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Research on Thermal Compensation of CNC Machine Tool Based on LabVIEW

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Abstract

Generally speaking, the thermal error of the machine tool occupies about 65% of the error of the machine tool. It is important to improve the accuracy of the machine tool by reducing the thermal error of the machine tool. An effective modeling method is to use artificial neural network. But at present the application of neural network models are mostly stays in the MATLAB simulation modeling, it is difficult to use in engineering practice. The newly developed BP neural network thermal error compensation model on virtual instrument obtained similar simulation result with dong by MATALAP. LabVIEW provides many interfaces, it is greatly convenient for communication and data processing. IPC equipped with LabVIEW communicates with NC machine tool through Ethernet to get real-time temperature data and displacements values related with in-feed axes and the thermal compensation error values are calculated by the neural model and transmitted to the machine tool numerical control system to realize the real-time thermal error compensation control. This method is applicable to thermal deformation error compensation modeling of different NC machine tools. The simulation results showed that the thermal error of CNC machine tool can be reduced from 136μm to 5μm below.

***Keywords**: NC machine tool; Thermal error modeling; BP neural network; LabVIEW; Network communication*

1. Introduction

Numerous studies show that the error caused by uneven heat conduction of CNC machine tools, *etc.* become the main error of precision processing machinery, typically in the vicinity of 40% ~ 70% of the total machining error [1]. Now the thermal error modeling with the artificial neural network has been an important way to realize the errors compensation for precision machining. Literature[3] presented a embedded compensation system using qt programming under Linux, but the system needs additional hardware platform and requires developer to have embedded development experiences. The embedded development period is long and ordinary developers are not familiar with the Linux operating system. Obviously the programming work is more convenient under Windows operating system.

In addition in the development of computer technology, there are a variety of programming software, *e.g.* C+ +, Java, *etc.*. However, engineering personnel have to spend a lot of time to learn and use these software, which would lead to long development cycle. LabVIEW, as a kind of virtual instrument software, can bring great convenience to the engineers, and has characteristic of shorter development cycle, better cross-platform and transplant performance.

LabVIEW is a development platform of virtual instrument, developed by the NI company for engineers, with a lot of software and hardware interfaces. Using hardware

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interface of LabVIEW, engineers can access through the module interface to avoid cumbersome interface programming, and to complex hardware interface the dll file of the operating system can invoked for a direct access [2]. Using LabVIEW software interface engineers can easily put the measurement data into the file to avoid tedious interface programming. The paper developed a universal BP neural network training program in LabVIEW for the thermal errors compensation modeling for NC machine.

2. Thermal Compensation System of CNC Machine Tool

The system adopted PC with LabVIEW as the thermal error compensation platform, the compensation principle structure as shown in Figure1. The computer get three actual temperature data (*i.e.*, motor shell, bearing seat, cross slide right temperature and environmental temperature) and the current axis displacement value from CNC system through the computer network interface and all data as the neural network inputs are carried out calculations in LabVIEW to produce compensation error values, they are transmitted back to the machine CNC system in time through the network interface. Finally the displacement compensation control would performed by the CNC system according to the error value in real time so as to reduce the effect of the thermal errors and make machining accuracy to be improved greatly.

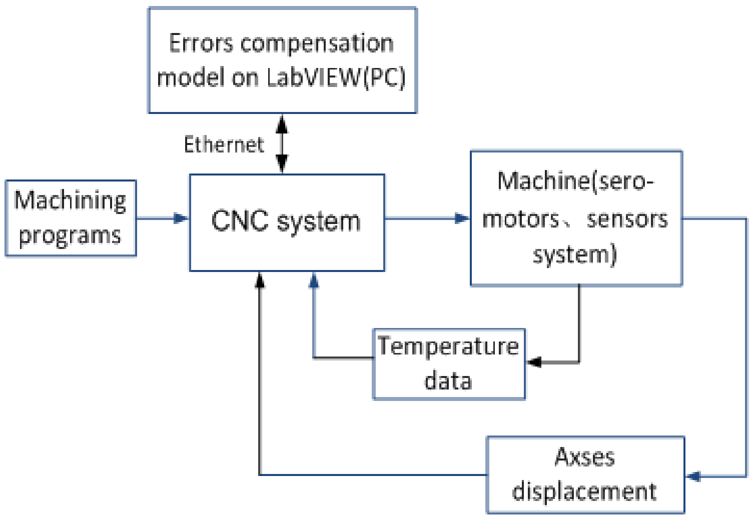


Figure 1. Compensation Principle Block Diagram

The nonlinear thermal error model of NC machine tool obtained in the paper as shown in, in which Three ones of the four inputs are temperatures difference values with respect to the ambient temperature for each axis, the another is a corresponding axis displacement values for machine tool, and the BP net output is a corresponding axis thermal error value.

