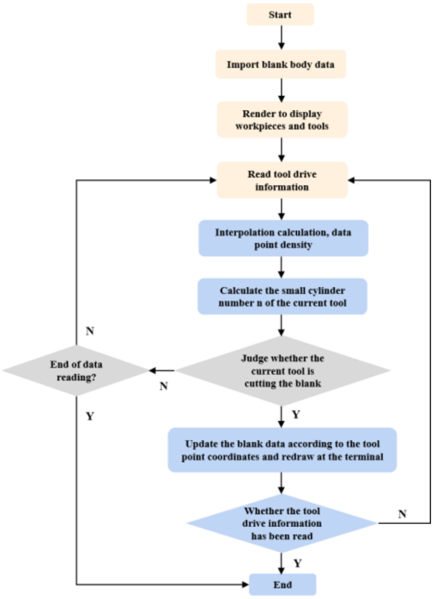

Figure 2: Dynamic turning process flow chart.

3.3 Simulation of Machining Process

First, input the NC machining program, and the computer uses the simulation program to translate process and calculate the NC machining program, and process the relevant information into the relevant data of computer graphics, then use the drawing function and animation technology of the computer to visually simulate the parts processed by the CNC machine tool on the screen. If the graphics on the screen are not consistent with the parts to be processed, it means that the NC machining program is wrong, return to modify until it is correct. The simulation processing process is shown in Figure 3.

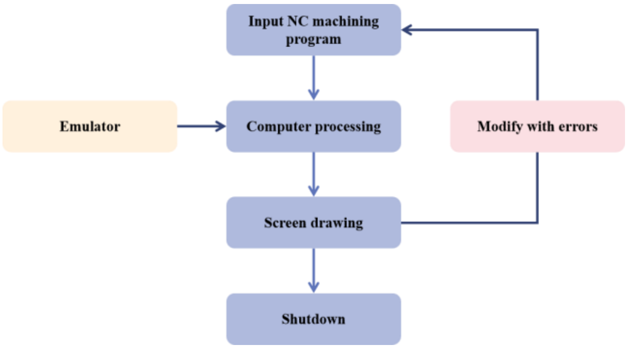

Figure 3: Simulated machining process.

3.4 Fixture Modeling

In the AutoCAD environment, we use the relevant drawing functions of AutoCAD to build the specific parts of the clamp, assemble each part into the specific parts of the clamp after assembly, and save it to form the fixture graphics library. During simulation, directly import the required clamp details from the fixture library, and then load them into the simulation environment through translation, rotation and other graphic transformations [17].

In addition, in the process of fixture design, standard parts (such as bolts and nuts) are often needed, according to the actual situation of fixture parts required by CNC machine tools, we have initially selected common fixture parts such as positioning parts, clamping parts, fasteners, and established the standard parts library of fixture parts, the user can select the required type and specification of standard parts and load them into the NC simulation environment.

After the solid models of blank, tool and fixture are built; they need to be "installed" on the computer, that is, installation simulation. For this, we use the coordinate transformation method to install and position the fixture, blank or work piece on the workbench. Set that the origin of the coordinate system of the fixture or blank coincides with the origin of the AutoCAD graphic coordinate system, the actual installation position can be realized by translating and rotating the coordinate system of the installation part.

3.5 Tool Motion Path Simulation

After NC code analysis and processing, the tool motion path in 3D simulation space is obtained. Then, according to the tool number, extract the relevant parameter data of the tool from the current tool library of the configured machine tool, and use the tool solid modeling method to generate the 3D solid model of the tool. The 3D solid model of the tool and the tool path are dynamically displayed at the same time, and the tool path generated by the tool moving according to the NC machining program is realistically reproduced on the computer screen, so as to check the rationality of the tool path and the correctness of the NC program. Figure 4 shows the process flow of tool path simulation [18].

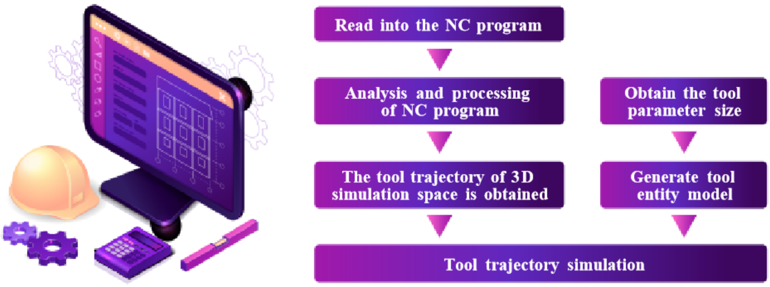

Figure 4: Simulation process of tool motion path.

