Remote performance evaluation, life prediction and fault diagnosis of RV reducer for industrial robot

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Abstract—For the reason of complex maintenance technology, long maintenance time and large downtime loss, the remote monitoring technology and intelligent diagnosis method are introduced into fault diagnosis of industrial robots; a remote fault diagnosis technology of industrial robots based on intelligent algorithm is proposed. The remote fault diagnosis platform of industrial robot is constructed, and three-layer architecture is designed, which is composed of perception layer, information transmission layer and fault diagnosis layer. RV Reducer of industrial robot is selected as fault diagnosis object, the state information of reducer is collected and processed, the signal processing and feature extraction are carried out by information fusion technology, performance state is evaluated by support vector machine, the remaining life is predicted by grey Markov model, and the potential fault is diagnosed by Bayesian network. The diagnosis results will provide decision support for reducer maintenance, and it will improve the maintenance efficiency, reliability level and user satisfaction.

1. INTRODUCTION
The number of industrial robots increases rapidly year by year, and the on-site maintenance work increases day by day, which will have three effects: First, with the rapid increasing of business trips and on-site maintenance work, manufacturer and application enterprises are not able to cope with the maintenance requests all over the country, so the application enterprises often complain about the slow maintenance response [1]. Second, as a high-tech intelligent equipment, industrial robot is used in large scale in recent years, and it is integrated with multi-disciplinary technologies. Because of lack professional maintenance personnel, enterprises need technical guidance from manufacturer of industrial robot. Third, as key equipment of enterprises, industrial robots are often used in key processes of production lines because of their high price. Generally, industrial robot has no backup equipment, and if there is a fault that it cannot be repaired in time, the enterprise will suffer a huge loss of production halt. Therefore, it is necessary to solve the contradiction of heavy task, high technical requirements and large downtime loss in maintenance process [2-3]. Remote maintenance is the feasible method to solve this problem, it is used to enhance the ability of fault identification, find potential problems, accelerate response speed and improve the maintenance efficiency.

Industrial robot is mainly composed of three subsystems: control, servo and transmission. Among them, the reducer in the transmission system is the joint of the industrial robot; it has the characteristics
of short transmission chain, small volume, large power, light weight and easy control [4-5]. The reducer controls power output and operation accuracy of industrial robot, and it is the most critical component in the industrial robot. For industrial robot, there are two types of reducers: RV (rotate vector) reducer and harmonic reducer [5-6]. In this paper, RV Reducer is chosen as the research object, because it is easier to damage.

RV Reducer is worn due to long-time work, such as surface damage, even wear, lubrication failure and other failure types. If it is not found and repaired in time, it may lead to more dangerous faults or accidents. In addition, the maintenance and replacement of RV Reducer may take a long time, which has a great damage to the production continuity [7]. For a long time, there is a lack of effective monitoring means. It is difficult to find and judge the type and position of the fault as early as possible, to prevent and maintain quickly and accurately, and to ensure continuous production [8].

In this paper, RV Reducer is selected as research object. Through the selection and design of special hardware systems such as data acquisition controller and auxiliary sensor, the state parameter signal of the reducer is obtained, and the signal processing and feature extraction are carried out. In order to improve maintenance level of industrial robots, support vector machine is used to evaluate the performance state of the reducer, Markov model is used to predict the remaining life, and Bayesian network is used to diagnose potential faults.

2. RESEARCH FRAMEWORK

In order to improve the reliability and maintainability of industrial robots, a combination of theoretical research, mathematical modelling, development and application, test and analysis is used to realize remote maintenance of industrial robots. The research ideas are as follows:

First of all, it is necessary to design remote diagnosis hardware system of industrial robot, which is composed of data acquisition controller, auxiliary sensor, field bus, ZigBee, switch, Ethernet, etc., it is mainly used to complete signal pick-up and transmission, and lay foundation for signal processing, feature analysis, performance evaluation, life prediction and fault diagnosis of reducer.

Secondly, according to collected state data, information fusion methods such as outlier processing, data compression, digital filtering, time domain analysis, frequency domain analysis, wavelet analysis and principal component analysis are used to extract the signal eigenvalues that can accurately reflect the operation state of the reducer, and provide data sources for the subsequent health assessment, life prediction and fault diagnosis.

