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Open CNC System Component Assemble Model based on Reliability

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Abstract

In order to realize the characteristics of the numerical control system including expandability and reconfigurability and to construct open CNC system platform with higher reliability, this paper established a component assembly model for numerical control system based on reliability. The numerical control system is divided into functional components which are relatively independent in logic. The numerical control system model is constructed based on the main evaluation indicator, the software reliability parameter of the numerical control system. The method is used in the interpolation module of the numerical control system with high requirement on timeliness. A solution is proposed based on improved particle swarm optimization (PSO), in which the rapid convergence of global optimal solution is guaranteed through flexible weighting method. According to the analytical result of the interpolation component assembly, a reliable and optimal open numerical control system can be constructed effectively and objectively based on the component assembly model in line with different evaluation indicator requirements.

Keywords: *Software reliability, Open CNC system, Assembly model, Component technology, Particle swarm optimization*

1. Introduction

Traditional numerical control system can achieve high accuracy and realize complex function. However, the exclusive closed system structure has closed implementation process in front of the users. Users cannot redefine and expand the system for the following reasons: software and hardware from various manufacturers cannot be compatible with each other; various modules in the system have different interaction modes and communication modes. In order to satisfy new manufacturing demand in actual finishing process, the numerical control system should have the software and hardware which can be combined and transplanted mutually. Since 1980s, developed countries in the West began to study the open CNC system. America, Europe, and Japan established their open architecture [1, 2], while other countries in the world developed different agreements and frameworks based on these architectures [3]. However, there is no uniform architecture for open CNC system in the world, resulting in a shortage of effective modeling method. The open CNC system should have the characteristics including reliability, transportability, expandability, and interoperability, but these characteristics are not equipped well. As an important part of the numerical control system

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software features are more powerful and increasing large scale, its reliability requirements are also increasing. Reliability is one of the most important factors for software quality [4]. Time is the key factor of the hardware reliability, but the source code is the key factor of the software reliability [5]. Software Reliability is great importance to the user [6]. Jelinski and Moranda proposed the famous J-M model based on software failure rate [7]. J-M model were improved later by making the unreasonable hypothesis reasonable so that the model would be more realistic [8]. Littlewood and Verall proposed the failure rate model where every fault does not contribute equally to the failurerate and each fault is still assumed to be removed permanently upon failure [9]. Pievatolo proposed a model where inter-failures are exponentially distributed with parameters [10]. Wu proposed an input defect failure rate of software reliability assessment model [11]. Raja proposed a time series software reliability model [12]. Su introduced a software reliability model by Neural network [13]. Tevfik used actual inter-failure data to carry out inference on model parameters via Markov chain Monte Carlo methods [14]. Hai Hu enhanced the software reliability estimation by modified adaptive testing [15]. After years of research, the software reliability has made great progress, but still did not achieve the desired objectives. Still there is not a software reliability model is proved to be both simple and applicable, and not widely used in engineering practice. The numerical control system is divided into functional components which are relatively independent in logic. The model of the numerical control system is constructed based on the software reliability metricas the main evaluation indicators including code length, code complexity, code defect density, and code reuse rate. A solution is proposed based on improved particle swarm optimization (PSO) algorithm, in which the rapid convergence of global optimal solution is guaranteed through flexible weighting method. The numerical control system software is reliable by this way, which can be easy to modify and expand. In addition, open CNC system in line with manufacturing demand can be assembled simply and efficiently.

2. Component Assembly Technology of Numerical Control System

The users need add new functions or modify certain functions in the original numerical control system to achieve the union require. A common method is that new function are stacked in the numerical control system. Due to a shortage of complete understanding in internal implementation of the system, when new function are added, the original function which are not needed in the system are not deleted to guarantee the normal running of the system. The system performance may be decreased in certain degree by use of the method, resulting in lower and lower intelligibility of the system and uncontrollable negative influence. The development method based on component technology for the numerical control system can solve the problems above perfectly. The component is an object-oriented BC model for the operation interaction and communication and is a kind of assembled and executable structure standard. According to the characteristics of the component, various functions of the numerical control system including coding, interpolation, PLC, and cutter compensation are included in the software. Then, these functional modules are included in the components. Then, the components are added or replaced in line with demand. In the end, the assembly of numerical control system is realized by defining, classifying, developing and constructing the components. According to actual demand, combinations of different components can realize different functions in the numerical control system. The sketch map of the component assembly is shown in the Figure 1.

