Research on Fault Prediction and Health Management (PHM) Based on Data-driven Industrial Robot

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Abstract: Industrial robots play an important role in industrial automation due to their stability, flexibility and excellent production efficiency. More and more companies choose industrial robots to replace manual operations in specific fields. However, as the number and use time of industrial robots continue to increase, the loss rate also increases, and equipment failure in important production occasions will bring unpredictable economic losses and safety problems. Therefore, it has high research value for fault prediction and health management (PHM) of industrial robots.

This paper combines the machine learning method, analyzes the working parameters and performance indexes such as load, torque, position and cycle time, designs a set of robot fault prediction and health management system, and introduces the predictive analysis model. The clustering of robots by clustering algorithms such as k-means eliminates the adverse effects of production environment complexity and device model diversity. On this basis, the degree of difference between the overall feature distribution of the robot arm and the cluster in the cluster is quantified, and the health evaluation standard is established to realize the real-time maintenance and fault prediction of the industrial robot.

1. Introduction

With the continuous development of industrial automation, manual operations in many production areas of the manufacturing industry have gradually been replaced by industrial robots. While enjoying the convenience brought by industrial automation, people also bear the risk of equipment failure in important occasions. In the current production environment, the maintenance of industrial robots mostly uses periodic inspection methods. Regular inspections can reduce the occurrence of problems to a certain extent, but the inspection is inefficient. The setting of the inspection cycle tests the experience of the maintenance worker. If the setting is improper, there may be a waste of manpower and material resources, and there is a risk that the accident is not discovered in time. Under this demand, PHM technology came into being.

In the mid-1990s, PHM technology was born in a military project in the United States. The US military designed a performance evaluation system for real-time detection of the operational status of helicopters for targeted maintenance and random access to Western military powers. Highly valued. [1] PHM technology has transformed from health monitoring to health management, from passive regular maintenance to proactive maintenance-oriented transitions, from large-scale investigations to specific component inspections.

The development of modern computer science and data science, the popularization of intelligent equipment, provides technical guarantee for equipment fault prediction and health management, and also reduces the realization cost of technology. The domestic PHM technology has already carried out a lot of work and achieved remarkable research results, [2] the civilian passenger aircraft PHM ground support system developed by the Shanghai Aircraft Design and Research Institute, [3] the high-speed railway traction power supply system PHM developed by China Railway Corporation Technology [4] and China Air and Air Missile Research Institute airborne missile launcher PHM system [5] and so on. However, there are few researches on fault diagnosis and health management methods for industrial robots. Therefore, it has a high research value for the industrial robot's fault prediction and health management (PHM) with good economic benefits.

2. Fault Diagnosis and Health Management (PHM) System Design

In order to realize real-time maintenance and fault prediction of industrial robots to avoid unestimable economic losses and safety problems, this paper proposes a data-driven industrial robot fault diagnosis and health management (PHM) system. The system is mainly divided into the following modules: data acquisition module, data processing module, model training module and health management module.

1) Data acquisition module: set a reasonable sampling frequency, and collect the working parameters and performance indicators such as load, torque, position, cycle time, etc. through the controller or sensor;

2) Data processing module: The data directly collected has the problem of incomplete integrity and consistency, so it cannot be directly analyzed. This module preprocesses the data, that is, "data cleaning", eliminating invalid data and abnormal data;

3) Data storage module: select a reasonable data structure and database to store the data to facilitate the training of subsequent models;

4) Model training module: select reasonable machine learning models and parameters, input data, train and evaluate models

5) Health management module: According to the output of the model, establish a fitness evaluation standard, and predict the failure according to the development trend of the output.

3. Determine the data analysis object

Determining the data analysis object is the most important part before building the evaluation model. In actual production work, there is often no simple one-to-one correspondence between industrial robot health and data characteristics. A fault situation may correspond to the comprehensive performance of multiple data features, and a data feature may also be a variety of fault conditions. Performance factor. Therefore, the selection of a reasonable analysis object can correctly guide the construction of the evaluation model.

At present, the principle of fault diagnosis of industrial equipment such as industrial robots is mainly [6]: current analysis method, insulation detection method, temperature detection method and vibration noise detection method. The current analysis method analyzes the waveform of the load current to diagnose the cause and extent of the motor fault. The insulation diagnostic method uses various electrical testing devices and insulation technologies to detect the insulation structure of the motor equipment to judge its working performance. Whether there are defects and abnormalities; the temperature detection method uses various temperature detecting devices to analyze the working part of the motor, and judges whether there is abnormality in the motor through the change of temperature rise; the vibration noise detecting method collects vibrations during the working process of the motor Noise, and related processing of the obtained signal to diagnose the cause and location of the failure of the motor equipment, this method is widely used in the diagnosis of mechanical damage.

