Research on Spacecraft Abnormal State Detection Method Based on Telemetry Data

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Abstract. A method of spacecraft abnormal state detection based on telemetry data is proposed. The abnormal state of spacecraft is detected by telemetry data preprocessing, correlation calculation, extremum point extraction and abnormal state extraction. This method makes full use of the historical telemetry parameter samples, combines the characteristics of the spacecraft telemetry parameter data and the law of data variation, compares the correlation between the telemetry data over a period of time and its historical sample data, and compares the extreme point errors, so as to realize the spacecraft abnormal state detection with only a small amount of historical data and without design knowledge. It overcomes the dependence of existing abnormal state detection methods on expert experience knowledge and the problem that the existing detection methods cannot solve the abnormal changes of telemetry parameters which do not exceed the normal range. It provides an effective and intuitive method and tool for spacecraft managers to analyze the changes of spacecraft state.

1. Introduction
Telemetry data is an important basis to reflect whether the spacecraft is running normally or not. Combined with telemetry data, spacecraft operation managers, field experts and designers can accurately detect the abnormal operation of spacecraft, analyze the causes of abnormal operation, and improve the design of spacecraft, so as to improve the overall design and operation management level of spacecraft. Among the current mutation detection methods, there are mutation detection methods based on statistical distribution, such as mutation detection using the range of statistical parameter change rate\(^1\)[2]. There are knowledge-based mutation detection methods, such as mutation detection using upper and lower limits of parameter design\(^3\). And there are mutation detection methods based on equipment failure principle. For example, using experimental data to analyze failure mechanism and carry out early abnormal detection. These methods can detect the variation of data in some aspects, but they need a lot of historical data to do statistics or master the knowledge of system design, and can only judge the single-point data at a certain time, and can not detect the abnormal changes that are not exceeding the limit, so they have certain limitations. In this paper, a method for detecting abnormal state of Spacecraft Based on telemetry data is designed, which mainly uses the historical telemetry data of spacecraft, combines the recent TT&C events and changes of state variables, completes the detection of abnormal state of spacecraft by comparing the difference between the data to be detected and the normal sample data. This method overcomes the shortcomings of the existing technology, and improves the detection efficiency and accuracy.
2. Extraction of feature extremum points from telemetry data

Spacecraft abnormal state detection method based on telemetry data includes telemetry data preprocessing unit, correlation degree calculation unit, extremum point extraction unit, abnormal state extraction unit, telemetry parameter original database, correlation degree threshold database, extremum point threshold database, etc. Its algorithm architecture is shown in Figure 1.

Fig. 1 Spacecraft Abnormal State Detection Algorithms Architecture Based on Telemetry Data

Among them, the original database of telemetry parameters stores historical telemetry data of telemetry parameters, correlation threshold database stores correlation threshold, and extremum threshold database stores extremum threshold.

The telemetry data preprocessing unit preprocesses the telemetry data sequence to be detected in a specific time length and the historical telemetry data sequence corresponding to the same time in the original database of telemetry parameters. The preprocessing includes error code and singularity elimination, mean calculation and null value filling.

Relevance calculation unit calculates the correlation coefficient method of the pre-processed telemetry data sequence and the historical telemetry data sequence, get the correlation coefficient of the telemetry data sequence to be detected and the historical telemetry data sequence, and compare the correlation coefficient with the correlation threshold stored in the relativity threshold database. According to the comparison results, we can judge which telemetry parameters are abnormal, and those whose correlation coefficient is greater than the threshold of correlation degree are regarded as abnormal, otherwise they are regarded as normal.

The extremum extraction unit extracts the extremum points of the telemetry data sequence to be detected and the historical telemetry data sequence corresponding to the anomalous telemetry parameters, and integrates the extremum points of the corresponding time points of the two telemetry data series through the linear interpolation point method. The extremum points of corresponding time points of two telemetry data series are integrated by linear interpolation point method, so that the
number of extremum points in the telemetry parameter series to be detected is the same as that in the historical telemetry parameter series.

The abnormal state extraction unit calculates the relative errors of extreme points in two telemetry data sequences point by point, and compares the relative errors with the extreme point thresholds stored in the database of extreme point thresholds. The extreme points whose relative errors are greater than the extreme point thresholds are the abnormal extreme points. The telemetry number is extracted from the abnormal extreme points. According to the abnormal time period, the change trend of the telemetry data in the abnormal time period is analyzed to realize the spacecraft abnormal state detection.

The method for calculating the correlation coefficient method of the pre-processed telemetry data sequence to be detected and the historical telemetry data sequence is as follows:

The formula for calculating the correlation coefficient $\text{Cov}$ is as follows:

$$
\text{Cov} = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2} \sqrt{\sum (y - \bar{y})^2}}
$$

Among them, $x$ is the sequence of telemetry data to be detected, $y$ is the sequence of historical telemetry data, and $\bar{x}$ and $\bar{y}$ are the mean values of sequence $x$ and $y$ respectively. The range of $\text{Cov}$ is $[-1, 1]$.

