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Research on CNC machine tool machining accuracy control and error compensation method based on fuzzy logic algorithm

Yunzhen Zhang[1,*] and Lu Wang[2]
[1] School of Energy and Intelligence Engineering, Henan University of Animal Husbandry and Economy, Zhengzhou, Henan, 450046, China
[2] Department of Investigation, Henan Police College, Zhengzhou, Henan, 450046, China
Corresponding authors: (e-mail: zhangyunzhen2025@126.com).

Abstract CNC machine tool is the basis of equipment manufacturing industry, with the continuous improvement of product precision requirements, the demand for high reliability and high precision machine tools is also more and more urgent, and the reliability of machining accuracy is an important indicator for evaluating the ability of machine tools to maintain machining accuracy. The study introduces the fuzzy logic algorithm, designs the adaptive fuzzy PID control controller for CNC machine tools, and realizes the error compensation according to the sensor fusion technology. The method of this paper is added to the speed loop control to improve the optimization parameters of the system, and then the method of this paper is compared with other control methods to calculate the estimated value of trajectory error in the machining process of CNC machine tools. According to the results of the study, the method of this paper has higher control accuracy and better convergence compared with other control methods, realizes the control of CNC machine tool machining accuracy in adaptive optimization model, effectively reduces the machining error of CNC machine tool, and has high practical application value.

Index Terms adaptive fuzzy PID control, CNC machine tool, machining accuracy, error compensation

I. Introduction

CNC machine tool is an indispensable and important equipment in modern manufacturing industry, and its machining accuracy directly affects product quality and process efficiency [1], [2]. However, due to the existence of various errors in the machining process, the machining accuracy of CNC machine tools often fails to reach the ideal state [3], [4]. In order to solve this problem, researchers have been exploring the machining error compensation and accuracy control technology of CNC machine tools.

Machining error refers to the difference between the actual machining results and the expected machining results, and this error can be caused by several factors, such as insufficient rigidity of the machine structure, accuracy problems of the transmission system, tool wear and so on [5]-[7]. These errors can cause the size, shape and surface quality of the machined parts to be inconsistent with the design requirements, which seriously affects the quality and performance of the products [8], [9]. In order to minimize the machining errors, researchers have proposed the error compensation technique [10]. Error compensation is performed by accurately modeling the machine tool system and compensating according to the source of error, so that the actual machining results are closer to the expected results [11], [12]. Currently, the commonly used error compensation methods are geometric error compensation and thermal error compensation [13], [14]. In addition to error compensation, accuracy control is also an important means to improve the machining accuracy of CNC machine tools [15]. Accuracy control is to monitor and adjust the machine tool system to ensure that it is always in good working condition during the machining process, so as to achieve high machining accuracy [16], [17]. Accuracy control includes both static accuracy control and dynamic accuracy control [18]. Static precision control, mainly through the structure of the machine tool and transmission system to optimize the design, in order to improve its stiffness and precision [19], [20]. Dynamic accuracy control is mainly through the control system to monitor and adjust the machine tool in real time to ensure its stability and accuracy in the machining process [21]-[23].

With the development of CNC machine tool processing technology, the use of CNC machine tools for mechanical components processing has become the main direction of machining, in the use of CNC machine tools for mechanical structural components processing, CNC machine tool error can significantly improve the machining accuracy and stability of the machine tool, is to achieve high precision and high quality parts processing provides an important technical means. Literature [24] proposed a global offset compensation method based on the measurement of the machined part, the global offset of the CNC machine tool has a model estimation, with the same remembering the calculated deviation between the measured and nominal dimensions of the part, and proposed other concepts of compensation that support the global offset method, and analyzed the advantages and disadvantages of the various methods. Literature [25] reviewed the design methods of thermal error models and introduced the ANFIS-grid model and ANFIS-fcm model, specifying that the ANFIS-fcm model has better prediction accuracy and fewer rules, revealing that the method can improve the accuracy and robustness of the thermal error compensation system. Literature [26] proposed a homogeneous transformation matrix (HTM) model to quantify the geometrical error of a machine tool in order to compensate it by software in order to provide engineering college students with a better understanding of the error compensation of CNC machine tools, and the application of the model in real situations was verified by the numerical problems solved. Literature [27] describes the research progress on the performance variation of CNC machine tools due to geometrical errors based on literature review and introduces the methodology for identifying the errors in translational and rotational axes, revealing the research challenges to improve the volumetric accuracy of machine tools. Literature [28] introduces a new type of automatic drilling and riveting system for aircraft assembly composed of two five-axis linked CNC machine tools, and based on the influence of each static/quasi-static error source on the relative positioning accuracy, it proposes an effective error compensation method, which is highly efficient, has a short computation time, and is able to meet the requirements of automatic drilling and riveting in aircraft assembly. Literature [29] pointed out that the machining accuracy of CNC machine tools depends on the accuracy of the probe, and proposed a new error compensation method to change the pre-travel of the probe in the given direction by changing the measurement speed in the given direction, and optimization of the method for use in practice to certify the significant reduction of its error. Literature [30] presents a methodology for constructing a thermal error compensation system for CNC machine tools, which is based on a part measurement system installed on the machine tool, permitting the development of their own automatic compensation system for thermal errors, applicable to any machine tool. Literature [31] discusses the classification of errors and the percentage of error sources in CNC machine tools and analyzes the kinematic errors in the operation of CNC machine tools, and proposes a key technology for computer-based error compensation and its application. Literature [32] proposed a two-dimensional thermal error compensation method to improve the compensation effect of CNC machine tools, which is able to accurately predict any thermal error on CNC machine tools, and significantly reduces the impact of thermal error differences on the compensation effect of the whole table. Literature [33] describes the wide application of gantry type computer numerical control machine tools in the manufacturing industry and proposes a movable gantry structure for its shortcomings of large space occupation, and this method can help to find out the most important errors and reduce the total error by about 90%. Literature [34] explored the knowledge of applying machine learning for accurate and cost-effective thermal error self-compensation and discussed data acquisition and processing, model and model learning, and self-learning methods, and made suggestions for future research by analyzing three efficient error compensation systems. Literature [35] proposed a new method for contour error prediction and compensation based on deep learning and reinforcement learning techniques, which can predict the tracking error and contour error with very good accuracy, and the machining quality has been significantly improved.

