

Application of Intelligent Technology in Electromechanical Engineering System

Xiaohu Zeng*, Yaxuan Cao

Department of Mechanical and Electrical Engineering, Jiangxi Biotech Vocational College, Nanchang, Jiangxi, China

Abstract:

Introduction: With the rapid development of science and technology, the systems in various industrial fields are becoming more and more complex and huge, and the degree of intelligence and integration is constantly improving.

Objectives: Combined with several theoretical branches of intelligent control research, this paper analyzes the current application of intelligent control in electromechanical control system from the aspects of construction machinery, mechanical manufacturing, robot technology and industrial process.

Methods: This paper also analyzes the research hotspot and focus of intelligent electromechanical fault diagnosis. This paper presents a fault diagnosis method of electromechanical actuator based on LVQ neural network. At the same time, this paper designs and improves the LVQ neural network learning algorithm and network parameters, and improves the classification effect of LVQ neural network. In this paper, a mechanical fault diagnosis method based on GA-SVM algorithm is proposed, and the real value coded genetic algorithm is used to improve the parameter optimization of support vector machine.

Results: Experiments show that this method improves the classification speed of support vector machine. Finally, the effectiveness and superiority of the two fault diagnosis methods designed in this paper are verified.

Conclusions: By summarizing the application status of intelligent control, this paper puts forward some development countermeasures to further develop intelligent control.

Keywords: intelligent control, green development, mechanical fault diagnosis, lvq algorithm.

INTRODUCTION

With the rapid development of science and technology, the systems in various industrial fields are becoming more and more complex and huge, and the degree of intelligence and integration is constantly improving¹. Accordingly, the problems of system reliability, fault diagnosis and prediction, maintenance guarantee and health management are becoming increasingly prominent. Fault prediction and health management technology is a promising dual-use technology to improve the reliability, maintainability and comprehensive supportability of complex systems and reduce maintenance costs. It is favored by the military and industry of various countries²⁻³. All parties are actively taking various measures to develop and utilize this kind of dual-use technology. Therefore, it is an inevitable trend to establish the integrated management architecture of airborne electromechanical system and implement PHM technology⁴. ML is a hot subject integrating many fields. It gives the ability of computer learning, analysis, reasoning and judgment. It has strong advantages in dealing with state monitoring, fault diagnosis and fault prediction of complex systems driven by massive data⁵. Therefore, for the key components of aircraft electromechanical system, combining machine learning with traditional fault diagnosis and fault prediction methods to study PHM technology based on machine learning has strong engineering practical significance and technical foresight.

OBJECTIVES

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METHODS

MODEL RESEARCH AND FAULT ANALYSIS OF ELECTROMECHANICAL ACTUATOR

The indirect drive linear electromechanical actuator is generally composed of controller, power drive module, motor, gear reducer, ball screw mechanism and feedback elements (linear variable differential transformer, resolver and current sensor). When working, the controller controls the power circuit through commands. The power circuit drives the motor to rotate, and then the gear reducer converts the motor output of high-speed and low torque into the rotation output of low-speed and high torque. Finally, the roller lead screw is converted into linear displacement, and the position sensor feeds back the detected position information to the controller to form a closed-loop control.

The failure of electromechanical actuator can be divided into electrical failure and mechanical failure⁶⁻⁷. Electrical faults mainly include motor fault, controller fault, power module fault and sensor fault. Mechanical failures mainly include gear reducer failure and ball screw failure. The specific failure modes are shown in Table 1.

Table 1. Electromechanical actuator failure mode

Faulty element	Failure mode
Electric machinery	Rotor eccentricity, winding open circuit, winding short circuit, bearing jamming and locked rotor
Controller	Inverter fault, Hall sensor fault, PID controller fault
Power module	Short circuit and open circuit of power tube
Sensor	The solution circuit is faulty and loose
Gear reducer	Broken gear and high gear friction
Ball screw	Excessive clearance, jamming and fracture