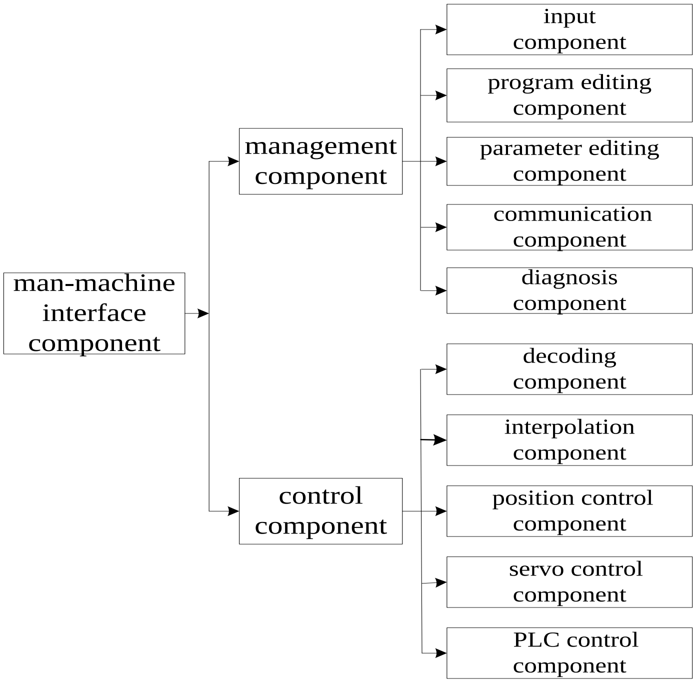

Figure 1. The sketch map of the component assembly

3. Assembly Model of Numerical Control System

3.1. Software reliability evaluation factors for the components in the CNC system

The factors influencing the reliability of the functional module in the numerical control system mainly include: code length, code complexity, code defect density, code reuse ratio. The 4 factors have their characteristics. Code length: the error rate of a component with long codes is certainly higher than that of a component with short codes. Designers may pay attention to the component with long codes during the reliability design. Therefore, under the premise of guaranteeing the function implementation, the designers will choose the component with short codes as far as possible. Common measurement methods include the code line method and the function point analytical method. Code complexity: it is more possible to encounter errors in design and programming more complex codes. In addition, the complexity leads to great influence on the maintenance cost of the program. The code complexity depends on the complexity of the data structure, nest depth, and vector data structure amount. In the present, the code complexity can be measured in some methods. The most representative methods are Halstead and McCabe. Code defect density: the error generated from the program development process will lead to code defect. The defect reflects the inconformity between the program and the demand. When the defect is undiscovered, the program will encounter a failure. The lower code defect density leads to higher software quality. When Di is the amount of unrepeated defects in the software design process, Ksloc is amount of code lines in the module, I is total review times, then the defect density is expressed by:

$$D_D = \sum_{i=1}^{I} \frac{D_i}{K_{SLOC}} \tag{1}$$

Code reuse ratio: by repeated use of common characteristics in the development process, current codes can increase the efficiency and shorten the development circle. The reuse ratio of the codes is measured by the ratio of unmodified code lines and total code lines.

3.2. Component assembly model of the numerical control system

In the construction of open CNC system, the software reliability parameters contained code length, code complexity, code defect density, and code reuse ratio are considered. This is a classical multiple objective optimization problem. The math model is shown as follows:

$$\min F(X) = [f_1(x), f_2(x), \cdots, f_n(x)] \tag{2}$$

$$s.t. g(x) = [g_1(x), g_2(x), \cdots, g_p(x)] \le 0 \tag{3}$$

Where $F(X)$ is vector objective function, X is decision vector, $x = (x_1, x_2, \cdots x_n)^T \in R^n$, $g(x)$ is constraint functions.

PSO has been used in multiple objectives optimization problem such as lowest code length, lowest code complexity, lowest code defect density, and highest code reuse ratio. The optimization problem of multiple objectives is solved by means of single objective function. Various performance factors of the numerical control system have different requirements on evaluation indicators. The adaptation function is constructed by means of linear weighting method.

