Health Prediction of Airborne System Based on Grey Prediction

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Abstract. With the development of civil aircraft technology, the scale of civil aviation industry in China is expanding, and the service capacity is gradually improving. Civil aviation industry has become an important industry in China's economic development. With the increasing complexity, integration and intelligence of aircraft, it is more and more difficult to diagnose and maintain the fault of airborne system. The traditional fault diagnosis and maintenance methods cannot meet the requirements of modern aircraft development. Especially in the field of aircraft maintenance, the thought of aircraft maintenance has gone through the transformation process from "preventive maintenance" to "reliability maintenance", and the maintenance method of aircraft has gradually changed from the previous scheduled maintenance to the situation-based maintenance.

1. Introduction

Prediction and Health Management (PHM) represents a change of method, that is, from the traditional sensor-based diagnosis to the intelligent system-based prediction, from the reactive maintenance to the active and active activities of accurate maintenance at the right time. The purpose of PHM system is to realize condition based maintenance, prevent insufficient and excessive maintenance, reduce support costs and improve maintenance efficiency. Fault prediction and health monitoring system is the key auxiliary system for the development of the new generation of aircraft. The breakthrough of its technology and the development of the system have important practical significance for the new generation of aircraft to adapt to the needs of the secondary maintenance system, improve the comprehensive support ability and combat effectiveness, and reduce the maintenance cost of the aircraft life cycle. Aircraft hydraulic system is one of the typical systems in aircraft structure, which has the characteristics of a kind of system. The study of PHM is very representative. The application of PHM technology has effectively accelerated the process of transformation from post maintenance and preventive maintenance to on-the-spot maintenance. Not only that, it has also essentially changed the traditional aircraft support system. By canceling the relay level maintenance, the maintenance link of the failed mechanical and electrical components can be effectively reduced, the maintenance efficiency can be improved, the aircraft fault state time can be shortened, and the three-level support system can be transformed into two-level support.

2. Principle of Grey System

2.1. The basic concept of grey system

The theory of grey system realizes the correct understanding and accurate description of the operation law of the system and makes scientific prediction based on the generation, development and extraction
of valuable information of some known information. The grey system theory is a theory to study the uncertainty of less data. On the basis of analysing the characteristics of less data, understanding the behaviour of less data, exploring the potential mechanism of less data, and synthesizing the phenomenon of less data, grey theory reveals the evolution law of things under the background of less data and less information. Specifically, in the context of less data uncertainty, data processing, phenomenon analysis, model building, development trend prediction, decision-making, system control and state evaluation are the basic contents of grey theory.

2.2. Grey modelling mechanism

Based on the concept of correlation space and smooth discrete function, the grey derivative and grey differential equation are defined in the grey system theory, and then the dynamic model of differential equation type is established with discrete data. Considering that this is the basic model of the intrinsic grey system, and the model is not unique and approximate, it is called grey model, which is recorded as GM (grey model). Grey model is the basic model of grey system theory and the basis of grey control theory.

The general modeling method is to use the original sequence to directly model, while the grey modeling is to change the irregular original data into the regular generated sequence to re model. As the system is polluted by noise, the original sequence presents a chaotic situation. The disordered sequence is called grey sequence (or grey process). The model of grey process is called grey model. Grey model is the core part of grey prediction. In practical application, as long as the modeling characteristics and methods are fully mastered, grey model generally has better fitting effect.

2.3. Grey sequence generation

Stochastic process is based on prior probability to study the statistical law of data. This method is based on a large amount of data. But sometimes, even with a large number of data, it is not necessarily possible to find statistical laws. Because the typical distribution studied in probability theory or stochastic process is very limited, it is difficult to deal with the theory and application of grey system for the non-typical distribution process (such as the distribution process other than stationary process, Gaussian process, Markov process or white noise process). By sorting out the given original data, the method to find the internal law of change is the generation of grey series.

The generation of grey sequence is a means to make the grey process white. It can provide intermediate information for modeling and weaken the randomness of the original data. It plays an extremely important role in the theory of grey system. The generation of grey sequence can find out the development trend of grey accumulation process, fully reveal the integral characteristics or laws contained in the discrete original data, and transform any non-negative and swinging sequence into non decreasing and increasing sequence.