In order to improve the machining accuracy of CNC machine tools, an adaptive fuzzy PID control method is proposed on the basis of the traditional fuzzy control method, which realizes the real-time identification of multi-source dynamic errors through multi-sensor data fusion technology. The fuzzy PID controller is embedded into the speed loop, and the traditional fuzzy control PID method is compared to verify the effectiveness of the method in this paper. At the same time combined with the adaptive parameter optimization estimation method for CNC machine tool machining parameters fitting estimation, in the adaptive optimization model to achieve CNC machine tool machining accuracy control. Add the controller in the machine tool control system, through the designed controller, determine the machining error and implement the error allocation to complete the error compensation control.

II. CNC machine tool machining accuracy control and error compensation models

The method constructs a closed-loop compensation system of “perception-decision-execution”, which is realized through three closely connected core links, and the construction flow of the method is shown in Figure 1. Firstly, the multi-sensor data fusion technology is used to identify the dynamic error in real time, integrate the scale, encoder and temperature sensor to construct the spatial error monitoring network, and obtain the sub-micron level six-degree-of-freedom error information through Kalman filtering. Secondly, the controller is dynamically optimized based on the model-referenced fuzzy logic control algorithm, the ideal error model is constructed as a reference, and the adaptive law is designed to achieve the asymptotic tracking of the error through the Lyapunov stability theory. Finally, the cross-coupling control technology is introduced to realize the multi-axis cooperative compensation, and the coupling error of the translation axis and the rotation axis is handled by the inter-axis coupling compensation term, which ensures that the spatial accuracy of the whole machine is controlled at the submicron level.

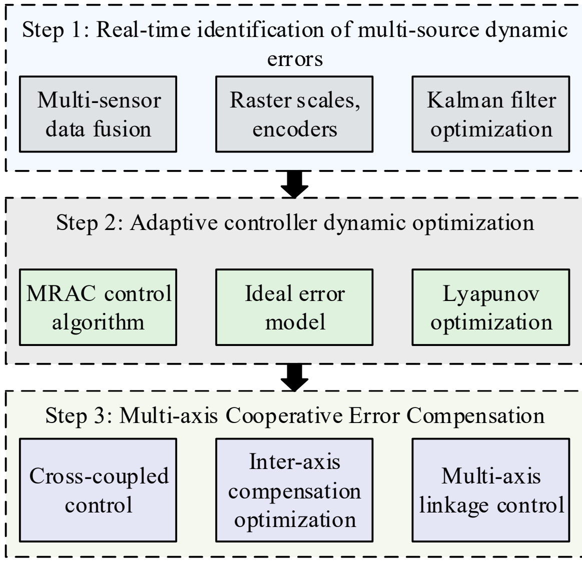


Figure 1: Method flow design

II. A. Real-time identification of multi-source dynamic errors

Multi-source dynamic error real-time identification is the first step of this compensation method, aiming at obtaining the actual error information of high-precision CNC machine tools during operation and providing inputs for subsequent adaptive control. This link adopts multi-sensor data fusion technology, comprehensively utilizing linear scale, angle encoder, temperature sensor and other multiple measurement devices to construct a real-time monitoring network of the spatial error field of the machine tool. Among them, the linear scale is arranged in each axis of the machine tool for measuring the positioning error; the angle encoder is installed in the key rotating vice for measuring the corner error; the temperature sensor is distributed in each part of the machine tool for measuring the thermal deformation error. The sampling frequency of the sensors is set to 500Hz, the spatial resolution is better than 1μm, and the temperature resolution is better than 0.1℃.

For the heterogeneous data collected by each sensor, spatio-temporal synchronization and coordinate transformation are carried out first to unify them into the reference coordinate system of the machine tool. Then, the Kalman filter algorithm is utilized to optimally fuse the multi-source data and recursively estimate the state vector of the error. Assuming that the error state vector is $x=[x_1,x_2,\cdots,x_n]^T$, where n is the number of error components, the state estimation equation is:

$$\hat{x}(t\,|\,t)=\hat{x}(t\,|\,t-1)+K(t)\left[z(t)-H\hat{x}(t\,|\,t-1)\right] \tag{1}$$

where: $z(t)$ is the vector of sensor measurements at moment t; H is the observation matrix; $\hat{x}(t\,|\,t)$ is the estimation of the state vector at moment t based on all the available information including current and past measurements; and $K(t)$ is the Kalman gain matrix.

