Automatic Interpretation for Telemetry Parameters Based on prediction method

Suhui Dong *, Changwen Cui, Pengju He, Changan He, Weiwei Kang
Jiuquan satellite lunch center Jiuquan, China

* suhuism@163.com

Abstract. Based on prediction method, a novel method of automatic interpretation for problem of the slow-varying telemetry parameters changing suddenly is proposed. Firstly, extract the envelope of the flight data and then filter the envelop. Secondly forecast the filtered envelop using linear prediction method and prediction method based on GM (1,1) model. Finally, according to the estimated value and standard deviation of the parameters, the statistical analysis of the target data is carried out, where the parameters are determined to be abnormal or not according to the analysis result, so as to realize the automatic interpretation function of the parameters. The test results show that the prediction method based on GM (1,1) model can effectively identify the mutation or pulsed parameters in the slow-varying telemetry parameters Compared with the traditional method of the artificial interpretation, this method can effectively improve the efficiency and accuracy of the telemetry parameter interpretation.

Keywords: Prediction method, GM (1,1) model, linear prediction, Automatic Interpretation.

1. Introduction

In the launch test, ground security control system accurately determining whether the vehicle is normal or not play a very important role in is directly related to the safety of important facilities around the navigation area and people's lives and property[1-7]. During the flight, the internal state and working conditions can be reflected by telemetry parameters. Analyzing telemetry data in real time and judging whether the telemetry parameters are abnormal or not timely and accurately is becoming more and more important for the safety of security control effect. At present, due to the existence of noise, interference and vibration in the flight test mission, it is difficult to realize automatic interpretation of telemetry data with inconsistent changing, and it is still judged by relevant experts with manually monitoring whether the key telemetry parameters exceeding the threshold range. With increasingly heavy and complexity tasks, there is a large amount of information, a large number of parameters, and a variety of parameter data. Experts alone struggle to keep interpretation, comparison, and review of testing data, not only because have a large workload and low efficiency, but also easy to cause artificial interpretation omissions and deviations, so the interpretation accuracy is difficult to control.

In order to solve this critical problem, many scholars have done in-depth research and scored fruitful results. In research literature [8] the architecture design of the telemetry parameter interpretation system platform is discussed including the platform composition, implementation details, and interpretation
rules in detail, but it is still a more vaguer concept without clearly analyzing of auto-judging method for telemetry parameter. In references [9-10] the correlation coefficient method and curve fitting method are presented to realize auto-judging telemetry parameters. Both methods can achieve the interpretation of slow variation parameters to a certain extent, but only succeed in the case of ground testing because the effects of disturbances during flight are not considered. In view of the above problems, this paper proposes an automatic interpretation method for telemetry parameters during flight based on prediction method. The prediction method predicts subsequent data based on the limited set of data in the single telemetry data, and it has high prediction accuracy for slowly-changing telemetry parameters, but has strong sensitivity to sudden changes. This paper adopts linear prediction and gray prediction with GM (1,1) model respectively for the same group data to achieve the purpose of automatic interpretation of abrupt or impulse parameters in the telemetry slow variation parameters. Finally, according to simulation calculation of engineering data and analyzing and evaluating of the results, the practicability and effectiveness of the two method in the automatic interpretation of the slow variation telemetry parameters are compared.

2. Algorithm design
During the flight, some slow-variation telemetry parameters will be pulsed or abruptly changed because they are directly affected by the working status of the equipment and external disturbances. Prediction method can be used to interpret mutation or pulse data, accurately determine every mutation or pulse, including occurrence time and action related to it, and so on. This paper uses two prediction models which are linear prediction and gray prediction based on GM (1,1) to realize the interpretation of flight vibration data and find out the abrupt points and mark them.