3. Classical GM(1,1) Model

3.1. Model principle

Grey prediction is to use grey model to predict, analyse the given initial data, build the model according to the known information, simulate the internal law of the system, and make accurate prediction for the unknown information of the system. Generally, grey prediction initializes the data first, not directly analysing the rules or mathematical relations between the data, but first adding or subtracting the data cumulatively. In this way, new data will have better regularity, form new time series data, and then build a mathematical model of the new series. The amount of sample data needed by the grey model is relatively small. The establishment of the model is based on the mathematical method, so it has a high accuracy of prediction, so it is widely used. The accumulation and subtraction of grey model is mainly to regularize the data. Accumulation is to add the initial data according to the time of occurrence to generate a new sequence, while subtraction is the opposite. The accumulated sequence can be reduced to the sequence before accumulation, and the incremental information can be obtained in the process of
modelling. The new data obtained through the process of accumulation and subtraction has certain rules and reduces the randomness, which is a very effective step for extracting the useful information in the data, which is also a unique advantage of the grey system.

3.2. General steps of the model
1. Level comparison test and modelling feasibility analysis. For a given sequence, whether the prediction model with high accuracy can be established or not can be generally analysed by the size of the stage ratio and the interval to which it belongs, that is, coverage.
2. Data transformation processing.
3. Make an accumulation of the original sequence \( X^{(0)} \) to generate \( X^{(1)} \)
4. Calculate the mean value sequence \( Z^{(1)} \) of \( X^{(1)} \), construct data matrix \( B \) and data vector \( Y \)
5. Model building
\[
X^{(0)}(k) + a^*Z^{(1)}(k) = u
\]  
6. Calculation \( a, u \)
7. Finding the value of generating sequence and restoring value of model
8. Model test: check whether the model accuracy meets the requirements given in advance
9. After the test accuracy meets the requirements, use metabolism method to obtain the prediction sequence one by one.
10. The feasibility of prediction is verified by comparing the prediction sequence with the known sequence.

4. Verification of Experimental Results
According to the flight parameter data on 566 flights of a certain aircraft, the parameters with changing trend in the flight process are screened out, the front landing gear release subset corresponding to the main hydraulic pressure in each flight process is extracted. Then the corresponding mean value is calculated, and a sample set of 566 main hydraulic system health parameters is obtained. This set is the prediction experiment sample, and its specific value is shown in Figure 1.

![Hydraulic mean value series of landing gear down stage of a certain type of landing gear](image)

First of all, carry out the level ratio test on its data, take the first 500 groups of data for modelling analysis, according to the formula
\[
\sigma(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)} \]  
so \( n = 500, \) get \( \sigma(k) \in (0.995, 1.004) \). The order ratio test sequence can be obtained as shown in Figure 2.
Fig. 2 Grey model level ratio test

The maximum value is 1.034 and the minimum value is 0.967, which does not conform to the limit of grey ratio. At this time, the original data needs to be adjusted to meet the scale limit. The common data transformation includes translation transformation, logarithm transformation, square root transformation and so on. Here, you can select translation change, add all the values of the original data to 50000, and get a new set of data series, and judge the level ratio of the data series as shown in Figure 3. The minimum level ratio is 0.9981, and the maximum is 1.0017, which is in line with the rules. Therefore, grey model can be used for this transformation sequence.

Fig. 3 Level ratio test of grey model of translation transformation

Select the first 500 sorties for modelling analysis, use the steps shown in 3.2, and the results are shown in Figure 4.

Fig. 4 Grey modelling raw data and training data

The residual sequence is shown in Figure 5. The maximum residual value is -52 psi, and the absolute average value is 8 psi. Because the hydraulic base value is too large and the hydraulic variation range is too small, it is not significant to use the hydraulic value sequence as the reference value of relative error. Therefore, the length of hydraulic variation range can be taken as the reference value in combination with the principle of aircraft hydraulic system and landing gear system. The relative error is as shown
in Figure 6, from which it can be seen that the error reaches the peak value of 21.1% in the 381st sortie, and the average error of 5.6% can be obtained by synthesizing 500 groups of data, meeting the prediction accuracy requirements.

Through this model, the average pressure of the last 66 sorties is calculated by metabolism method, and the predicted results are compared with the real ones. The results are shown in Figure 7.

By calculating the residual and relative error, the maximum residual value of 66 groups of data predicted is -60psi; the absolute average residual value is 12psi; the peak error of 66 groups of error series data is 24.1%, and the average error is 5.9%.

5. Conclusion
The research content is the health prediction of the landing gear retraction and extension system based on the grey prediction method. Because the landing gear retraction and extension system is driven by the main hydraulic system, the main hydraulic pressure mean value provides the most valuable information, so the main hydraulic pressure mean value sequence of the landing gear retraction and extension stage is selected as the prediction data. Using the classic GM (1,1) grey prediction method to predict the future trend well.

Acknowledgments
This work is supported by the scientific research group of the College of Aviation.

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