Finally, the link can output real-time dynamic error information of six degrees of freedom of the machine tool under on-line operating conditions, including the position errors Δx, Δy, Δz of the three linear axes X, Y, and Z, and the angular errors $\Delta\alpha$, $\Delta\beta$, and $\Delta\gamma$ around the three axes, with a resolution of sub-micron, which can provide high-precision feedback signals for the adaptive controller.

II. B. Adaptive fuzzy PID control

II. B. 1) Fuzzy control algorithm

(1) Basic concepts of fuzzy control

The input of a general controller is a deviation signal e, and the controller converts the exact value of e into a fuzzy value by performing fuzzification. The fuzzy value of the deviation e is described by a fuzzy language, a subset E of the fuzzy language set of the deviation e can be introduced, and according to the synthesis rule of inference, fuzzy decision making is carried out on E and the fuzzy control rule R, and the fuzzy control output U is calculated, whose expression is shown in Eq. (2):

$$U = E \circ R \tag{2}$$

Classical mathematical sets are very exact, for example, all positive integers form a set, 4, 5, 6, etc. belong to this set, while -4, -5, -6 do not belong to this set. It will only belong or not belong, there will be no in-between. However, in actual production and life, many situations cannot be accurately described. For example, the weight of a pig can be "heavy" or "light" or "medium", but the degree of "heavy" or "light" is not the same. Pigs may be between "heavy" or "light", or they may be between "heavy" and "medium", and classical mathematical theories cannot represent these situations, and fuzzy sets can solve these problems.

Fuzzy sets solve the above problems by membership functions. The fuzzy set is shown in equation (3):

$$A = \left\{ (x, u_A(x)) \mid x \in X \right\} \tag{3}$$

X is the given domain, $A = \{x\}$ is a fuzzy set in the domain X, with u_A representing the affiliation function, i.e., the characteristics of this set are characterized by the affiliation function u_A: $X \to [0,1]$.

The degree of affiliation function can describe the degree of an element belonging to a certain set, which takes the value between 0 and 1, does not belong to is described by 0, completely belongs to is described by 1, in the middle of the nature of the belonging to the components of the more, the greater the value of the belonging to the component, belonging to the components of the fewer, the smaller the value of the value of the smaller.

(2) Composition of fuzzy control system

The composition of the fuzzy control system is shown in Fig. 2.

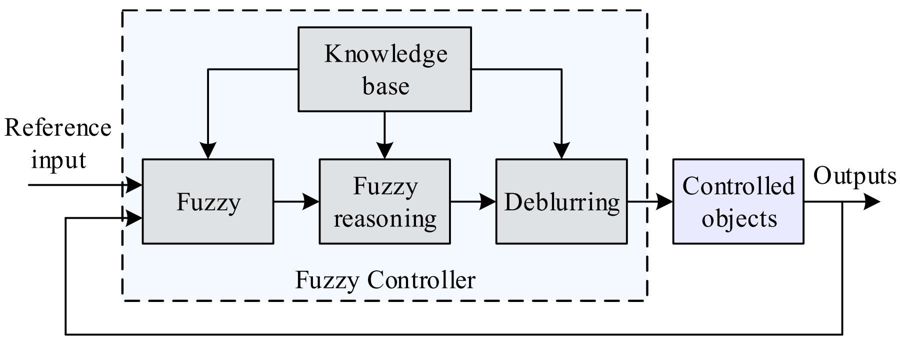


Figure 2: The structure of the fuzzy control system

From the above figure, it can be seen that the fuzzy controller contains four major parts: fuzzification, knowledge base, fuzzy reasoning, and defuzzification. Fuzzy control is realized through fuzzy sets and fuzzy reasoning. The first input to the fuzzy controller is a precise value, but fuzzy reasoning is modeled after the way people describe problems, so the precise value is first replaced by a fuzzy quantity, which is described by an affiliation function. The above operation is called fuzzification. After fuzzification, fuzzy inference is done according to the fuzzy inference rules formulated at the beginning, and the result of inference is also a fuzzy quantity, which is also described by the degree of affiliation function, and this value can not be sent to the control object immediately, but also through the transformation, and finally get a precise value of the control quantity, and send it to the control object. The above process is defuzzification.

Fuzzy inference is a mathematical representation of the fuzzy experience in the whole knowledge base to get the output quantity of the desired control, and its mathematical expression is as follows, assuming that A and B are fuzzy subsets of the input and output quantities, and their affiliation functions are u_A and u_B, respectively, and the inference rule will be established between A and B, and such a rule is a kind of mapping relationship between A and B, and the fuzzy inference is noted as $A \to B$, the affiliation function representation is notated as $u_{A \to B}$, and its mathematical expression formula is as follows:

$$u_{A \to B}(x, y) \Box [u_A(x) \wedge u_B(y)] \vee [1 - u_A(x)] \tag{4}$$

A more intuitive expression has the following formula below:

$$u_{A \to B}(x, y) \Box \left[A(x) \wedge B(y) \right] \vee \left[1 - u_A(x) \right] \tag{5}$$

where $A(x)$ and $B(x)$ are the expressions of the affiliation functions of the two sets.

