Research on Construction Method of Wavelet Telemetry Data with Improved Threshold

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Abstract—**In order to strengthen the applicability of data denoising algorithm, this thesis study the common telemetry data denoising algorithm based on the data of engine speed, flight space speed, cabin temperature and humidity, and establishes the evaluation model of error square sum and curve similarity to evaluate the denoising performance. Experiments show that the polynomial fitting has the greatest denoising error and slow convergence speed. The five-point cubic smoothing has the smallest overall denoising error, the median filtering algorithm can change the effect of smoothing effect by adjust it's moothing window, but ignores the authenticity of data. Therefore, the above three data denoising algorithms do not meet the requirements of telemetry data processing. In this thesis, an improved threshold function is proposed which effectively improves the data jump and excessive smoothing and reduce the denoising accuracy compared with the traditional thresholding function in order to makes the measured value closer to the true value. The algorithm is applied to the noise processing of four kinds of telemetry data, the results show that the denoising accuracy is improved significantly compared with the other three algorithms, which makes the measured value closer to the true value to reflect the changing trend of the original measurement data more truthfully, and the curve similarity is improved significantly, which are all above 80%.**

Keywords-Function Construction; Measurement Error; Telemetry Data; Curve Similarity

I. INTRODUCTION

In order to ensure the safety of aircraft flight, a lot of testing work needs to be done before the official flight. Due to the measurement of telemetry parameters and the vibration, electromagnetic interference, quantization error and propagation path during transmission, the original data will inevitably have measurement errors. At this time, the measured values usually have burrs, sharp corners, sudden changes, etc., which may cause some interference to the signal analysis. In order to improve the measurement accuracy of the telemetry system, reduce the fitting error, and ensure the safety of the aircraft, the research on the construction method of the telemetry data function is very important.

Common function construction methods mainly include simple polynomial fitting, differential evolution [1-3], ant colony optimization [4], moving average, weighted local polynomial regression, etc [5]. (Zhang B, J. et al, 2015). polynomial fitting is simpler to implement, but it has disadvantages such as large fitting error and slow speed. Differential evolution and ant colony optimization algorithms have been widely used in numerical optimization, but only for combinatorial optimization problems on continuous regions, and are not suitable for numerical optimization on discrete regions [6-7]. The real-time cost of the sliding average algorithm data is exchanged for stability, and the larger the amount of data selected, the larger the delay; When the number of smoothing points is small, although the sum of the squares of the residuals is small, the smoothness is very poor and still has a broken line shape; The weighted local polynomial regression method has a poor smoothing effect when the error obeys the normal distribution; Zhao B. [8] presents a data processing method based on wavelet analysis for the problem of smoothing noisy data, the noise intensity is estimated and the data filtering is effective. Liang J, [9] derived from the literature to use Kalman filter for data smoothing, with small estimation bias and good real-time performance. However, for aircraft display systems, such methods are often poorly evaluated for parameters such as maximum delay and maximum error. Wavelet transform can simultaneously analyze signals in time domain and frequency domain. The denoising can be summarized into three methods: the wavelet coefficient modulus maxima denoising method proposed by Mallat; the spatial correlation noise reduction based on wavelet coefficients proposed by Sui W T, et al. [10] wavelet threshold denoising shrinkage method based on traditional hard and soft threshold ideas proposed by Donoho and Johnstone [11-13]. By studying the traditional soft threshold and hard threshold function, it can be concluded that the hard threshold method can preserve the edge features of the data and has the advantage of effectively retaining the authenticity of the data. However, this method does not have continuity, and it is easy to cause visual distortion such as vibration and pseudo-Gibbs effect at discontinuous points during signal reconstruction [14]. The advantage of soft threshold method is that the image is smoother after denoising, but it will make a fixed error between the estimated coefficient and the original coefficient, and make the edge information of the image blurred after denoising, resulting in image distortion after denoising [15]. In order to improve the denoising performance of the threshold function of wavelet method, Breiman proposes a compromise algorithm garrote threshold function, which is based on the traditional soft and hard threshold functions, and retains the advantages of the soft threshold function and the hard threshold function. However, the method ignores the feature that the noise will gradually decrease with the increase of decomposition scale under wavelet transform [16].