3. Data Acquisition for Thermal Error Compensation Modeling

The establishment of the neural network model requires a large number of training sample data and the test ones. For this purpose, a type KVC850MA five-axis machining center was chosen as a research object and made experiments on it to collect the related data, as shown in Figure 2. For example of X-axis, the temperature values of the axis motor shell, upper bearing seat and cross slide on the right and the environmental temperature could be read and recorded on the CNC screen and made a precision acquisition of the axis displacement error data for the moment under corresponding temperatures with a laser interferometer. The X-axis experimental steps as followed: (1)

after machine tool start-up, preheated for 30 minutes and then confirmed machine zero point., and let the machine move to the X-zero point, and then run in the test program done in advance. First, the machine run to X-zero in 10 m/min running speed, and recorded data at a time in 54 mm intervals , each test to be completed in a full travel back and forth data records. Heating time interval for 20 minutes. Programmed set points error data acquisition on the machine tools was made with the laser interferometer system, each setting point pause 5 seconds, effective stroke 810 mm, before and after the end of each with 5 mm allowance, a total stroke of 820 mm, the X-axis temperature parameters were recorded on each measurement point, and the data were collected during the testing points. After the machine was running up 4 hours, cooling experiments started, for 2h cooling experiment. one machine stopped 20 min each running test program, full schedule data should be recorded on setting points, a total of 16 sets of data collected.

Figure 2. Data Acquisition Spot of KVC850MA Machining Center

4. Realization of the Thermal Error Modeling on Labview

The PC is used as a compensation platform in the system. In LabVIEW there are many ways to implement neural network, including through LabVIEW CIN nodes, by calling MATLAB program with MATLAB script node or by the G language itself. That CIN nodes are created through C+ + compiler is required to be strict in data format, to generate some files to be invoked is rather complex, and its portability is not good and its operation not easy. The second method to use the MATLAB script node to call MATLAB need computer with MATLAB software, there are two problems in practice , first, a bit higher requirements for computer configuration; secondly, for the average users are generally not familiar with MATLAB. In conclusion, using LabVIEW G language itself would be more appropriate for developers, it has characteristic of convenient operation, strong portability and do not rely on the platform. After the development completed, the operating system platforms supported by the LabVIEW can be used. If making programs in LabVIEW to be modular programs, it is better for the development of large program.

4.1. The Realization of the Neuron

The basic mathematical expression for neurons:

$$s = \sum_{i=1}^{n} w_i x_i + b \tag{1}$$

$$y = f(s) = 1/(1+\exp(-s)) \tag{2}$$

The realization of the basic neurons in LabVIEW as shown in Figure3.

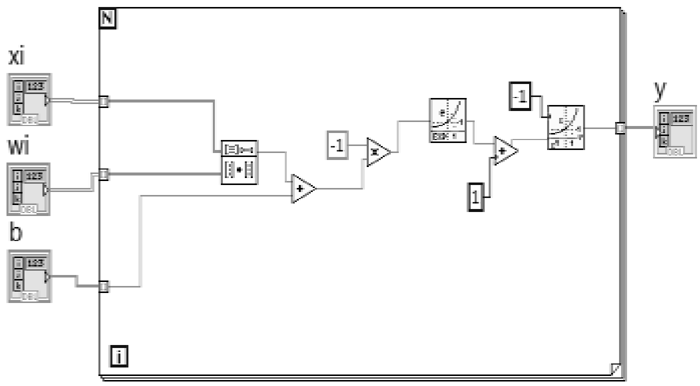


Figure 3. Realization of the Neuron

Among them, xi as sample, *wi* for weights, b as the threshold value, y is the output, the exponential function using LabVIEW function inside.

4.2. Realization of the BP Neural Network

In term of literature [4], the BP neural network is realized by seven steps:

(1) BP network initialization. Including the input threshold values, weights values and neural network layers numbers.

(2) the output of the BP hidden layer. On the basis of input samples and the hidden layer neural network weights and threshold the output of the hidden layer can be calculated. The relationship is as follows:

$$H_j = f(\sum_{i=1}^{n} w_{ij} x_i - a_j) \qquad j = 1,2,3,...,n \tag{3}$$

$$f(x) = 1/(1+e^{-x}) \tag{4}$$

Among them xi, as the input samples w_{ij}, a_j, H_j, for hidden layer weights and threshold value and the hidden layer outputs.