According to the formal formulation of logical triad, the major premise is the control experience of the fuzzy rule $A \rightarrow B$ in the knowledge base, and the conclusion B^* is introduced by applying the synthesis law in the fuzzy relationship through the minor premise A^*. The reasoning process is as follows:

Major premise: " $A \rightarrow B$ "

Minor premise: " A^* "

Conclusion: " $B^* = A^* \circ (A \rightarrow B)$ "

II. B. 2) PID control algorithm

In the voltage-current double closed-loop control system under the average current control mode, whether it is the voltage loop or the current loop, its internal regulator must be designed separately, but the current inner loop as a feed-forward link of the voltage outer loop, the two must be interconnected. Therefore, for the switching power supply, whether analog or digital control, the design of the double closed-loop system must begin with the design of the controller.

In the system of analog continuous signal control, the control law of the PID controller can be expressed by equation (6), where K_P is the proportionality coefficient, T_I is the integral time coefficient, and T_D is the differential time coefficient. Then:

$$u(t) = K_P \left[e(t) + \frac{1}{T_I}\int_0^t e(t)dt + T_D \frac{de(t)}{dt} \right] \tag{6}$$

In the digital discrete signal control system, PID control algorithm is usually realized by the master chip, the specific principle of continuous signal sampling at a certain sampling frequency after the discrete digital signals, these discrete signals and the difference between the given value of the PID controller adjustment, and then converted to a continuous analog signal for the system. The discrete form of digital PID control law can be expressed as follows:

$$u(k) = K_P \left\{ e(k) + \frac{T}{T_I}\sum_{j=0}^{k} e(j) + \frac{T_D}{T}\left[e(k) - e(k-1)\right] \right\} \tag{7}$$

The simplification yields:

$$u(k) = K_P e(k) + K_I \sum_{j=0}^{k} e(j) + K_D [e(k) - e(k-1)] \tag{8}$$

where T is the sampling period, k (k takes 1, 2, 3, ...) is the number of samples, $e(k)$, $e(k-1)$ are the values of the k th and $k-1$ th deviation, respectively, K_I is the integration coefficient, $K_I = K_P T / T_I$, K_D is the differentiation coefficient, $K_D = K_P T_D / T$.

In the selection of the sampling period, to follow two major principles, one is its value should be as small as possible, the smaller the sampling period of the information collected is more accurate, continuous signals can be viewed as an infinitely small sampling period of discrete signals; the second is that it must follow the Shannon sampling theorem, that is, the sampling frequency must be greater than two times the switching frequency. Based on the two principles can obtain better accuracy and improve the dynamic performance of the power supply.

Equation (8), also known as position-based PID control algorithm, there is an integral role in the formula, so it will be generated each time $e(k)$ cumulative, the amount of computation is relatively large, and is prone to integral saturation phenomenon. For this reason, it is necessary to carry out certain amendments to the position-type PID control form, the improved incremental PID control algorithm is easy to program, faster processing speed, the control law is:

$$\begin{aligned} \Delta u(k) = & K_P \left[e(k) - e(k-1)\right] + K_I e(k) \\ & + K_D \left[e(k) + 2e(k-1) + e(k-2)\right] \end{aligned} \tag{9}$$

where k (k takes 1, 2, 3, ...) is the number of samples, $e(k)$, $e(k-1)$, $e(k-2)$ are the k th, $k-1$ th, and $k-2$ th deviation values, respectively, K_P is the proportionality coefficient, K_I is the integration coefficient, $K_I = K_P T / T_I$, and K_D is the differential coefficient, $K_D = K_P T_D / T$.

II. B. 3) Fuzzy Adaptive PID Control Principles

Traditional PID control algorithms are widely used by electrical control systems because of the advantages of practical simplicity and ease of calculation, but for the complex and variable phase-shifted full-bridge converter, the traditional PID control algorithms are difficult to achieve the expected control effect due to the fixed parameters [36].

The K_P, K_I and K_D parameters in the fuzzy adaptive PID control system are expressed as:

$$\begin{cases} K_P = K_P' + \Delta K_P \\ K_I = K_I' + \Delta K_I \\ K_D = K_D' + \Delta K_D \end{cases} \tag{10}$$

where K_P', K_I', K_D' are the initial set values of the PID parameters, ΔK_P, ΔK_I, and ΔK_D the outputs of the fuzzy controllers, K_P, K_I, and K_D are the fuzzified PID parameter values.

II. B. 4) Design of fuzzy adaptive PID controller

According to the specific design rules and methods of fuzzy controllers, the fuzzy adaptive PID controller is designed in the following steps:

First, the inputs are fuzzified. Fuzzy control can only recognize fuzzy quantities, so the sampling data need to be converted into fuzzy rules "recognizable" fuzzy quantities. Let the error value e between the given value and the actual output value of the system, the rate of change of the error $ec\left(ec = de/dt\right)$, and the fuzzy subsets of the output variables ΔK_P, ΔK_I, ΔK_D be divided into {negative large, negative medium, negative small, zero, positive small, positive medium, positive large}, which are abbreviated as $\{NB, NM, NS, Z, PS, PM, PB\}$; the quantization level of each fuzzy variable is 7, i.e., the thesis domain is $\{-3, -2, -1, 0, 1, 2, 3\}$.