In order to effectively eliminate the noise of telemetry data and improve the accuracy and applicability of data measurement, this paper studies the construction method of aircraft telemetry data function. This method makes the measured value of the system closer to the true value, which makes it easier for the ground monitoring personnel to test the flight state of the aircraft. Let them perform accurate, real-time fault analysis.

II. TELEMETRY DATA PROCESSING SYSTEM

With the requirement for ensuring flight safety of aircraft is becoming higher and higher. It is necessary to do quantity testing work before formal flight to real-time monitoring and maintenance of flight status to ensure formal flight safety. So, it is very important to develop a efficient telemetry data monitoring system and to study an efficient data denoising algorithm. In order to improve the flexibility and portability of the telemetry system, this thesis uses C++—QT technology to complete the design of data monitoring software which is realizes the dynamic configuration of telemetry engineering task files based on IRIG 106 standard PCM data frame format, frame integrity judgment, data shunting, character conversion and engineering data conversion, to divides and restores the original engineering quantity signal by integrating various parameters along the way. At the same time, the thesis use the double buffer pool technology to receive and store data, which improves the efficiency of data analysis and meets the real-time requirements of system monitoring and maintenance.

Based on the telemetry system, this paper studies the software design of the portable data monitoring system and the construction method of telemetry data function. The telemetry system usually comprises two parts: an aircraft transmitting end and a ground receiving end, a telemetry transmitting end and a ground receiving end, and the transmitting end comprises a device such as a sensor, a converter, an encoder and a transmitter; the receiving end includes a receiving module, a data processing module, a recording module, a display module, and the like. The general structure of telemetry system is shown in Fig 1.

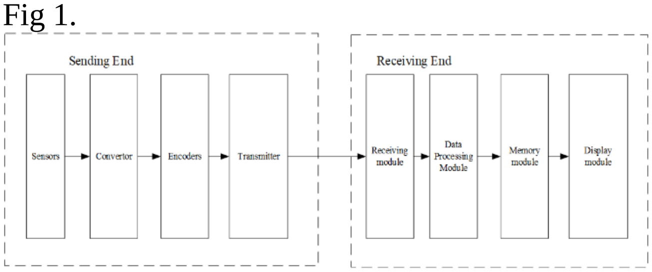

Figure 1. Overview of telemetry data processing structure.

As can be seen from Fig.1, at the sending end, the system collects and encodes the measured information, and edits the multi-channel parameter information into group signals suitable for single channel transmission according to a certain system. This signal is modulated by a transmitter carrier to form an electrical signal which is then transmitted into space.

At the receiving end, after the telemetry signal is transmitted via the radio link, it is first sent to the receiver by the receiving antenna for carrier demodulation to obtain the group signal. Then the data processing module performs signal processing, branching, storage, conversion and other analytical processing to recover the engineering quantity signal, and performs function construction on the parsed data to effectively reduce the measurement error, improve the telemetry data analysis efficiency and fault analysis accuracy. Finally, the measurement information is displayed through the visual interface.

III. Wavelet Function Construction Method With Improved Threshold Function

The wavelet threshold includes global threshold and hierarchical threshold. In order to remove data noise to the greatest extent and avoid local jitter caused by noise removal, the paper uses hierarchical threshold wavelet method to perform telemetry parameter denoising processing, ie for each group of data. The threshold processing is used for multiple times, and the noise of different frequencies is removed layer by layer from low frequency to high frequency, which not only can preserve the details of the data, but also can better smooth the data. Avoid excessive noise smoothing, or incomplete noise removal [17]. Wavelet Hierarchical Threshold Denoising Principle One-dimension wavelet delamination threshold denoising includes four modules: selecting wavelet basis function, determining the number of decomposition layers, carrying out threshold processing and signal reconstruction. The specific threshold noise reduction process is shown in Figure2.

