An unsupervised prediction method for radar transmitter degradation fault based on isolation forest

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Abstract. The transmitter is prone to premature degradation and failure for the frequent work and the harsh working environment of the marine radars. The existing method of degradation fault based on data-driven require a large number of negative samples or need to set failure threshold. To solve the above problems, an unsupervised prediction method for radar transmitter degradation fault based on isolation forest is proposed. The proposed unsupervised prediction method can predict the degradation fault of radar transmitter when there are no fault samples and the fault threshold is not reached.

1. Introduction
As the core component of the radar, the transmitter should have a certain service life and reliability when it leaves the factory. However, the transmitter is prone to premature degradation when the marine radar equipment is usually under adverse working conditions, such as frequently work and the harsh working environments. For the complex electronic equipment such as marine radars, the transmitter degradation fault prediction and diagnosis currently mainly rely on three aspects: regular maintenance before the fault occurs, alarms of BIT (Built-in Test, BIT) when the fault occurs, and expert overhaul after the fault occurs \cite{1}. In other words, fault prediction and diagnosis only stay in the regular maintenance and alarm after the fault occurs. Unfortunately, regular maintenance costs are high and resources are wasted seriously. Once the equipment is degraded during use, it will cause serious losses. Maintenance after the fault is to maintain the equipment after it fails, which can’t meet the actual needs.

At present, the commonly used methods for predicting and diagnosing the degradation of marine radars are mostly based on data-driven methods \cite{2}. The existing equipment fault prediction and diagnosis methods have the following characteristics: Firstly, fault prediction requires a large number of fault samples as prior knowledge to build a fault prediction and diagnosis model \cite{3}\cite{4}. Secondly, the model needs to manually set the degraded fault threshold to judge whether the monitoring data is approaching the fault state \cite{5}. However, for the marine radar equipment with complex system structure, its degradation fault prediction has the following problems: Firstly, components of the radar can reach a certain service life before leaving the factory. Secondly, it is difficult to collect a large number of fault sample data. Thirdly, the numerical selection of the artificial fault threshold directly affects the accuracy of fault prediction and diagnosis. In order to solve the above problems, this paper proposes an unsupervised prediction method for radar transmitter degradation fault based on isolation forest. This
method can realize the degradation fault prediction of the marine radar transmitter with the condition of no-fault samples and no artificial threshold.

2. Design of algorithm

Isolation forest is an efficient outlier detection algorithm proposed by Zhou Z H and others [6]. It is widely used in power anomaly analysis [7] and water consumption anomaly detection [8]. The structure of the marine radar transmitter is complex, and its degradation fault detection can’t simply use traditional fault detection algorithms and models. In recent years, the popularity of machine learning algorithms and the advent of the era of big data have provided new ideas for the prediction of radar transmitter degradation fault. This paper takes the marine radar transmitter as the research object and adopts the isolation forest model to predict the transmitter degradation fault.

Isolation forest is an unsupervised anomaly detection method based on random binary trees, which is suitable for continuous monitoring of radar transmitter timing data. Figure 1 shows the algorithm flow of radar transmitter degradation fault detection based on isolation forest.

2.1. Isolated forest

The isolation binary tree is the basic unit that constitutes the isolation forest. Since the isolation forest belongs to unsupervised learning and does not require training set for training, the construction of the binary tree mainly includes four steps:

- Randomly select N sample points from the monitoring time series data of the transmitter to be detected and put them into the root node of the tree.
- Randomly select a data feature, and randomly generate a split point p in the current node data (its value is between the maximum and minimum values of the specified feature).
- A hyperplane is formed based on this dividing point, and the current node data space is divided into two subspaces. The data less than p in the specified feature is placed on the left side of the current node, and the data greater than or equal to p is placed on the right side of the current node.
- Repeat steps 2 and 3 for each child node until the data itself cannot be divided or the maximum depth of the binary tree \( \log_2 N \) is reached, the recursion ends.

After completing the above four steps, multiple isolation binary trees can be obtained, which can further form an isolation forest.

2.2. Anomaly score calculation

Due to the randomness of the formation of isolation binary trees, a single class of binary trees is not reliable. So firstly, each binary tree in the isolation forest is traversed. Secondly, the tree depth of the data sample to be tested in each number is calculated. Finally, the sample x is calculated in the isolation forest. The average tree depth is \( E[h(x)] \), the anomaly score can be calculated by formulas (1) - (3), where \( s(x, n) \) is the value of the anomaly score and \( c(n) \) is the average path length, \( H(k) \) is the number of harmonics, and \( \zeta \) is Euler's constant.