It is assumed that the open CNC system is consisted of several functional modules, M = {m_1, m_2, m_3, …,m_n}. Component C_i is corresponding to functional module Mi, C_i={c_1, c_2, c_3, …, c_m }. M is the component number corresponding to functional module C_i. In the math optimization model of the multiple objectives for the open CNC system, a variable x_{ij} should be defined. When the functional module i uses the component j in the component library, x_{ij} is 1. Or else, x_{ij} is 0. Namely:

$$x_{ij} = \begin{cases} 1 & \textit{the functional module i uses the component j} \\ 0 & \textit{else} \end{cases} \tag{4}$$

The objective function of open CNC system can be presented as:

$$f_1 = \min(L) \sum_{i=1}^{m} \sum_{j=1}^{n} L_{ij} x_{ij} \tag{5}$$

$$f_2 = \min(C) \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} x_{ij} \tag{6}$$

$$f_3 = \min(D) \sum_{i=1}^{m} \sum_{j=1}^{n} D_{ij} x_{ij} \tag{7}$$

$$f_4 = maxZ = min\ (Z' - max(\ Z\ )) = Z' - \sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} x_{ij} \tag{8}$$

Where L_{ij} is component j of the code length of the function module I, C_{ij} is component j of the code complexity of the function module I, D_{ij} is component j of the code defect density of the function module I, Z_{ij} is component j of the code reuse of the function module i, Z' is more than maxZ number.

4. Implementation of Improved PSO

4.1. Algorithm principle

In the PSO algorithm, the member in the group is a particle. Each particle flies in multiple searching spaces [16]. In addition, the particle updates its speed and location in line with its experience, neighbor experience, and group experience [17]. It is assumed that particle j flies in the searching space n, the location and speed are updated as follows:

$$x_{jk}(t+1)=x_{jk}(t)+v_{jk}(t+1) \tag{9}$$

$$v_{jk}(t+1)=\omega\cdot v_{jk}(t)+c_1\cdot r_1[p_{jk}-x_{jk}(t)]+c_2\cdot r_2[p_{gk}-x_{jk}(t)] \tag{10}$$

$$(k=1,2,\cdots,n;\ j=1,2,\cdots,m)$$

Where m is population size, ω is size inertial factor, p_{jk} is K-th component of the vector, p_j in partially optimum position of the particle j, p_{gk} is K-th component of the vector, p_g in global optimum position of the particle, c_1, c_2 is cognitive coefficient and society coefficients, r_1, r_2 is a random value between 0 and 1

4.2. Structure adaptation function

In the component assembly process, in line with different requirements of various performance factors, the components are selected. Linear weighting method is used to construct the adaptation function based on various single objective functions. The objective function is shown in the equation

$$F(x) = W_1 f_1 + W_2 f_2 + W_3 f_3 + W_4 f_4$$

$$=W_1\sum_{i=1}^{n}\sum_{j=1}^{m}L_{ij}x_{ij} + W_2\sum_{i=1}^{n}\sum_{j=1}^{m}C_{ij}x_{ij} + W_3\sum_{i=1}^{n}\sum_{j=1}^{m}D_{ij}x_{ij} + W_4\Big(Z'-\sum_{i=1}^{n}\sum_{j=1}^{m}Z_{ij}x_{ij}\Big) \tag{11}$$

Constraint conditions: $\sum_{i=1}^{4}W_i = 1 \quad \sum_{i=1}^{mi}x_{ij} = 1$

W_i is the weight vectors corresponding to code length, code complexity, code defect density, and code reuse ratio.

4.3. Improved PSO

According to the analysis on the characteristics of component assembly in the numerical control system, the particle location is integrated to solve the dispersion optimization problem in the component assembly scheme. The updated equation for new particle location and speed is shown as below:

$$x_{jk}(t+1)=Fix\left(x_{jk}(t)+v_{jk}(t+1)\right) \tag{12}$$

$$v_{jk}(t+1)=\omega\cdot v_{jk}(t)+c_1\cdot r_1[p_{jk}-x_{jk}(t)]+c_2\cdot r_2[p_{gk}-x_{jk}(t)] \tag{13}$$

Function Fix(x) refers to the integrate of X. When x_{ij} is smaller than1 or bigger than n, x_{ij} is a random value between 1 and n.

