Early Warning of Position Accuracy for Pin Hole using Rules and Model based on LSSVM and PSO during Tractor Manufacturing Process

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Abstract. The factors affecting the processing quality of pin hole on the end face of tractor gearbox were analyzed. The main influencing factors on position accuracy of hole group include ambient temperature, the number of workpieces processed by drilling cutter and so on during precision manufacturing. The early warning rules of processing quality during tractor manufacturing process were proposed based on single-factor analysis and double-factors analysis. Then an early warning model for position accuracy of pin hole was established based on LSSVM while PSO was used to optimize the unknown parameters. The experimental results show that the RMSE of the model is 0.0058 and the RE is 0.075%, which verifies the validity of the established processing quality early warning model.

1. Introduction

Tractor is typical agricultural machinery and the power of agricultural production. The improvement of tractor’s manufacturing quality will promote the development of agriculture. The driveline is a key component of tractor. The front and rear gearbox is connected by positioning the pin holes on the joint surface to form the transmission system. The position accuracy of pin holes on the end face of gearboxes contributes a lot to the quality of the connection, which further affects the overall performance of the tractor. Effectively controlling the position accuracy of pin hole is the key to ensure the manufacturing quality of the drive train of tractor.

Enterprises of tractor manufacturing usually adopt strategy of first article inspection or sampling inspection to control the quality of workpieces, in which way they can’t obtain the quality data of every piece and have to use a post-error prevention mechanism. As to the position accuracy of pin hole on the end face of tractor gearbox, only the first piece in a batch is tested by the three-coordinate measuring instrument located in laboratory. The measurement of the hole diameter is usually made by plug gauges or callipers on site in manufacturing enterprises. The online measurement technology and early warning method of position accuracy remain to be explored to meet the requirements of quality control.

Precision manufacturing is the key to improve the level of the manufacturing industry. For precision manufacturing of the pin hole on end face of tractor gearbox, the position accuracy is highly demanded whereas affected by many factors. Method of early warning is needed especially to avoid damage because it is difficult to acquire intermediate quality data in a closed manufacturing environment using CNC (computer numerical control) machine tool. Research on the early warning rules and models for precision manufacturing of the hole group will certainly help to improve manufacturing quality and reduce manufacturing costs.
Early warning means giving notices or warnings and taking measures before a disaster or danger occurs, according to previous experience, knowledge or model, to prevent hazards and reduce unnecessary losses. The quality early warning modelling refers to the construction of quality control model according to relevant theory and the law of the occurrence of the hazard. The passive quality control is thus changed to the active quality control [1].

Steps used for constructing quality early warning model include analysis of influencing factors on processing quality and then algorithms such as support vector machine (SVM) [2], neural network, grey prediction model [3] chosen for modelling. Some commonly used methods for optimizing the early warning model are particle swarm optimization algorithm (PSO) [4], differential optimization algorithm [5], and colony algorithm [6], etc.

Subtractive clustering fuzzy recognition and fuzzy reasoning algorithm were used to construct the quality prediction model of deep hole surface roughness considering the speed of cutting and feeding as the influencing factors [7]. Machining parameters such as tool radial forward angle, tool nose radius, cutting speed and feed rate were drawn as the influencing factors of surface machining quality and analyzed to construct model using genetic algorithm [8]. The prediction model of turning quality during the production of automobiles was established based on neural network and particle swarm optimization considering feed speed, tooltip radius, cutting speed and depth as CNC turning process parameters [9]. An early warning model was established based on SVM whose unknown parameters were determined combining firefly algorithm and random heuristic search algorithm to optimize [10].

Based on analyzing the factors affecting the processing quality of pin hole on the end face of tractor gearbox, the objective of the research is to establish the early warning rules and intelligent model of position accuracy during precision manufacturing process of hole group.

2. Knowledge acquisition and early warning rules

2.1. Influencing factors on processing quality
The manufacturing quality of parts affects the final quality of products directly. During the manufacturing process, the quality of parts is affected by many factors. According to the source of the factors, it can be divided into human, machine, material, method, environment and measurement.

The main influencing factors of gearbox processing quality are machine tool fixture and spindle rotation error caused by ambient temperature, tool deformation caused by long working time, tool wear and fixture deformation caused by machine tool working time, etc. Especially for high precision manufacturing, the influence of ambient temperature on the quality of processing cannot be ignored. As to the working time of tool, the number of workpieces processed by drilling cutter is considered as an influencing factor because reamer will change the cutter after processing certain pieces. The diameter of pin hole interacts with the position accuracy because they are formed under the same conditions.

2.2. Analysis of influencing factors
Practically data of pin hole on the end face of gearboxes were collected from manufacturing execution system (MES) using in tractor enterprise to investigate the correlation between position accuracy with its main influencing factors. Since the influencing factors and the method of establishing quality early warning model of horizontal position accuracy are the same as vertical position accuracy, vertical position accuracy was taken as a representative example to analyze the influencing factors and establish quality early warning rules and model in the following sections. The available data of position accuracy is limited because the strategy of first article inspection mentioned above. Typical vertical position accuracy measured by three-coordinate measuring instrument during 10 months in 2018 was analyzed using SPSS software correlation analysis method. The results of correlation analysis of single factors are shown in Table 1. It verified that the three factors of ambient temperature, number of workpieces processed by drilling cutter and diameter of pin hole are correlated with position accuracy respectively.
Table 1. Relevance Analysis.

| Relevance     | \( x_1 \): Ambient temperature (°C) | \( x_2 \): Number of workpieces processed by drilling cutter | \( x_3 \): Diameter of pin hole (mm) |
|---------------|-------------------------------------|------------------------------------------------------------|-------------------------------------|
| y: Position accuracy (mm) | 0.673                               | 0.435                                                      | 0.712                               |

MATLAB software was used to do double-factors analysis. The data fitting maps are shown in Fig.1.