2.1. Linear prediction
The telemetry data of the present time can be predicted based on the telemetry data earlier, as shown in formula (1).

\[ y_n = \alpha_1 y_{n-9} + \alpha_2 y_{n-8} + \alpha_3 y_{n-7} + \alpha_4 y_{n-6} + \alpha_5 y_{n-5} + \alpha_6 y_{n-4} + \alpha_7 y_{n-3} + \alpha_8 y_{n-2} + \alpha_9 y_{n-1} \]  

(1)

Where \( y_n \) is the telemetry data at present, \( y_{n-i} \) is the telemetry data earlier, \( \alpha_i \) is coefficient. Analyzing statistical characteristics of the historical data of the ground testing at launching site, we find that the parameter value of which the rate changing suddenly outside ten standard deviations of the mean, and most of the noise values are generally within or near three standard deviations of the mean. According to this discovery of determines statistical properties of history test data. Taking six standard deviation of the raw data as the standard to detect data stream suddenly changing. When the difference of predicted value and real value exceed six standard deviation of the raw data, the point is marked which means at the point data changes suddenly.

2.2. Prediction based on GM(1,1)model
The gradation prediction is the whitening process of the gray process, and GM (1,1) model is the basic model of the gradation prediction method. Differential equations is used as a tool of GM (1,1) model, explicit information and hidden information in the data is fully developed and utilized to accurately discover the intrinsic change rule among factors of the original data sequence. The gradation prediction method with GM (1,1) model with no need for a large number of samples or regular distribution, has its own characteristics of less calculation and higher accuracy, especially for mass data. The principle of the gradation prediction with GM (1,1) model is shown in Figure 1.
Let $x^{(0)}$ denote the data sequence of the telemetry parameter:

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n))$$  \hspace{1cm} (2)

$x^{(1)}$ is the accumulation sequence of $x^{(0)}$:

$$\begin{cases} 
x^{(1)}(1) = x^{(0)}(1) \\
x^{(1)}(k) = \sum_{m=1}^{k} x^{(0)}(m) \quad (k > 1) 
\end{cases}$$  \hspace{1cm} (3)

$z^{(1)}$ is the proximate mean sequence of $x^{(1)}$:

$$z^{(1)}(k) = \frac{1}{2} (x^{(1)}(k) + x^{(1)}(k - 1)) \quad k \geq 2$$  \hspace{1cm} (4)

The differential equation of the GM (1,1) model can be expressed as:

$$x^{(0)}(1) + az^{(1)}(k) = b$$  \hspace{1cm} (5)

Then the least squares estimation of the parameter $u = [a \ b]$ is

$$u = (B^T B)^{-1} B^T Y$$  \hspace{1cm} (6)

Where

$$B = \begin{bmatrix} -z^{(1)}(2) \\ -z^{(1)}(3) \\ \vdots \\ -z^{(1)}(n) \end{bmatrix}, \quad Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}$$  \hspace{1cm} (7)

Put $a, b$ into formula (5) and solve, the GM (1,1) prediction model is

$$x^{(1)}(k+1) = (x^{(0)}(1) - \frac{b}{a} e^{-ak} + \frac{b}{a}$$  \hspace{1cm} (8)

It can be obtained after first order reduction
3. Simulation and calculation

To analysis the flight telemetric testing data of a certain missile, firstly get the upper envelope of the data. Then predict the data point by point using the linear prediction method, taking the linear prediction coefficient as: \[ \alpha = [\alpha^1, \alpha^2, \alpha^3, \ldots, \alpha^9] = [1 1 1 2 2 3 3 4 4]/21 \]. The filtered data of the upper envelop is shown in Figure 2. The upper half part of figure 2 shows the filtered data and its linearly predicted data curve. Throughout the flight, several pulses will occur due to severe shock caused by the separation. The lower half part of figure 2 shows the data produced by subtracting linear data from the original data point by point. As can be seen from the figure, when the data in slow changing environment, the original data and the predicted data are in good agreement. When the data suddenly changes there will be a sluggishness at first, because linear prediction method is linearly derived from the historical points. Taking advantage of the forecasted data lagging of the raw data, the abrupt point can be detected.

\[ \hat{x}^{(0)}(k + 1) = \hat{x}^{(1)}(k + 1) - \hat{x}^{(1)}(k) \]  

Figure 2. Linear prediction of the envelope

Taking six standard deviation of the raw data as the standard to detect data stream suddenly changing. When the difference of predicted value and real value exceed six standard deviation of the raw data, the point is marked which means at the point data changes suddenly. Figure 3 shows the points marked by the linear prediction method. It can be seen from the figure that using the linear prediction method can only mark the points with large mutations, and the points with small mutations are ignored.