Inertia weight of PSO algorithm plays a great role in contingency speed of the algorithm. According to various studies, smaller weight coefficient is good for fast contingency of PSO, while greater weight coefficient helps to find the local optimal solution in the iteration process. In order to realize the fast contingency of global optimal solution in PSO, flexible weighting method is proposed that the weight coefficient is changed with the optimal solution in global iteration process. The principle is as follows: firstly, the optimal weight coefficient $w_1 = w_2 = 1.4495$ is used; when five times of global optimal solutions are the same, a local optimal solution is considered. At this time, the weight coefficient is increased to $w_1 = w_2 = 2.4495$. If five times of global optimal solutions change, the weight coefficient changes to $w_1 = w_2 = 1.4495$. When 5 global optimal solutions are the same again, the weight coefficient is $w_1 = w_2 = 0.4495$ until the end of the iteration. The detailed process is shown in Figure 2.flexible weighting method.

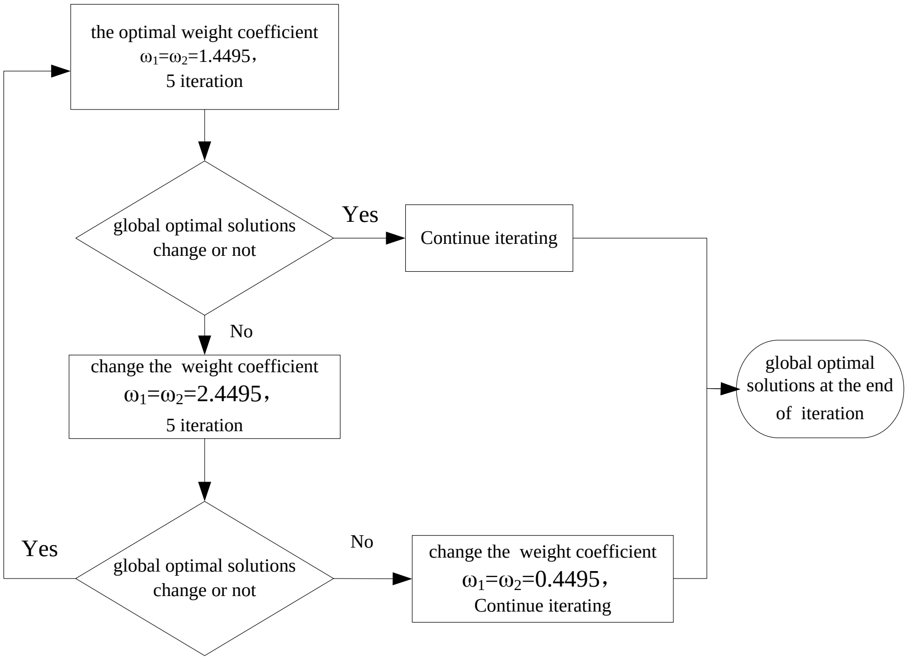

Figure 2. Flexible weighting method

4.4. Implementation process of the algorithm

The coding method uses the integration particle location, $x = (x_1, x_2, x_3, \cdots, x_m)$. The value of x_i is the integer between 1 and n. N is the component number corresponding to functional module i. It means that functional module i is consisted of component x_i. A group of codes are corresponding to a group of assembly scheme. Serial number is m. Original group comes out randomly. Specific implementation process is shown in Figure 3.