The above several methods are based on the premise of adding an external structure such as a sensor, and obtain corresponding data features. However, in actual production, the number of industrial robots invested is huge, and the production environment is complicated, so it is not suitable for installing external sensors. Considering the complexity of the production environment and the diversity of equipment models, in order to improve the robustness and versatility of the evaluation model, this paper proposes a diagnostic method based on the mechanical arm torque signal, which is extracted and fixed according to each action cycle of the robot. The statistical characteristics of the signal, such as extreme values, variance, MES and expected values, for the health assessment of industrial robots. The advantage is that the controller can directly obtain the signal of interest without the need for additional sensors and other structures, thereby reducing the adverse effects caused by the production environment and the device model.

4. Build evaluation model

In this paper, the evaluation model is built as a data-driven model. Through algorithm or statistical analysis, the internal relationship between data is obtained from a large amount of sample data, and the mapping from sample data to device state is realized. The construction of the model is mainly divided into the following two problems: the elimination of the impact of the production environment and equipment model; the reasonable analysis of the torque signal of the mechanical arm. Industrial robots in different production environments, performing different production tasks and different types of equipment will make significant differences in data characteristics such as mechanical arm torque signals. Therefore, it is necessary to divide the robot into clusters and analyze them in the same cluster; The statistical characteristics of the torque signal need to be reasonably selected, and the mechanical arm is analyzed as the evaluation standard of the robot health.

4.1 Robot cluster analysis

The complexity of the production environment and the diversity of equipment models are the main factors that cause modeling difficulties. In this paper, the robots are divided into clusters by clustering machine learning methods, and similarities are performed in similar environments under similar environments. device. Under this cluster, you can directly compare the similarity of the data characteristics of the robot. The robots in different clusters are not comparable and have no practical meaning to guide the assessment.

4.1.1 Principle and classification of clustering algorithm

Clustering algorithm is an important method in machine learning and is widely used in data mining, data analysis and artificial intelligence. Clustering, according to the similarity between data points, divides the data set into several disjoint subsets, each of which is called a "cluster". Through such division, data points in the same cluster have as large a similarity as possible; data points in different clusters have as large a dissimilarity as possible. Based on different data types, learning strategies and application fields, clustering algorithms can be divided into two categories: traditional clustering algorithms and new clustering algorithms. [7] Traditional clustering algorithms are mainly divided into partition-based clustering, hierarchical-based clustering, grid-based clustering, density-based clustering, and model-based clustering. The new clustering algorithm classifies according to the intrinsic properties of the dataset samples. The classification criteria include sample dimensions, similarity, update strategies, and preprocessing methods.

Clustering problems can be described by mathematical formulas as:

$$\mathrm{MSE} = \frac{1}{m}\sum_{j=1}^{k}\sum_{y_i \in C_j}\left\|y_i - z_j\right\|^2$$

Given a sample set containing m unlabeled samples$D = \{x_1, x_2, \cdots, x_m\}$， The algorithm divides the sample set D into k clusters that do not want to intersect.$C = \{c_1, c_2, \cdots, c_k\}$Using the mean square error MES as the objective function of the cluster, define it as$\mathrm{MSE} = \frac{1}{m}\sum_{j=1}^{k}\sum_{y_i \in C_j}\left\|y_i - z_j\right\|^2$

z_j represents the cluster center, The smaller the value of the mean square error MSE, the better the corresponding clustering effect.

4.1.2 Introduction of Clustering Algorithm K-means

The clustering algorithm of the robot is clustered by K-means clustering algorithm. The mathematical principle of this method is simple, the convergence speed is fast, the effect is good, and the interpretability is high. However, the selection of the initial clustering center has a great influence on the clustering effect. The algorithm flow of K-means can be expressed as follows:

Step1: Randomly select K samples from the dataset as the initial clustering centerC $= \{c_1, c_2, \cdots, c_k\}$

Step2: For each sample in the data set x_i, calculate the Euclidean distance from the K corresponding cluster centers, and divide it into the class corresponding to the cluster center with the smallest distance;

Step3: For each category c_i, recalculate its cluster center $c_i = \frac{1}{|c_i|}\sum_{x \in c_i} x$, that is, calculate the centroid of all samples of the class;

Step4: Repeat Step2 and Step3 until the position of the cluster center no longer changes.