(3) BP output calculation. In terms of the hidden layer output H, connection weights and threshold b, the calculation of the neural network output O. The relationship is as follows:

$$O_k = \sum_{j=1}^{l} H_j w_{jk} - b_k \qquad k = 1,2,3,...,m \tag{5}$$

(4) BP calculation error. According to the network to predict the output O and expectations output Y, computing network prediction error e. The relationship is as follows:

$$e_k = Y_k - O_k \qquad k = 1,2,...,m \tag{6}$$

(5) the update weights of BP forecast error threshold based on the network, calculate the w_{jk}, w_{ij} new weight。Calculation process is as follows:

$$w_{ij} = w_{ij} + \eta H_j (1 - H_j) x(i) \sum_{k=1}^{m} w_{jk} e_k \qquad i = 1,2,3,...,n; j = 1,2,3,...,l \tag{7}$$

$$w_{jk} = w_{jk} + \eta H_j e_k \qquad j = 1,2,3,...,l; k = 1,2,3,...,m \tag{8}$$

Among η as for learning rate.

(6) the BP threshold update. According to e calculate the new threshold a, b. The calculation is as follows:

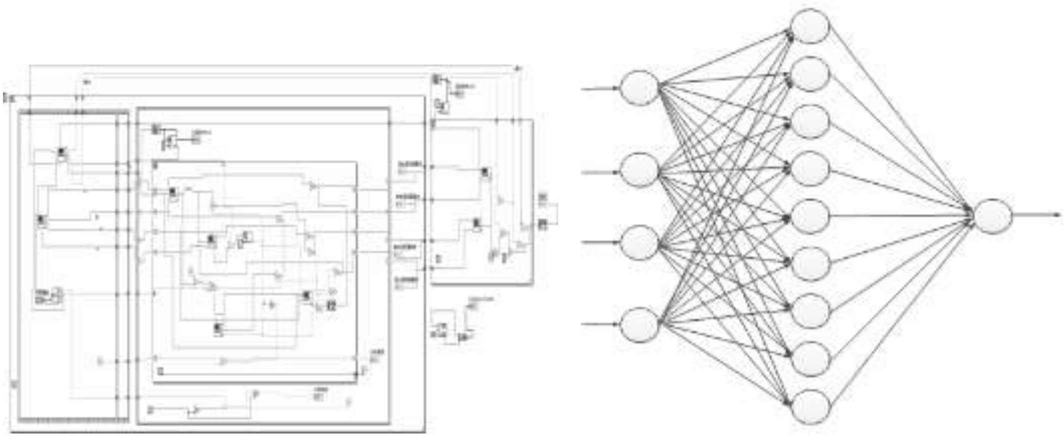
$$a_j = a_j + \eta H_j (1 - H_j) \sum_{k=1}^{m} w_{jk} e_k \qquad j = 1,2,3,...,l \tag{9}$$

$$b_k = b_k + e_k \qquad k = 1,2,3,...,m \tag{10}$$

(7) Determine whether meet the conditions, if not satisfied, return step 2.

4.3. The Training of the BP Neural Network Based on Labview

The BP neural network adopts the 4-9-1 modeling structure for CNC machine tool thermal compensation based on the LabVIEW program as shown in Figure4 (a),(b). The training interface developed in PC is shown in Figure5.



(a) (b)

Figure 4. The 4-9-1 BP Neural Network Structure for the Compensation

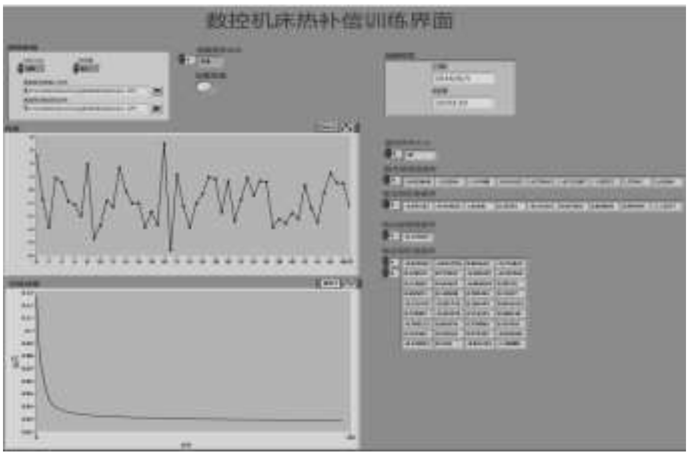


Figure 5. Training Interface for BP Neural

In the drawing, set training number is 100, learning rate 0.2, and X-axis experimental data were used for BP training. The training error seen become smaller and smaller, and finally to a fixed value in the Figure 6, also can be seen residuals within the following 5μm from the in the Figure 7. And in the same time the weight training thresholds will be stored in the excel file for the use of thermal error of machine tool model.