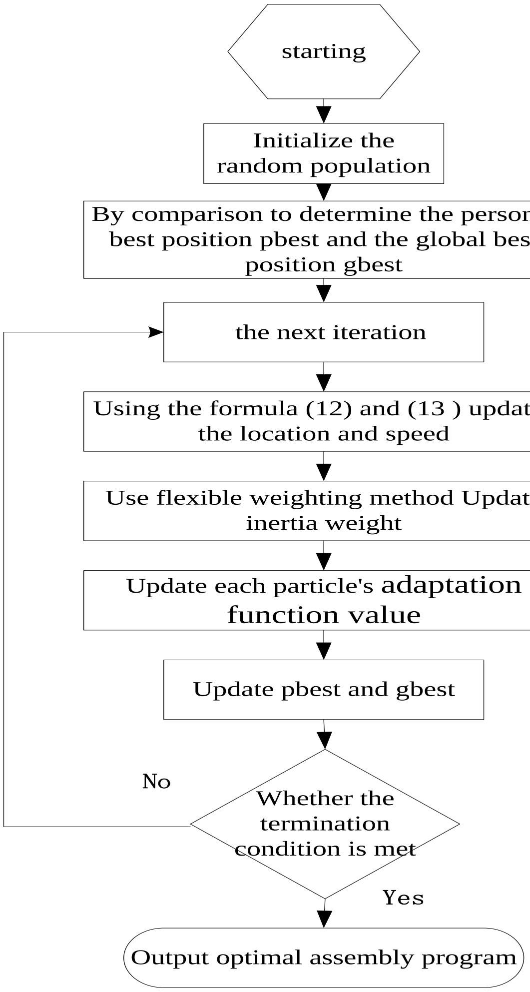

Figure 3. Improved PSO flowchart

5. Minor assembly example and result analysis

Numerical control system is the process to run the software based on the hardware support, with work process shown in Figure 4. The finishing process, supplementary data, and control parameter are input into the numerical control system through human-machine interface or communication interface. Interpolation module is responsible for the calculation. Location control module compares the actual feedback location with theoretical value of the interpolation calculation. The server machine is controlled by the deviation to realize the motion on all coordinates.

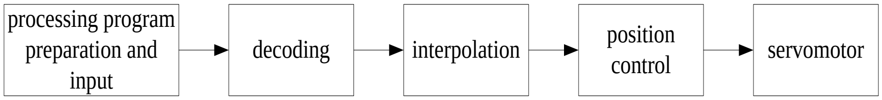

Figure 4. Numerical control system work process

The interpolation module is the core module of the numerical control system. The minor assembly is based on the interpolation module. In order to prove the effectiveness of the algorithm, several classical components are listed. It is assumed that the interpolation modules of the numerical control system include linear interpolation module, arc interpolation module, parabola interpolation module, and spiral interpolation module. Different components in the component library are created based on different interpolation algorithms to classify the performance of each component. The structure of interpolation modules is shown in Figure 5.