Thirdly, intelligent algorithm is introduced to analyse and judge the running state of the reducer, support vector machine is used to evaluate performance state of the reducer, grey Markov model is used to predict remaining life of the reducer, and the Bayesian network is used to diagnose potential reducer faults, and they are used for preventive maintenance of the reducer. Finally, software system of remote diagnosis is developed. The research framework is shown in Figure 1.
3. REMOTE DIAGNOSIS TECHNOLOGIES
Performance evaluation, life prediction and fault diagnosis in performance degradation process are key points of remote diagnosis, so as to achieve preventive maintenance of equipment or product. RV Reducer is selected as research object, intelligent algorithm is introduced to analyse and judge operation state of the reducer. In order to improve the efficiency and effect of fault diagnosis, support vector machine, Markov model and Bayesian network are used for performance evaluation, life prediction and fault diagnosis of industrial robot reducer.

3.1. Remote performance evaluation
In order to evaluate degree of performance degradation for reducer, it is necessary to grade its performance, so as to know reducer performance in time according to operation status. According to actual demand of reducer, its performance is divided into four grades: good, slight fault, dangerous fault and serious fault.

After determining performance level, performance evaluation model is established by SVM, as shown in Figure 2. The process of using SVM to evaluate various performance indexes of reducer is as
follows: 1)Collecting enough historical data covering various performance states of reducer; 2)Using corresponding feature extraction and selection methods to process data and extract feature vector; 3) Importing feature vector into SVM trainer to establish performance evaluation model; 4)Using LabVIEW and Matlab to program SVM algorithm; MATLAB script node is used to realize its mixed programming, and data communication of MATLAB script node is completed by adding input and output; 5)Online evaluation results of reducer performance are obtained by integrating vibration, angle, temperature and other signals.

3.2. Remote life prediction
Reducer is taken as research object; its remaining life prediction is the emphasis of CBM (condition based maintenance) realization. Remaining service life of damaged components or systems can be estimated by remote life prediction, which is very important for maintenance scheduling and production scheduling.

In this paper, the grey Markov model is used to predict the remaining life of the reducer, as shown in Figure 3. The prediction process is as follows: 1)Vibration signal data of reducer is monitored and collected from normal to failure; 2)One-dimensional characteristic vector in degradation process of the reducer performance is obtained to analyses and process vibration signal; 3)Changing trend life curve of reducer is analyzed, appropriate fault prediction point and failure critical point is selected, prediction start time point \( t_b \) and failure critical point threshold \( t_I \) are recorded, and time interval between two points is actual remaining service life; 4)Take performance degradation index sequence before prediction start point \( t_b \) as training sample, and Markov prediction model is used after that, development trend of the data is forecasted by multi-step, and original prediction sequence is updated by actual observation data. When predicted value exceeds threshold of failure critical point \( t_I \), the point is recorded as predicted failure point, which is predicted failure time \( t_{pr} \) and remaining service life \( ARSL = t_{pr} - t_b \) of reducer at predicted starting point \( t_b \); 5) RMS error (RMSE) is used as index to evaluate effect of prediction method. The smaller RMSE is, the model has higher prediction accuracy.

3.3. Remote fault diagnosis
Reducer is the important component of industrial robot, and the effective fault diagnosis is the key to ensure normal operation of industrial robot. When vibration signal is used for fault analysis of reducer,
it is incomplete to obtain fault feature information of vibration signal only from a single domain. At present, Bayesian network method is the most effective theoretical model in the field of uncertain knowledge expression and reasoning, and it is one of the effective methods to solve incomplete problem, it is shown in Figure 4.

![Figure 4. Fault diagnosis](image)

In this paper, fault diagnosis process of reducer is as follows: 1) Design fault mode of reducer, install vibration sensor on the reducer, and use signal acquisition device to collect the fault vibration signals; 2) De-noise collected Wavelet signals; 3) Extract feature information of frequency and amplitude domain of wavelet packet decomposition and carry out clustering discrete processing algorithm of fuzzy C-means (FCM); 4) Bayesian parameter estimation algorithm is used to carry out multi feature information fusion for fault feature information; 5) According to relationship between fault feature information and fault mode, training samples is used to build Bayesian network; 6) Naive Bayes (NB) classifier is built through Bayesian network, the result of information fusion is simplified, and calculation result of maximum posterior estimate probability is used to identify the type of fault.

4. CONCLUSIONS
With the rapid development of information technology, media technology and communication technology, remote monitoring and fault diagnosis have gradually become an important way to maintain industrial robots. The really running state of industrial robots can be obtained accurately. It is of great significance for enterprises to find out potential safety danger as early as possible, and they will be analyzed and diagnosed in real time. The industrial robot user can make maintenance plans quickly, so as to improve maintenance level, reduce failure rate and ensure continuous operation of production line.

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