Figure 3. Mark points based on linear prediction
Taking the same flight telemetric testing data as target data, getting the upper envelope of the data. Then predict the data point by point using the prediction method based on GM (1,1) model, according to the gray prediction method with GM (1,1) model, taking 10 sampling points to calculate the prediction data point by point. Once a new sampling data enters, the older sampling point is removed every step. The upper half part of figure 4 shows the original data and the gray predicted data curve based on the GM (1,1) model. The lower half part of figure 4 shows the data produced by subtracting predicted data from the original data point by point. It can be seen that the new gray prediction has a stronger effect on the abrupt data.

![Figure 4. Prediction method based on GM (1,1) model](image)

Similarly, taking six standard deviation of the raw data as the standard to detect data stream suddenly changing. When the difference of predicted value and real value exceed six standard deviation of the raw data, the point is marked which means at the point data changes suddenly. Figure 5 shows the points marked by the prediction method based on GM (1,1) model. It can be seen from the figure that regardless whether large or small mutations can be marked, therefore, the prediction method with GM (1,1) model is more sensitive to mutations.

![Figure 5. Mark point based on prediction of GM (1,1) model](image)

### 4. Conclusion
During the flight, the saltation of telemetry data often means jitter appearing, failure or other unexpected conditions, and when interpreting of telemetry data it is a key concern. Focus on the problem of difficulty and low efficiency in interpreting the mutation telemetry parameters, creatively put forward auto-
judging method which realize marking telemetry mutation points based on prediction algorithm. Linear prediction and prediction method with GM (1,1) model were adopted respectively with 6σ principle to realize auto-identification of the mutation points. Comparing those two methods, it is found that the prediction method with GM (1,1) model is more sensitive to mutation. Applying gray prediction method based on GM (1,1) to the automatic interpretation can improve interpreting efficiency and accuracy.

References
[1] HAN Feng, CHEN Han, CHEN Fang. Research on the Trajectory of a Rocket-towed Net System[J]. Acta Armamentarii, 2015.
[2] John R. Bucknell. The Nuclear Thermal Turbo Rocket - A Conceptual High-Performance Earth-to-Orbit Propulsion System[C]// 51st AIAA/SAE/ASEE Joint Propulsion Conference. 2015.
[3] Bo Dong, Xiaoyan Tong, Yu Liu. A new type of rocket engine ground sensing and test system based on compressive sensing[C]// 2015 IEEE International Conference on Mechatronics and Automation (ICMA). IEEE, 2015.
[4] Andrew Gilbert, Bryan Mesmer, Michael Watson. Exergy based optimization of rocket system staging times[C]// 2016 Annual IEEE Systems Conference (SysCon). IEEE, 2016.
[5] Chua Y M. The Complex System Records Model: Recordkeeping for Wicked Problems - eScholarship[J]. 2012.
[6] Charles B. Keating, Polinpapilinho F. Katina, Joseph M. Bradley. Complex system governance: Concept, challenges, and emerging research[J]. International Journal of System of Systems Engineering, 2014, 5(3):263-288.
[7] Jingjie Chen, Zhou Zhou, Hong Geng. Research on multi-leveled troubleshooting model based on Petri nets[C]// 2013 Chinese Automation Congress (CAC). 2013.
[8] RongGang The Automatic Design on the Telemetry Data Processing Software. Dual Use Technologies & Products [J] 2013, (4):53-55
[9] LiXIn,A Novel Method of Automatic Interpretation for Slow-Varying Telemetry Parameters. Journal of Astronautics [J]. 2018, 39(5): 585-592.
[10] ZhangQian, Design and Realization of Automatic Interpretation Based on Model ,Computer Technology and Development[J, 2014, (7): 17-20,24]