II. C. Multi-axis cooperative error compensation

Let the machine belong to the type of five-axis linkage, where the translational axes are X, Y and Z, and the rotational axes are A and C. Define $p = [x, y, z]^T$ as the position vector of the tool tip point in the workpiece coordinate system, and $\varepsilon = [\varepsilon_x, \varepsilon_y, \varepsilon_z]^T$ as the corresponding position error. Similarly, $\theta = [a, c]^T$ is the angle vector of the axis of rotation, and $\delta = [\delta_a, \delta_c]^T$ is the corresponding angle error. From the kinematics theory, it can be seen that the tool tip point position error $\boldsymbol{\varepsilon}$ is not only related to the errors of X, Y and Z axes, but also affected by the errors of A and C axes. Therefore, the multi-axis cooperative compensation control law can be expressed as:

$$u_p = K_p \varepsilon + K_{pa} \delta \tag{11}$$

$$u_\theta = K_a \delta + K_{ap} \varepsilon \tag{12}$$

where $u_p = [u_x, u_y, u_z]^T$ and $u_\theta = [u_a, u_c]^T$ are the compensated control inputs for the translational and rotational axes respectively; K_p and K_a are the corresponding error gain matrices; K_{pa} and K_{ap} are the coupling compensation gain matrices. The values of the elements of the gain matrix need to take into account the structural parameters of the machine tool and the kinematic model to ensure proper compensation amplitude and phase. Generally speaking, when the error magnitude is within 5 μm, the order of magnitude of the coupling compensation gain is controlled at 0.01~0.10.

The execution process of the multi-axis cooperative compensation control law: first, obtain the motion commands and error feedback of each axis in real time; second, calculate the compensation control inputs of the translational and rotational axes; and finally, superimpose the compensation values to the original motion commands to drive the motor. Through closed-loop iteration, the coupling error in the process of multi-axis linkage can be suppressed to ensure the spatial trajectory accuracy of the tool tip point relative to the workpiece. The compensation effect of this link is closely related to the number of axes, the type of motion, the complexity of the trajectory and other factors, and in typical five-axis linkage machining, the dynamic error of the whole machine can be controlled in the sub-micron level.

III. Operational validation of the machine

III. A. Signal Input Servo Control Simulation

III. A. 1) Servo Simulation of Step Signal Inputs

A step signal is given to the servo control system and the response of the two control methods is observed through the SCOPE window. The result graph is shown in Fig. 3. As can be seen from the figure, the black curve is the given step signal, the purple curve is the response curve of the traditional PID control, and the blue curve is the response curve of the adaptive fuzzy PID control added in this paper. As can be seen from the figure, after adding the adaptive fuzzy PID controller in the velocity loop, the response time of the feed servo control system becomes smaller and faster, and the overshooting phenomenon is avoided by the regulation of this controller in the system response process. During the response process, the value of K_p, K_i changes continuously with time according to the fuzzy control rules.

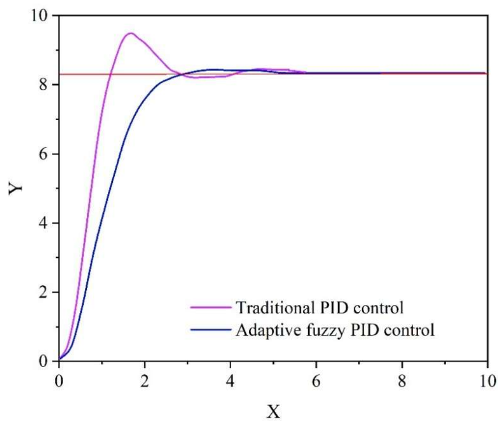


Figure 3: Comparison of step input simulation

III. A. 2) Servo Simulation of Sinusoidal Tracking Signal Inputs

A sinusoidal signal is given to the servo control system, and the real-time tracking performance of the two control methods can be observed through the Scope window, and the simulation results are plotted in Fig. 4. The simulation time is 10 s. The blue curve in the figure is the sinusoidal tracking result of the servo system with adaptive fuzzy PID control added to the velocity loop, the purple curve is the traditional PID control, and the green curve is the given sinusoidal signal. As can be seen from the figure, the addition of adaptive fuzzy PID control compared to the traditional PID control tracking performance is better, through the simulation test also concluded that the chapter in the feed system control to join the adaptive fuzzy controller is still very necessary, can greatly reduce the workload of the field debugging personnel, but also to make the performance of the feed system to get a better improvement.