4 RESULTS AND DISCUSSION

4.1 Simulation Error Analysis

4.1.1 Principle analysis of radial error of sampling interpolation points

If $P_0(x_0, y_0)$ is the starting point of the arc, there is $R^2 = x_0^2 + y_0^2$. Calculate the distance R'_{i+1} from the interpolation point A'_{i+1} to the center of the arc, combined with the coordinate increments Δx and Δy, there are:

$$R'_{i+1} = \sqrt{x_{i+1}^2 + y_{i+1}^2} = \sqrt{(x_i + \Delta x)^2 + (y_i + \Delta y)^2} \tag{4.1}$$

Substitute equation (3.7) into equation (4.1) and simplify it to obtain:

$$R'_{i+1} = \sqrt{(1+\theta^6)^i}R \tag{4.2}$$

Let δ'_{i+1} be the radial error of interpolation point A'_{i+1}, then there is:

$$\delta'_{i+1} = R'_{i+1} - R = \left(\sqrt{(1+\theta^6)^i} - 1\right)R \tag{4.3}$$

4.1.2 Test of experimental data

In the above radial error algorithm, the parameter values are shown in Table 1, through Matlab simulation, the error comparison between OpenGL algorithm and the author's algorithm is shown in Figure 5.

Algorithm	*i*	$\theta(rad)$	$R(mm)$	*Simulation time*	*Error*
OpenGL interpolation algorithm	100	0.001~0.01	100	3m47s	δ_{i+1}
Author's algorithm	100	0.001~0.01	100	2m49s	δ'_{i+1}

Table 1: Parameter value and algorithm comparison.

In Figure 5, the black line represents the "fill point radial error δ_{i+1}" generated by the OpenGL algorithm, and the red line represents the error δ'_{i+1} generated by the author's algorithm. It can be clearly seen from Figure 5: $\delta'_{i+1} < \delta_{i+1}$, the error generated by the author's algorithm can be reduced by about 30%.

4.2 Simulation Effect of Turning

Carry out turning simulation test on the terminal of numerical control program simulation software system based on AutoCAD, the process conditions are as follows: Φ= 30mm, L=100mm bar; Discrete precision value: $m = 100, n = 30$. When inputting the blank parameters on the terminal, click the simulation to display the whole processing process of the blank smoothly and dynamically, the whole process takes 2min49s, with high processing efficiency and realistic 3D processing effect.

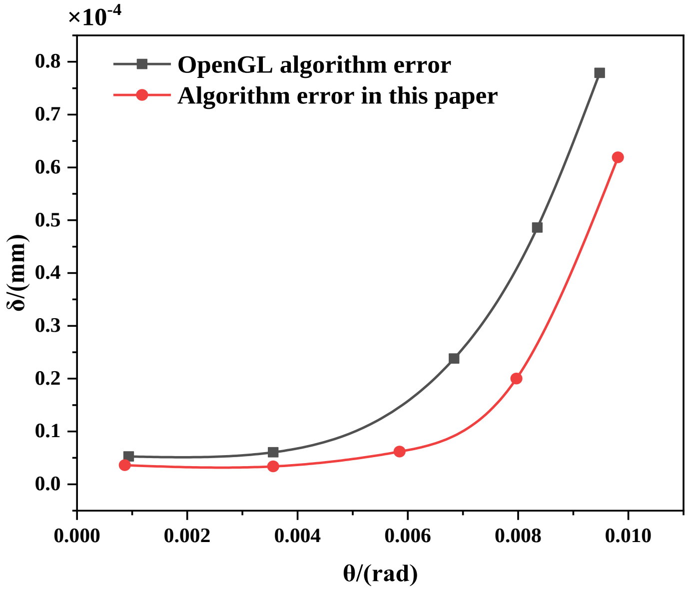

Figure 5: Error comparison before and after algorithm improvement.

5 CONCLUSION

The author puts forward the development of NC program simulation software based on AutoCAD, and realizes the dynamic graphic simulation of NC machining process by using the 3D scanning volume generation function provided by the software platform AutoCAD. Different from the previous NC machining simulation system, our simulation system is mainly used to extract the key geometric information required for quality prediction and analysis while performing the graphic display of the machining process and the collision and interference inspection between objects. After the simulation is completed, the 3D solid model of the part can be obtained, and the machining dimension and surface roughness of the part can be observed, thus realizing the visualization of the simulation results.

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