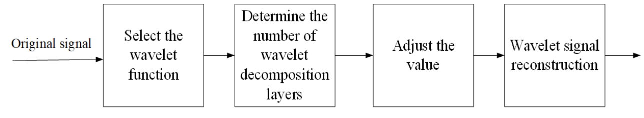

Figure 2. Wavelet threshold method signal reconstruction flowchart.

As shown in Fig 2, firstly, it is necessary to select a base wavelet function and an appropriate decomposition layer according to the data type to decompose the noise signal, so that the noise signal is distributed in the high frequency part [18]. Then, a suitable threshold and threshold function are selected to quantize the high-frequency coefficients generated by the wavelet decomposition, and the wavelet coefficients of the noise suppression are generally expressed as the larger amplitude of the wavelet coefficients is retained, and the smaller amplitude is set to zero; Finally, the quantized wavelet coefficients are reconstructed to obtain an estimated value of the original signal, and data denoising is completed. In the construction of wavelet threshold denoising function, the selection of threshold and threshold function has a great influence on the denoising effect. Since the threshold and threshold functions are not unique, different threshold functions have different denoising effects and decomposition layers. Therefore, the paper will study the threshold function and threshold determination method and optimize and improve the defects of the existing threshold function to improve the denoising accuracy and applicability of the algorithm.

IV. Wavelet Algorithm Design for Improving Threshold Function

In order to effectively measure the data noise and suppress the influence of noise, according to the characteristics that the amplitude of the wavelet coefficient of the effective signal is large and the amplitude of the wavelet coefficient of the noise signal is small, the article uses a multi-layer threshold method for threshold estimation, which is for each group of data. Use more than one threshold processing. Removing noise at different frequencies layer by layer from low frequency to high frequency not only preserves the details of the data, but also smoothed the data better and minimizes the fitting error. Let the number of decomposition layers be j. When it is a sublayer not less than j, all coefficients are retained. When the number of decomposition layers is i ($0<i<j$), just keep the coefficient with the largest absolute value. There are K such coefficients. Let the general signal be α and the detailed signal is d, and the specific formula is defined as:

$$K = \frac{M}{(j+2-i)^{\alpha}}. \quad (1)$$

In formula (1), both M and α are empirical coefficients, and the default value is L(1), which is the length of wavelet coefficients after the first layer decomposition of M, namely M=L(1); As a rule of thumb, if you use the Brige-Massart strategy for signal compression, α = 1.5; and when denoising, α = 3. Based on the determination of the threshold, the paper uses MATLAB to carry out the simulation experiment. It is concluded that the optimal decomposition layer of the four parameters of the engine speed, airspeed, cabin temperature and humidity of the telemetry is 2, ie j = 2.

According to the principle of wavelet layered threshold, when the threshold of noise limited wavelet coefficients is determined, an optimal threshold function is needed to filter the noisy wavelet coefficients effectively to remove the noise coefficients [19-20]. In order to improve the signal distortion caused by data hopping and excessive smoothing of traditional soft and hard threshold function denoising, the article improves and optimizes on the basis of the traditional threshold function, so that the function has continuity, the threshold can change with the change of the decomposition scale, reduce the deviation between the wavelet coefficient and the original coefficient, and improve the smoothness of the curve. In this way, the measurement accuracy and applicability of the wavelet function construction method can be maximized.