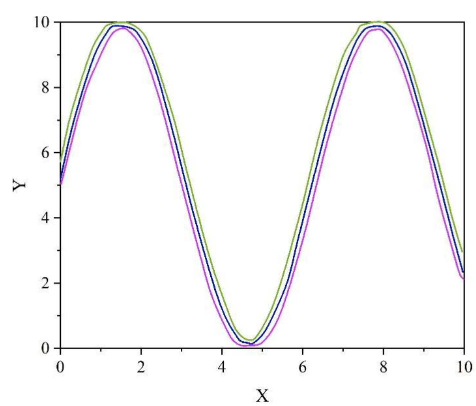


Figure 4: The sine trace input simulation is compared

III. B. CNC machine tool machining accuracy control results and analysis

In order to verify the performance of this paper's method in realizing the application of CNC machine tool processing control, simulation test, the experiment was established on the basis of CAD/CAM software, the simulation software for CNC machine tool processing accuracy control is Matlab, the cutting speed of CNC machine tool processing is

143 m/min, the parts of the multi-axis CNC machining of the feed amount of 0.34 mm/r, the toolbar length of 120 mm. Data acquisition is carried out through the built-in sensors, and the data acquisition card AD chip sends the acquired data to DynoWare2825A for processing. CNC machine tool machining accuracy control parameters are distributed as shown in Table 1.

Table 1: Control parameter of machining precision of nc machine tool

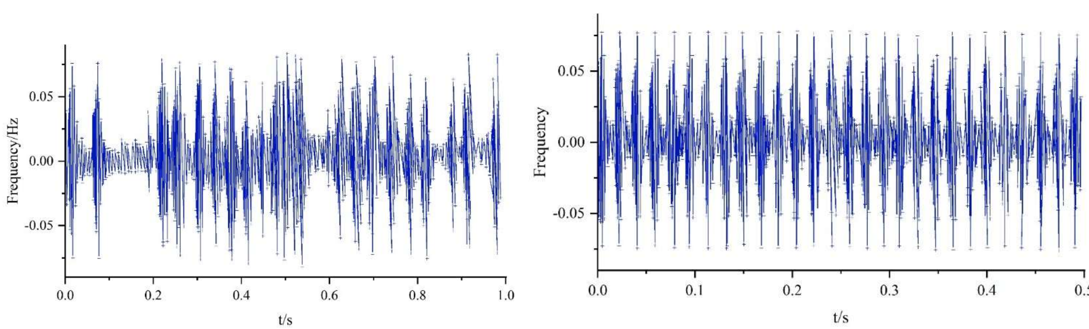
Parameter	Elastic phase	Plastic phase
Load conversion coefficient	0.71	0.78

According to set the optimized CNC machine tool machining accuracy adjustment parameters, set the single point at the machining line width, parameter optimization adjustment, the optimization results are shown in Table 2.

Table 2: Hydraulic CNC machine tool machining parameter design results

Parameter	Numerical value
P_c	36.00
T_c	136.00
D_i	34.00
$[\sigma]^t$	57.60
φ	4.64
δ_p	9.78
δ	36.94

Validation on the CNC machine tool machining accuracy control platform, while combining the adaptive parameter optimization estimation method for CNC machine tool machining parameter fitting, for the fitting demand, different degrees of control, the fitting results of the implementation of the frequency analysis, the fitting results are shown in Figure 5, (a) and (b) respectively, before and after the machine tool machining parameter fitting parameters. As can be seen from the figure, in the CNC machine tool machining parameters before the fitting, the results are unevenly distributed, presenting a scattered distribution of frequency fitting results. And after the CNC machining platform and machining tool loading experiments, machining parameters after fitting, parameter stability is higher, effectively controlling the machine tool machining accuracy.

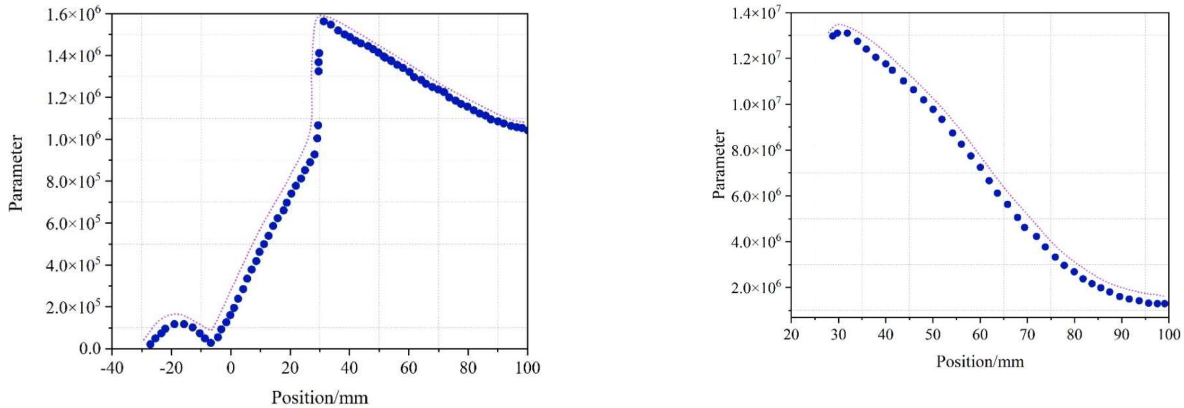


(a) The machining parameters of machine tools are fitting before

(b) The machining parameters of machine tools are fitting

Figure 5: The fitting result of the machining parameter of nc machine tool

On the basis of determining the tool attitude and the most available tool parameters, the CNC machine tool machining accuracy control is realized in the adaptive optimization model, and the parameter-seeking trajectory results of CNC machine tool machining are obtained as shown in Fig. 6, with (a) and (b) being the stress parameter and the stiffness parameter, respectively, the blue color in the figure represents the optimization results, and the purple dotted line represents the optimization trajectory route. Analyzing the figure, we know that the method of this paper can effectively realize the parameter optimization and machining accuracy control of CNC machine tool machining.