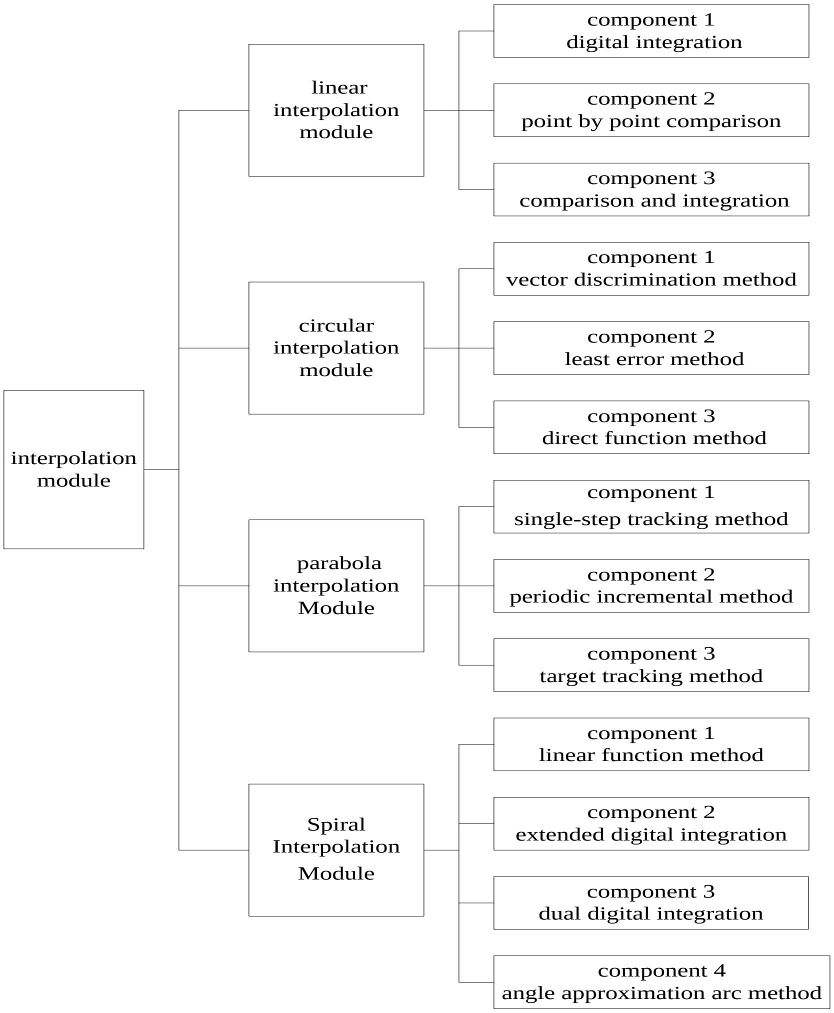

Figure 5. The structure of interpolation modules

Among the evaluation indicators for component performance, code length, code complexity, code defect density, and code reuse ratio are measured independently. Then, the values are excluded the unit. The weights of various factors: W=[0.3,0.3,0.3,0.1] $c_1 = 1.49445, c_2 = 1.49445$.

Run the improved PSO algorithm by Matlab, the result of the first 9 iterations shows in Table1.

Table 1. The result of the first 9 iterations

Population	adaptation value
2 1 3 3	4.68
2 2 1 1	4.68
3 2 3 1	4.43
2 1 1 4	4.42
2 3 2 1	4.42
2 2 2 1	4.42
2 2 3 1	4.17
2 2 3 1	4.17
2 2 3 1	4.17

Seen from Table 1, the min adaptation function value is steady at 4.17, with corresponding optimal individual 2231, and corresponding components including point by point comparison method, min least error method, target tracking method, and linear function method. Through actual analysis, the optimal individuals generated from PSO belong to best minor assembly scheme among all interpolation schemes.

Run genetic algorithm on MATLAB, the above scheme is stimulated and compared with the improved PSO result. Through 100 iteration, the stimulation result has the min adaptation function value 4.17 and optimal individual 2231. The stimulation adaptation values and iteration times of improved PSO and genetic algorithm are shown in Figure 6. According to the result, improved PSO and genetic algorithm can lead to optimal individual. However, the genetic algorithm needs intersection calculation and variation calculation, so the contingency speed is slower than that of improved PSO. Therefore, the high-performance open numerical control system can be constructed fast and efficiently by means of improved PSO.

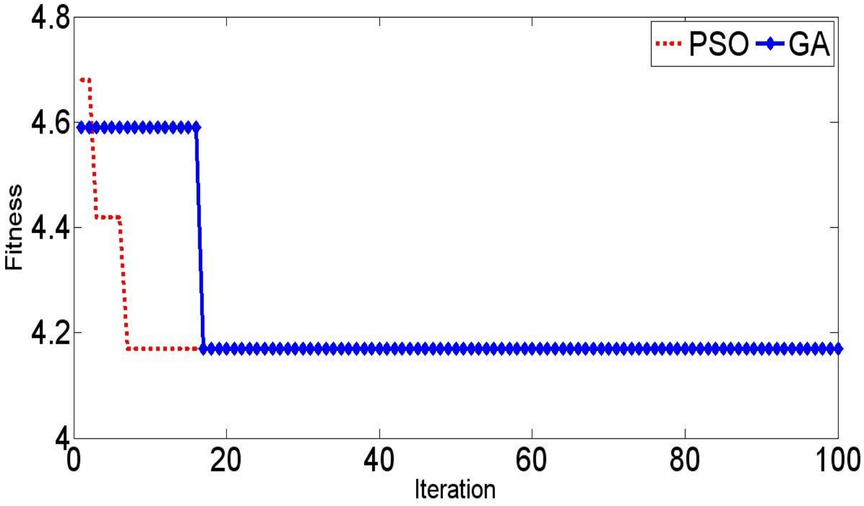

Figure 6. Adaptation values and iteration times

6. Conclusion

Open CNC system component assembly model based on the software reliability is constructed, in which the software reliability metric as the main evaluation indicators including code length, code complexity, code defect density, and code reuse rate.. According to the characteristics of optimal minor assembly scheme and local contingency of particle swarm, the multiple objective optimal math model based on particle swarm optimization algorithm is put forward. A minor assembly is carried out on the interpolation module with higher requirement of timeliness in the numerical control system. The effectiveness of the method is proved in the example.

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