First, introduce a contractible equation based on the hard threshold function so that there is continuity at point $\pm\lambda$. Since the amplitude and density of noise increase with the increase of the decomposition scale, it is not appropriate to use the same threshold to process the wavelet coefficients at each scale. Therefore, in order to solve the problem of excessive killing of wavelet coefficients using global thresholds, the paper uses the multi-layer threshold method generated by Brige-Massart strategy to estimate the threshold, that is, using different thresholds for estimation at each layer. Let the threshold $\lambda_j = \sigma\sqrt{2lnN}/\log(j+1)$, where j represents the decomposition scale, $\sigma = median(|\omega_{j,k}|/0.6745)$. The improved threshold function is defined as follows:

$$\overline{\omega}_{j,k} = \begin{cases} \omega_{j,k} - \frac{\lambda_j^n}{\omega_{j,k}} & |\omega_{j,k} \geq \lambda| \\ 0 & |\omega_{j,k} < \lambda| \end{cases} \quad (2)$$

In equation (2), $\omega_{j,k}$ is the wavelet coefficient, $\overline{\omega}_{j,k}$ is the estimated wavelet coefficient value (k is a positive integer), λ_j is the threshold on the scale j, and λ_j is reduced because the scale j is increased, so that $\overline{\omega}_{j,k}$ is close to $\overline{\omega}_{j,k}$. Can effectively overcome the effects of constant deviation. When $\omega_{j,k} \rightarrow \pm\lambda$, this is the case in higher order power functions. $\frac{\lambda_j^n}{\omega_{j,k}} \rightarrow 1, \left(\omega_{j,k} - \frac{\lambda_j^n}{\omega_{j,k}}\right) \rightarrow 0$, This shows that the improved threshold function is continuous at λ; in addition, due to the situation of $\omega_{j,k} \rightarrow \infty$, and then $\left(\omega_{j,k} - \frac{\lambda_j^n}{\omega_{j,k}}\right) \rightarrow \omega_{j,k}$, it is known that the advantages in the hard threshold function are preserved; it can be seen from the function definition of equation (2) that when n = 1 and $\omega_{j,k} \geq \lambda$ occurs, the following situation is obtained: $\overline{\omega}_{j,k} = \omega_{j,k} - \lambda_j$. When $\omega_{j,k} < -\lambda$ occurs, the following situation is obtained: $\overline{\omega}_{j,k} = \omega_{j,k} + \lambda_j$, indicating the improved threshold function and the soft threshold function is the same; when$n \rightarrow \infty$,the improved threshold function is similar to the hard threshold function; indicating that the smaller the value of the higher-order factor n is, the smoother the curve of the improved threshold function is.

V. Algorithm Experiment Research And Result Analysis

In order to verify the superiority of the improved threshold function in the denoising of telemetry data, the paper selects 200 airspeed experimental parameters to verify the algorithm based on matlab. First select the appropriate wavelet basis function; then determine the optimal number of decomposition layers of the signal; on this basis, different threshold functions are applied to reconstruct the wavelet signal to remove the noise signal; finally, the paper uses the error square sum (SSE) and curve similarity (NCC) two quantitative indicators to quantitatively analyze the denoising effect of different threshold functions. The smaller the sum of error squares and the larger the similarity value of the curve, the better the denoising effect of the function is, and it is used to smooth the parameters of the actual telemetry system.

The paper conducts an experimental study based on the telemetry airspeed parameter signal of the telemetry. The curve changes before and after the airspeed data of the aircraft are shown in Fig 3.

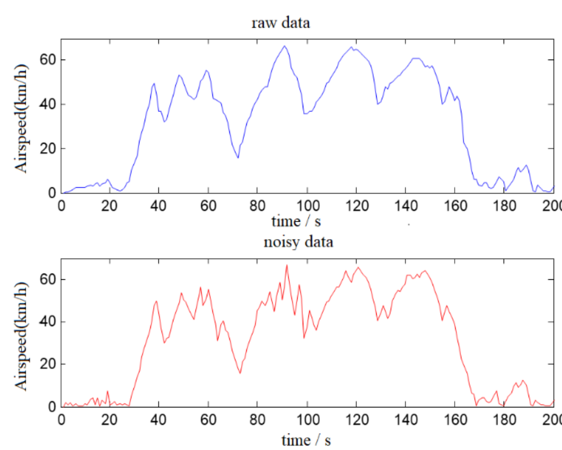

Figure 3. Airspeed raw data, noise data curve change diagram.