Considering the frequency and influence of electromechanical actuator faults and the difficulty of simulating fault injection, three faults are selected for analysis and research, namely, motor bearing jamming fault, gear broken tooth fault and excessive ball screw clearance fault⁸. (1) The motor bearing is stuck. When the electromechanical actuator works, if there is foreign matter winding in the motor or mechanical fatigue in the bearing bore, it will cause the sudden jamming of the motor bearing. At this time, the motor output signal is fixed at the stuck position and will not change, resulting in the stagnation of the output displacement of the electromechanical actuator and serious failure. The fault injection can be realized by transferring the output signal to the stuck position of the obtained electromechanical actuator at a certain time. (2) Broken gear fault. In the working process of the gear reducer of the electromechanical actuator, if the tooth surface breaks, it will affect the meshing stiffness of the gear, cause the mass imbalance of the whole gear system, cause centrifugal force, and make the gear output signal have the sinusoidal frequency modulation characteristic with the rotation frequency as the cycle. This fault feature is equivalent to adding a sinusoidal modulation signal to the original gear output signal. Therefore, the gear broken tooth fault can be simulated by adding a sinusoidal modulation signal to the gear output signal to realize the injection of this fault. (3) Ball screw clearance is too large. Due to installation or wear of electromechanical actuator, the clearance of ball screw is too large. During movement, the nut will rotate and slide due to its own gravity, resulting in elastic displacement and reduced positioning accuracy. When the allowable range is exceeded, the electromechanical actuator will fail and the output displacement signal will deviate.

MODEL RESEARCH AND FAULT ANALYSIS OF HYDRAULIC PUMP

The hydraulic pump is the key component of the civil aircraft electromechanical system. It sucks the hydraulic oil with a certain pressure from the oil tank, presses it out and transports it to the working oil circuit by changing the volume, converts the mechanical energy into hydraulic energy and provides power for the whole system. The commonly used hydraulic pumps in civil aircraft electromechanical system include axial or radial piston pump, gear pump and vane pump⁹⁻¹⁰. The working principle of these pumps is basically the same, but the way to change the volume is different due to different structures.

Compared with other hydraulic pumps, the structure of the intelligent axial piston pump studied in this paper is complex. In the working process, due to the influence of design parameters, manufacturing process and working environment, it often causes various forms of failure, such as wear, fatigue, corrosion and aging, resulting in a variety of failure modes and corresponding

failure characteristics. Some common failure modes and corresponding failure characteristics of hydraulic pump are shown in Table 2.

Table 2. Common failure modes and characteristics of hydraulic pump

Failure mode	Fault characteristics
Variable mechanism failure or disharmony	Insufficient flow and oil pressure
Channel blockage	Insufficient outlet pressure or pulsation, abnormal speed
Dirty oil and air in the pump	Abnormal vibration and high noise
Internal leakage	Abnormal outlet flow
Serious suction and relief valve unloading	Abnormal pump heating, outlet pressure and speed
The pump and motor shaft are not concentric	Abnormal speed and flow
Wear or strain between plunger and cylinder bore	Large pressure fluctuation and low volumetric efficiency
Plunger stuck	The pump does not rotate or the speed is too low
Bearing failure	Abnormal input shaft vibration

Considering the frequency and influence of hydraulic pump fault and the difficulty of simulating fault injection, two faults are selected for analysis and research, namely the non concentric fault between pump shaft and motor shaft and internal leakage fault. (1) Shaft misalignment fault. When the hydraulic pump works normally, the pump shaft is concentrically connected with the transmission shaft of the hydraulic motor and rotates driven by the output of the hydraulic motor. When the rotation speed of the pump shaft is larger, the pump shaft will become unstable. When the allowable range is exceeded, the hydraulic pump will fail and the outlet flow will be disturbed. This fault characteristic is equivalent to that the input voltage is disturbed. Therefore, the fault injection can be realized by adding a disturbance voltage to the input voltage to simulate the shaft non concentric fault. (2) Internal leakage fault. According to the dynamic characteristics of the hydraulic pump, the theoretical output flow of each working point under zero pressure is fixed. Because the working pressure is not equal to zero during normal operation, it decreases. The difference between the two is the internal leakage of each working point. The greater the working pressure, the smaller the actual flow and the greater the internal leakage. When the allowable range is exceeded, the hydraulic pump will fail and the outlet flow will change significantly. This fault feature is equivalent to the increase of leakage coefficient, so the internal leakage fault can be simulated by increasing the leakage coefficient to realize the injection of this fault.

RESULTS

FAULT DIAGNOSIS OF ELECTROMECHANICAL ACTUATOR BASED ON LVQ NEURAL NETWORK

LVQ neural network was proposed by Finnish scholar Kohonen in 1989. It is a hybrid neural network combining supervised learning and unsupervised learning. It integrates the ideas of competitive learning and supervised signal learning, which can give better play to the advantages of competitive learning and supervised learning.