(a) Stress parameter (b) Stiffness parameter

Figure 6: The parameters of nc machine tool are optimized

The results of the machining accuracy comparison are shown in Figure 7. As can be seen from the figure, the accuracy of CNC machine tool machining using the method of this paper is high, reducing the machining error and improving the quality and quality of machining.

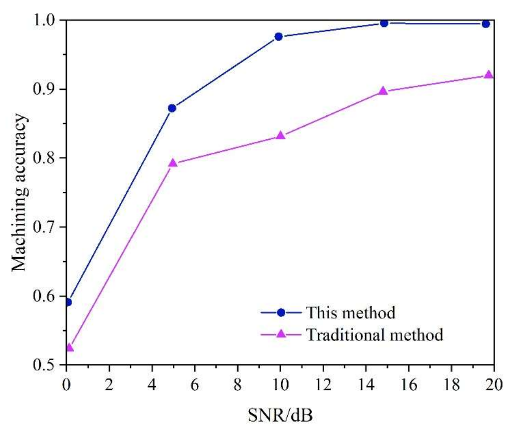
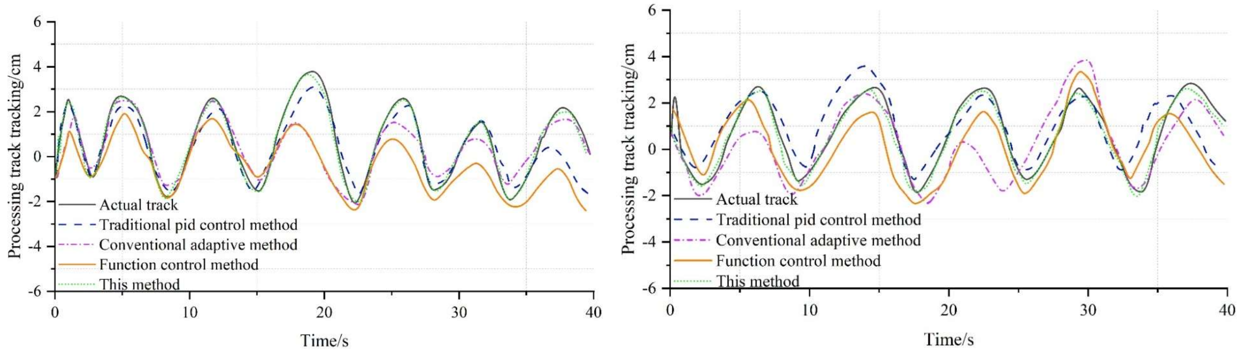


Figure 7: Performance comparison of machining accuracy

III. C. Analysis of the effect of machining trajectory tracking

When using the fuzzy adaptive PID control method, traditional PID control method, conventional adaptive method and function control method to carry out machine tool machining error control, the machine tool machining trajectory tracking process is implemented to determine the machining trajectory tracking effect, and the test results are shown in Figure 8. To carry out machine tool machining error control, if the machining trajectory tracking results and the actual machining trajectory of the error between the larger, will directly affect the subsequent error control effect. According to the experimental results, it can be seen that the proposed method detects that the machine tool machining trajectory is consistent with the actual machining trajectory, while there are deviations between the machine tool machining trajectory detected by the other three literature methods and the actual machining trajectory. Thus, it can be seen that the proposed method is effective in carrying out machine tool machining error control.



(a) The x axis processing trajectory of machine tool is tracked

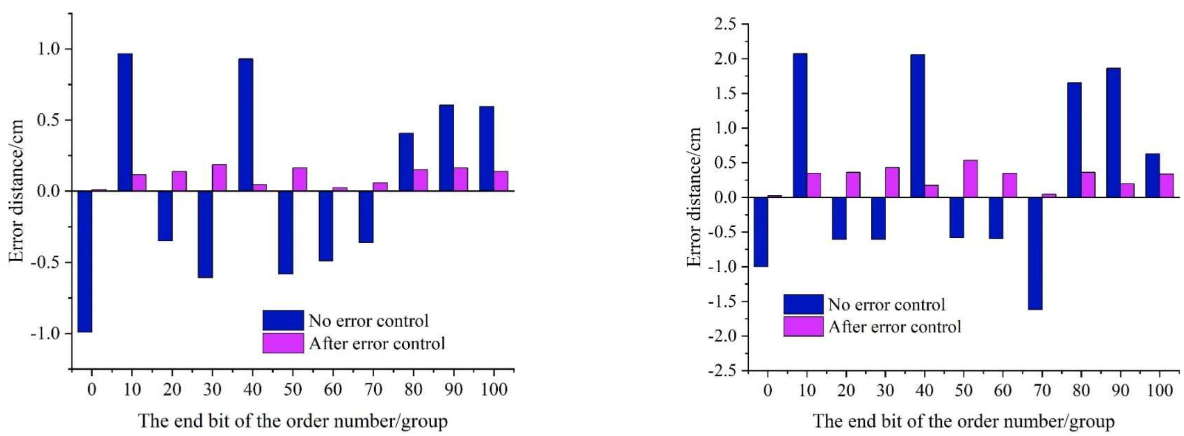
(b) The y axis processing trajectory of machine tool is tracked