The method for extracting extreme points in the telemetry data sequence $x$ to be detected is as follows:

$$
(x_{i+1} - x_i) \times (x_i - x_{i-1}) = \begin{cases} < 0, & x_i \text{ is Extreme point} \\ \geq 0, & x_i \text{ is not Extreme point} \end{cases} \quad (1 < i < N)
$$

The extraction method of extreme points in historical telemetry data sequence $y$ is as follows:

$$
(y_{i+1} - y_i) \times (y_i - y_{i-1}) = \begin{cases} < 0, & y_i \text{ is Extreme point} \\ \geq 0, & y_i \text{ is not Extreme point} \end{cases} \quad (1 < i < N)
$$

Among them, $x$ is the telemetry data sequence to be detected, $y$ is the historical telemetry data sequence, and $N$ is the sequence length.

3. Abnormal state detection

Through the integration and analysis of feature extremum points, the abnormal state of spacecraft is extracted. The schematic diagram of the integration process is shown in Figure 2. Integration process of extremum sequence: First, by comparing the two extremum sequences, find out whether there are extremum points with the same abscissa (b in Figure 2), and then make corresponding complements to other points.

![Fig.2 Extreme Point Integration Method Architecture](image)

For the complementary value of B-point in the sequence of detection extremum points, the coordinates of $a$ and $c$ points in the sequence of telemetry data to be detected before integration are set respectively as $x_a$ and $x_c$. And the coordinates of $a$ and $c$ points in the sequence of historical telemetry data are set separately as $y_a$ and $y_c$. The calculation formulas of B-point are as follows:
Among them, \( x \) is the telemetry data sequence to be detected and \( y \) is the historical telemetry data sequence.

For the abnormal state extraction unit, the method of calculating the relative errors of extreme points in two telemetry parameter sequences point by point is as follows: the formula of calculating the relative errors of extreme points at B point in Fig. 3 is as follows:

\[
y_b = \frac{y_c - y_a}{x_c - x_a} (y_c - y_a) + y_a
\]

Among them, \( E \) is the relative error of extreme points, which are the coordinates of extreme points of the integrated telemetry data sequence to be detected and the coordinates of extreme points of historical telemetry data sequence. If the relative error \( E \) is greater than the threshold value, the extreme value is considered abnormal, and vice versa.

If the distance between two adjacent fault points is larger than the set distance threshold, the two fault points are considered to belong to two fault segments respectively. Otherwise, the two fault points are considered to belong to the same fault segment, and the information of the fault occurrence period is finally obtained.

For example, by analyzing the telemetry data of spacecraft telemetry parameters, according to the characteristics of telemetry parameters, we choose one day as a unit to calculate the mean and variance of the data, which avoids the short-term data deviating from the short-term data due to the large changes of the short-term state data of spacecraft and other time data, and thus can be more effective. The real historical data of telemetry parameters are well preserved and the singularities in telemetry parameters are eliminated. After eliminating singular points, the change of telemetry data is relatively smooth, so it is suitable to use linear interpolation method to fill empty points. The thresholds of correlation coefficients for different types of parameters in different subsystems of spacecraft may be different. The thresholds of correlation coefficients can be obtained by training historical data of parameters. By integrating the extremum points of the data to be detected and the sample data, the problem that the location of the extremum points is different and the relative error can not be calculated can be avoided. In addition, the relative error thresholds of extreme points of telemetry data with different telemetry parameters can be obtained by training historical data.

4. Conclusions

In this paper, a method of spacecraft abnormal state detection based on telemetry data is designed, in which the correlation threshold of different parameters can be trained by historical data or set artificially by experience, so as to improve the accuracy of correlation determination. The extremum extraction unit can integrate the extremum points of the parameters to be detected and sample data, so as to avoid the problem that the relative errors can not be calculated due to the different locations of extremum points. In the abnormal state extraction unit, the relative error thresholds of extreme points of different parameters can be trained by historical data, or can be set artificially by experience, which can improve the accuracy of abnormal time extraction of parameters. The design in this paper makes full use of the historical telemetry parameter samples, combines the characteristics of the spacecraft telemetry parameter data and the law of data change, compares the correlation between the telemetry data over a period of time and its historical sample data, and compares the extreme point error. It does not need design knowledge, but only a small amount of historical data. It improves the detection efficiency and accuracy, thus overcomes the dependence of the existing abnormal state detection methods on expert experience knowledge and the problem that the existing detection methods can not solve the abnormal changes of telemetry parameters which do not exceed the normal range. It provides an effective and intuitive method for spacecraft managers to analyze the state changes of spacecraft.
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