![Data fitting diagrams](image)

**Figure 1.** Data fitting diagram where red marks represent the over-tolerance data of position accuracy.

2.3. Early warning rules

The early warning rules are proposed as follows based on above single-factor analysis and double-factors analysis.

1. The ambient temperature exceeds 30 degrees Celsius and more than 120 pieces were processed by drilling cutter.
2. The ambient temperature exceeds 30 degrees Celsius and the diameter of pin hole is greater than 14.970 mm.
3. The diameter of pin hole is greater than 14.970 mm and more than 120 pieces were processed by drilling cutter.

When either one of the above three rules is met, the position accuracy is more likely to be over-tolerance, and error prevention mechanism should be taken, such as checking machine tool fixture and spindle rotation, changing machine tool cooling fluid, or replacing drill cutter, to avoid potential over-tolerance of position accuracy for following gearbox manufacturing.

3. Early warning model based on LSSVM and PSO

3.1. Least squares support vector machine (LSSVM)

SVM is a statistical learning theory algorithm. It can also find the global optimal solution for small sample size, non-linearity and high dimension pattern recognition problems with high prediction accuracy. Because of the introduction of support vector, it reduces the computational complexity and avoids over-learning of models. SVM can be used in classification, regression prediction and early warning of engineering applications. It is widely used, but it is a quadratic programming problem,
which is prone to multiple local optima. To solve this problem, Suyken et al. proposed LSSVM, which transforms quadratic programming into linear programming. Compared with SVM, LSSVM has a simpler structure and fast calculation speed. The basic idea of SVM is to transform data from low-dimensional space to high-dimensional space using kernel function and to minimize the sum of squares of distances from data to the hyperplane. LSSVM uses a square method to transform inequality constraints into equality constraints.

\[ J(w, \xi) = \min \frac{1}{2} \|w\|^2 + \frac{1}{2} C \sum_{i=1}^{N} \xi_i^2 \]
\[ s.t. \quad y_i = w^T \varphi(x_i) + b + \xi_i, \quad i = 1, 2, \ldots, N \]

Where \( C \) is a penalty factor, \( \xi \) is a relaxation variable and \( J(w, \xi) \) is an optimization function. The quality early warning model base on LSSVM is deduced and calculated as follows.

\[ f(x) = \sum_{i=1}^{N} \alpha_i \varphi(x_i) + b \]

Radial basis function shown below was used as the kernel function of LSSVM.

\[ K(x, x_i) = \exp \left[ \frac{-(x-x_i)^2}{2\sigma^2} \right] \]

Therefore, the key to establish the quality early warning model is to find the parameters \( \sigma \) of the radial basis function and penalty factor \( C \).

3.2. Particle swarm optimization (PSO)
PSO is an optimization algorithm proposed to simulate the feeding process of birds. It can be used to find the optimal solution of function. PSO can be used to optimize function, train neural network and so on under no need to set too many parameters, while achieve fast convergence speed and good ability to find the global optimal solution.

PSO uses massless particles to simulate birds' foraging. Particles have two characteristics: velocity and location, which represent the moving speed and location of each particle. All particles search for the optimal solution in their search space, share their optimal solution with all particles and compare to know the current global optimal solution. Then the particle changes its speed and location through the current optimal solution. In this research, PSO was used to find the global optimal solution of parameters \( \sigma \) of radial basis function and penalty factor \( C \).

4. Results
Set the number of particle swarm \( N=20 \), velocity of particle swarm \( v_{\text{min}}=v_{\text{max}}=25 \), learning factors \( C1=C2=2 \), weight between 0.2 and 0.5, maximum number of iterations =200. The results of global optimal solution of parameters of radial basis function and penalty factor are \( \sigma=0.01 \) and \( C=113.7015 \) respectively.

Quality early warning model of pin hole position accuracy was established based on LSSVM and PSO. Then the early warning model was verified using vertical position accuracy data of pin hole on the end face of tractor gearbox, which were measured with a three-coordinate measuring instrument in a tractor processing workshop from February to November 2018. Considering the different measurement units of the collected data include temperature, number of workpieces and diameter, the normalization method was used to pre-process the data at first. To obtain as much information as possible from experimental data and avoid over-fitting, k-fold cross-validation method was used to test and train the collected data. The realization process of the k-fold cross-validation method is briefly introduced as follows.

Step 1: Divide the normalized data into \( k \) parts randomly.
Step 2: Select one of them as test set and the rest as training set.
Step 3: Make every data set has an opportunity to be a test set, calculate the model from each training set, and test with the test set. This paper uses the average absolute error between the test value and the actual value as the evaluation index.
Step 4: At the end of training, the average value of k measurement parameters is calculated and used as the precision index of the model. Then root-mean-square error (RMSE) and relative error (RE) were calculated to analyze and evaluate the effectiveness and stability of the quality early warning model. Results show that RMSE of the quality early warning model is 0.0058 mm and RE is 0.075%.

5. Conclusion
The research focuses on the issues that high-precision processing exits the problem of the position accuracy of pin hole affected by ambient temperature and other factors, while it is difficult to obtain quality inspection data in real time during manufacturing processes using numerical control machine. Firstly, the early warning rules of pin hole position accuracy were put forward in this paper according to acquired knowledge and factors analysis, which can be used for qualitative warning. Then an early warning model based on LSSVM and PSO was constructed to estimate the processing quality of pin hole position accuracy quantitatively in advance. The experimental results show that the RMSE and RE of the quality early warning model are 0.0058 mm and 0.075% respectively. So it can be concluded that the quality early warning model is effective and can provide decision support information for subsequent optimization of processing quality, improve product quality and reduce production cost.

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