Figure 8: The test results of the machine shaft processing trace of different methods

III. D. Analysis of the effect of error control

III. D. 1) X-axis and Y-axis error control analysis results

Experiment from the machine tool test object machining trajectory randomly selected 100 groups of end position, respectively, from the CNC machine tool X-axis direction and Y-axis direction to analyze the proposed method of error control, the results are shown in Figure 9, (a) and (b) for the X-axis, Y-axis error control analysis results, respectively. After the X-axis error control treatment, the error range is [-0.21mm, 0.22mm], while the error range is [-1.1mm, 1.2mm] without the error control treatment, and the proposed method can effectively reduce the end position error. After the Y-axis error control processing, the error range is [-0.12 mm, 0.43 mm], while the error range without error control processing is [-1.9 mm, 2.1 mm], and the proposed method has less fluctuation in the machining trajectory error control.



(a) X-axis error control analysis

(b) Y-axis error control analysis

Figure 9: X, Y-axis error control analysis results

III. D. 2) Machining error testing

Based on the above experimental results, four error control methods are used to carry out error adaptive control, and the actual machining error of different methods is tested, and the test results are shown in Figure 10. Analyzing the figure, it can be seen that when carrying out CNC machine tool machining error control, the machining trajectory error tested by the proposed method is consistent with the actual machining error. This is mainly because the proposed method in the machine tool machining trajectory contour error control, based on the kinematic equations of machine tool machining, a detailed analysis of the relevant impact of the error indicators, so the method in the processing error control, the control effect is good.

III. D. 3) Actual machining error control effect test

When the proposed method, the traditional PID control method, the conventional adaptive method and the function control method are used to carry out machine tool machining error control, the actual error control effect of the different methods is tested, and the test results are shown in Figure 11. Analysis of the figure can be seen, to carry out machine tool machining error control, the traditional PID control method due to the implementation of the geometric elements of the machining workpiece inspection process there are problems, so the method in the machining error control, the control effect is lower than that of the proposed method test results; conventional adaptive method due to the design of the error controller, the controller's actual control process is more complex, so the method of machine tool machining error control control when control The effect is slightly worse; the function control method is not satisfactory in machining error control due to the large error in recognizing the corresponding geometric errors of different part features; and the proposed method has good control effect and high performance in machining error control due to the accurate error allocation based on the estimated error estimate when designing the machining controller.

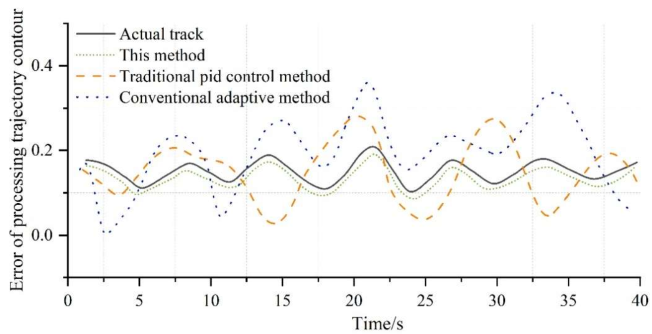


Figure 10: Processing error test results of different methods

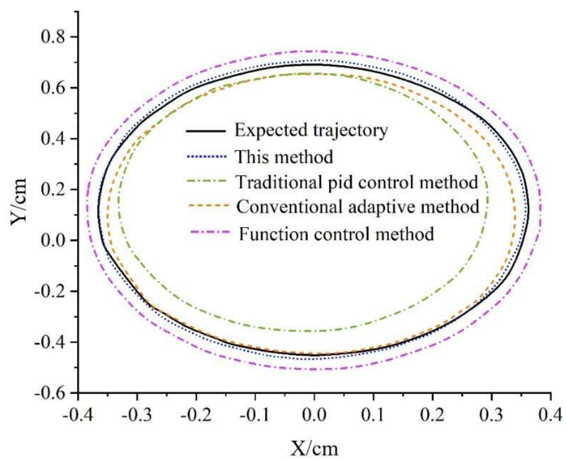


Figure 11: The results of the processing error control effect of different methods

IV. Conclusion

The study takes CNC machine tool machining accuracy and error compensation as the main research object, combined with adaptive fuzzy control PID method for fitting control. The servo control system parameters are first optimized to improve the machine accuracy, followed by simulation experiments. The experimental results show that the method of this paper for CNC machine tool machining accuracy control has high accuracy and good performance. Secondly, the error range is [-0.21mm, 0.22mm] after the X-axis error control treatment under the proposed method, and [-0.12mm, 0.43mm] after the Y-axis error control treatment, which effectively reduces the end pose error, and the processing trajectory error control fluctuation is small, and the accurate error distribution is realized.

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