The general learning algorithm of LVQ neural network is as follows:

- (1) Network initialization. The initial value of each neuron weight vector W_{ij} in the competition layer is set as a small random number, and the initial learning rate η and training times T are determined.
- (2) Enter the sample vector. Let the input vector of the input layer be $X = [x_1, x_2, x_3, \dots, x_n]$.
- (3) Calculate the Euclidean distance between the weight vector of the competition layer and the input vector. Given by the following formula (1):

$$d_j = \sqrt{\sum_{i=1}^n (x_i - w_{ij})^2} \quad (1)$$

(4) Look for winning neurons. Select the neuron with the smallest distance between the input vector and the weight vector as the winning neuron, which is recorded as j^* .

(5) Update connection weights. Adjust the weight of the winning neuron. The rules are as follows: if the classification corresponding to the winning neuron is consistent with the tutor signal, that is, the classification is correct, the weight vector is adjusted according to formula (2); If the classification is wrong, the weight vector is adjusted according to formula (3).

$$w_{j^*}(k+1) = w_{j^*}(k) + \eta [X - w_{j^*}(k)] \quad (2)$$

$$w_{j^*}(k+1) = w_{j^*}(k) - \eta [X - w_{j^*}(k)] \quad (3)$$

Where: η is the learning rate, and the value is related to time.

(6) Judge whether the set maximum number of iterations is reached. When it is met, the algorithm ends. Otherwise, go to step (2) to continue training. Finally, when the set number of training times is reached, the training result is.

The LVQ neural network learning algorithm designed in this paper is improved on the basis of the general learning algorithm pair introduced above, which can further improve the training effect. The central idea is that in the competition layer, if the two weight vectors closest to the input vector, one corresponding to the correct classification and the other corresponding to the wrong classification, update the two weight vectors, so as to classify the data that is not easy to classify and improve the generalization ability of classification. To this end, we introduce the concept of window, which is defined as follows:

$$\min\left(\frac{d_i}{d_j}, \frac{d_j}{d_i}\right) > \frac{1-\beta}{1+\beta} \quad (4)$$

Through window judgment, when the two weight vectors close to the input vector are different categories, the two weight vectors will be adjusted.

FAULT DIAGNOSIS OF HYDRAULIC PUMP BASED ON GA-SVM

GA-SVM algorithm, as its name suggests, uses genetic algorithm to optimize the parameters of support vector machine.

In the GA-SVM algorithm designed in this paper, the kernel function selected by SVM is Gaussian kernel function (RBF), and the penalty factor C and RBF model parameter γ in SVM parameters need to be set. At present, it is mainly through trial and error method, grid search method and other methods to select relatively better parameter values. According to the previous theoretical analysis, genetic algorithm is an effective optimization algorithm. Therefore, this paper uses genetic algorithm to optimize the parameters of support vector machine. The main idea is: on the basis of setting the optimization range of penalty factor C and RBF model parameter γ , use genetic algorithm to optimize the parameters. After finding the optimal parameters, use the parameters to train SVM model, and then use the trained model to classify the fault data. In view of the fact that the binary coding accuracy and efficiency of the previous genetic algorithm can not meet the requirements of parameter optimization, this paper improves the genetic algorithm and introduces real value coding, that is, a floating point in a certain range is used to represent each gene bit of an individual. The specific design of the algorithm is as follows:

(1) Set the parameter optimization space as follows:

$$\begin{cases} C \in [2^{-9}, 2^9] \\ \gamma \in [2^{-9}, 2^9] \end{cases} \quad (5)$$

(2) The parameters C and γ are used as the population genes of genetic algorithm, and they are encoded. The real value coding is adopted, that is, a floating point number in the optimization space is used to represent each gene value to generate an initial population.

(3) The individual genes of the population are transformed into SVM parameters for SVM cross validation. The fitness is calculated with the accuracy obtained by cross validation as the fitness function.

(4) The operation of gene editing by real value coded genetic algorithm is set as follows.

(5) The optimal parameters are obtained, the SVM model is trained, and the fault classification and diagnosis are carried out according to the obtained model.

DISCUSSION

On the basis of establishing the simulation model of electromechanical actuator and hydraulic pump, two key components of electromechanical system, analyzing their fault mechanism and obtaining fault data, this paper focuses on the three aspects of fault data processing, fault diagnosis and life prediction in PHM technology based on machine learning algorithm, and verifies the effectiveness and superiority of their respective methods.

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