The cluster clustering of robots can be divided into two stages. The first stage is clustered according to the model and usage time of the equipment, and then the second stage of clustering is carried out by the production environment, work tasks and working conditions of the equipment. Eliminate the adverse effects of the complexity of the production environment and the diversity of equipment models.

4.2 Manipulator analysis

For industrial robotic arms, the drive motor torque caused by different action cycles is different. The figure shows the information of each axis torque obtained on the robot controller. It can be seen that the torque changes periodically when the cyclic action is performed. Therefore, when the robot arm performs similar actions, the characteristic distribution of the moments should be very similar. Based on the previous division of the robot cluster, the robot arm can be analyzed in the cluster. The difference between each robot arm and the cluster is quantified by an algorithm such as SOM self-organizing map, and the distribution deviation is used as the final output result.

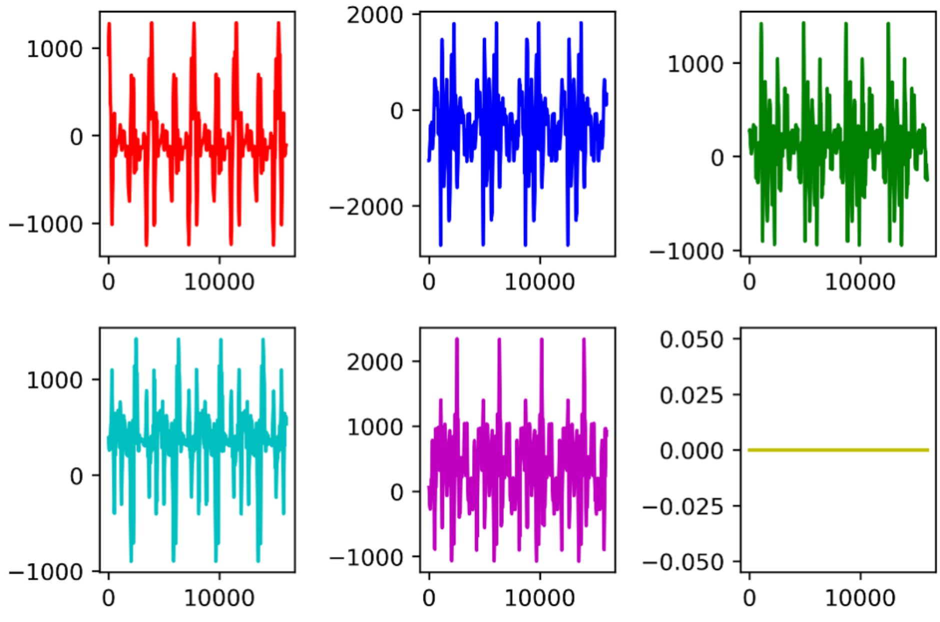

Figure 1 Simulation of the torque of each axis of the industrial robot

5. Troubleshooting and health management

Health assessment refers to analyzing the real-time operation of the equipment through the model and evaluating the working status of the equipment. The relevant data features are obtained from the device in real time, and after being preprocessed, input to the trained model, and then the output of the model is analyzed correspondingly.

By analyzing the distribution deviation value of the model output, the health evaluation standard is established, and the mechanical degree of the mechanical arm is sorted according to the degree of the difference. According to the statistical theory, 90% or 95% is proposed as a confidence interval. When the distribution deviation exceeds the boundary corresponding to the confidence interval, the conclusion that the mechanical health of the robot arm gradually decreases can be obtained. By predicting the development trend of the distribution deviation value, it is also possible to predict the life of the robot and play an important role in guiding equipment maintenance and fault detection.

6. Conclusion

With the increasing degree of industrial automation, the use of industrial robots has brought convenience to people and puts higher demands on the reliability of equipment. Failure of equipment in critical production situations can result in unpredictable economic losses and safety issues. In view of the current research on the domestic robot PHM method, this paper has pioneered the research on the PHM technology of industrial robots and proposed a relatively complete scheme.

The article introduces the birth and development of PHM technology and analyzes the application potential of PHM technology in the field of industrial robots. In the research data analysis object, considering the complexity of the production environment and the diversity of equipment models, a new idea of using controller signals instead of external sensor signals is proposed, and the torque signals of each arm and their statistical characteristics are taken as the analysis object. . In the model construction part, the clustering method in machine learning is used to divide the robot into clusters in stages. The similarity of data points in the cluster is high, and the data of different clusters is highly different. On this basis, the degree of difference between the overall distribution of each robot arm and the cluster in the cluster is quantified. Finally, the health evaluation and fault prediction methods based on model output are briefly introduced.

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