\[
s(x, n) = 2^{\frac{E[h(x)]}{c(n)}}
\]

\[
c(n) = 2H(n-1) - \frac{2(n-1)}{n}
\]

\[
H(k) = \ln(k) + \zeta
\]
3. Experimental setup and results

3.1. Experimental setup

Based on the above algorithm theory, the monitoring data of the 8 monitoring points for the radar transmitter is used to predict the degradation fault. The data of each monitoring point doesn’t reach the fault threshold, and it is still within the normal working index of the transmitter. Each monitoring point has 192 historical data. At the 193rd time step, a degradation fault occurs. To realize the visualization of the experimental results, the experiment was divided into two groups. The first group of experiments used the monitoring data of two monitoring points to predict the degradation fault; the second group of experiments used the data of 2 to 8 monitoring points to predict the degradation fault. The operating system of the computer is windows 10 in our experiments, the computer is equipped with 4 GB of RAM and 2.50 GHz of CPU clock speed. The version of software MATLAB is MATLAB 2016a. The relevant parameters of the algorithm are set as follows: the number of iTrees in the isolation forest is 100, and the number of samples selected when training a single tree is N=150. According to the size of the historical data, the outlier ratio is set to 10, and the experiment is used to verify whether the algorithm can predict degradation fault in advance within 182~192-time steps.

3.2. Experimental results and analysis

Experiment 1 uses the data of two monitoring points to predict the degradation fault. The historical data of the monitoring points is shown in Figure 2.

The isolation forest algorithm was used to predict the degradation fault of the transmitter on the data of two monitoring points, and the visual failure prediction results are shown in Figure 3. There are 6 degradation failure early warning points, and the time steps are 185, 188, 189, 190, 191, 192, respectively. For two monitoring points, the degradation fault prediction can be achieved 8-time steps in advance.
Experiment 2 used 2-8 monitoring point data to predict degradation fault. Unfortunately, there are many monitoring points that cannot be visualized, the degradation fault prediction results are shown in Table 1. It can be seen from Table 1 that as the number of monitoring points increases, the time step for early warning of degradation faults also advances. When the number of monitoring points is 8, the degradation fault warning time can be completed 10-time steps in advance.

**Table 1** Multi-monitoring point degradation fault prediction results.

| Number of monitoring points | Degradation fault prediction alarm time step |
|-----------------------------|---------------------------------------------|
| 2                           | 185, 188, 189, 190, 191, 192                |
| 3                           | 182, 183, 184, 185, 188, 189, 190, 191, 192 |
| 4                           | 184, 185, 188, 189, 190, 191, 192           |
| 5                           | 182, 183, 184, 185, 188, 189, 190, 191, 192 |
| 6                           | 183, 184, 185, 186, 187, 188, 189, 190, 191, 192 |
| 7                           | 184, 185, 186, 187, 188, 189, 190, 191, 192 |
| 8                           | 182, 184, 185, 186, 187, 188, 189, 190, 191, 192 |
4. Conclusion
This paper proposed an unsupervised prediction method for radar transmitter degradation fault based on isolation forest, which is used to predict the degradation fault of radar transmitter with small samples, no failure samples, and sensor monitoring data do not exceed the fault threshold. The process of the radar transmitter degradation fault prediction model is discussed. By setting up different monitoring points to research the influence of models on the prediction results for degradation faults, the experimental results show that the more monitoring points, the earlier the warning time of degradation faults. The experiment proves that this method can effectively predict the degradation faults of radar transmitters.

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References
[1] Chen Xinzhong. (2008) Design of BIT (built-in test) system for radar. Electronic Measurement Technology., 31: 134-137.
[2] Zhai Yuting, Fang Shaojun. (2020) A Degradation Fault Prognostic Method of Radar Transmitter Combining Multivariate Long Short-Term Memory Network and Multivariate Gaussian Distribution. IEEE Access., 8: 199781–199791.
[3] T. Zimnickas, J. Vanagas, K. Dambrauskas, A. Kalvaitis, and M. A“ubalis. (2020) Application of advanced vibration monitoring systems and long short-term memory networks for brushless DC motor stator fault monitoring and classification. Energies., 13: 820.
[4] C. Xiao, Z. Liu, T. Zhang, and L. Zhang. (2019) On fault prediction for wind turbine pitch system using radar chart and support vector machine approach. Energies., 12: 2693.
[5] Z. Dai, L. Yao, and J. Qin. (2019) Research on fault prediction of radar electronic components based on analytic hierarchy process and BP neural network. In 12th Int. Conf. Intell. Comput. Technol. Autom. (ICICTA). pp. 91–95.
[6] Liu FT, Ting KM, Zhou ZH. (2008) Isolation Forest. In IEEE International Conference on Data Mining. pp. 413-422.
[7] Huang Fuxing, Zhou Guangshan, Ding Hong, Zhang Luoping, Qian Shuyun and Yuan Peisen. (2019) Electric energy abnormal data detection based on isolation forests. Journal of East China Normal University (Natural Science)., 5: 123-132.
[8] Zhao Chenxiao, Xue Huifeng, Wang Lei and Wan Yi. (2020) Water Consumption Abnormal Data Detection Method based on Isolation Forest. Journal of China Institute of Water Resources and Hydropower Research., 18: 31-39.