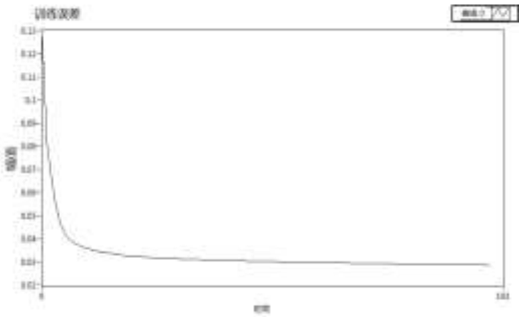


Figure 6. Training Error

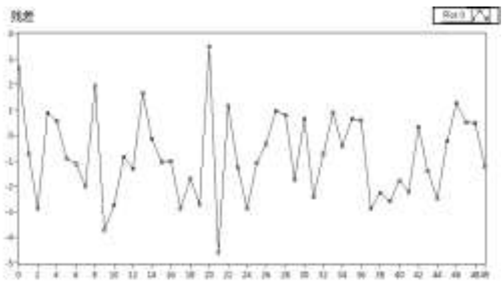


Figure 7. Residual

4.4. The Realization of the Thermal Error Compensation on LABVIEW

CNC machine tool thermal compensation system based on LABVIEW uses TCP/IP protocol the as communication protocol with CNC machine tool, KVC850MA / 2. This paper uses the network interface of LabVIEW programming, machine tool as Sever, the IP address is 192.168.1.30, PC Client, IP address is 192.168.1.30, port 8099, subroutines shown in Figure 8, and human-computer interface as Figure 9. The first, it receives the integer part of floating-point, then receives floating-point decimal part, and finally, the sum of the two gets floating point number required.

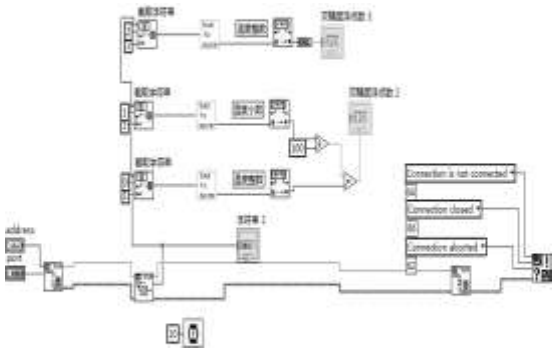


Figure 8. Network Programming

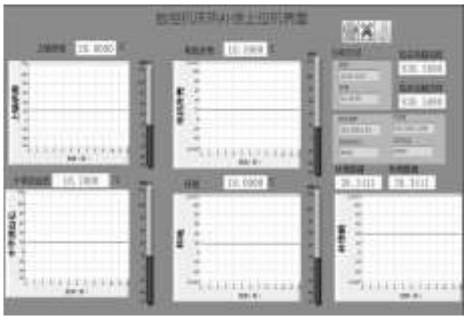


Figure 9. Compensation Interface

5. Conclusion

CNC machine tool thermal compensation system based on LABVIEW is realized the same compensation effect as one with MATLAB , and it is more convenient to use, can be used as a kind of doesn't depend on the development environment of independent running program, low requirement to the computer configuration, the results showed that the scheme is feasible.

This system is suitable for general machine tool thermal error compensation, *i.e.*, not only applied to the machine KVC850MA / 2 for the thermal deformation modeling, but also for different NC machine tools the doing. The way of network communication is used in this system, there are of convenient installation, fast communication and better real-time performance. The neural network with the virtual instrument used to compensate the machine, there are several advantages: high efficiency, stability, short development cycle and broad prospect of application. But the compensation system has some shortcomings, neural network nodes cannot be modified any time, the definite pattern (4-9-1 BP structure) is not completely suitable for all sort of NC machine tools, the better or best compensation model is depend on specific machine tools, but the way discussed above is common.

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