Based on the MATLAB platform, this paper uses two different wavelet bases, biorthogonal and symlets, to perform two-layer denoising on the noisy space velocity data. Taking the denoising error value as the criterion, it is concluded that the noise-free airspeed signal is decomposed by the bior5.5 basis function, and the effect is the best.

In order to analyze the denoising superiority of the improved threshold function wavelet method, the paper uses three different threshold functions to perform two-layer wavelet decomposition on the space velocity data of noisy aircraft. The denoising minimum error squared sum value and the curve similarity value of different threshold functions are obtained by experiment. See Table Ⅰ, and the denoising curve display effect diagram is shown in Fig 4, 5, and 6, respectively.

TABLE I. THREE THRESHOLD FUNCTION AIRSPEED DATA DENOISING EVALUATION INDEX VALUE

Denoising Evaluation Index	Soft threshold	Hard Threshold	Improved Threshold Function
SSE	3046.4	2721.5	2477.4
NCC	0.985	0.988	0.990

It can be seen from the evaluation index values of the denoising of the noisy space velocity data by using three different threshold functions as shown in Table Ⅰ. The denoising error of the soft threshold function is the largest, indicating that the method will excessively denoise; the hard threshold function denoising relative soft threshold function denoising error value is significantly reduced, and the curve similarity is also improved; the improved threshold function has the best denoising performance, and the denoising accuracy and curve similarity are significantly better than the other two threshold functions.

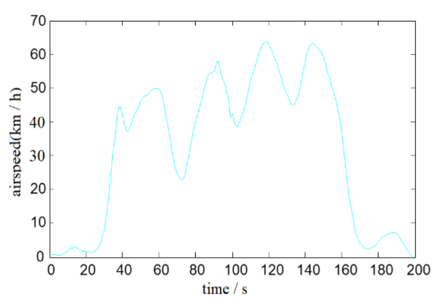

Figure 4. Soft threshold method airspeed denoising curve diagram.

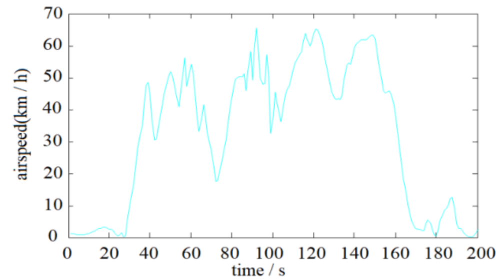

Figure 5. Hard threshold method airspeed denoising curve diagram.

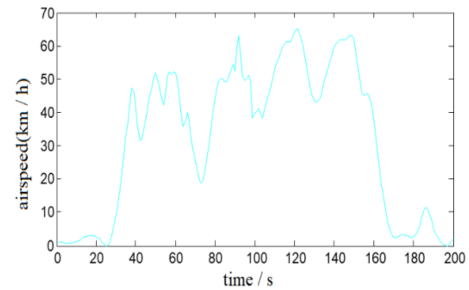

Figure 6. Hard threshold method airspeed denoising curve diagram.

Fig. 4 and Fig. 5 are graphs showing the denoising process of the noisy space velocity data shown in Figure 3 using the traditional soft and hard threshold functions, respectively. Combined with the denoising effect index value in Table Ⅰ, the soft threshold method is used to denoise the airspeed data as shown in Figure 6. The advantage is that it has the highest signal-to-noise ratio. The overall trend of the data curve after denoising is relatively smooth; However, the disadvantage is that the fitting error is the largest, especially for the data points between 40 and 60, the smoothness is too strong, some useful information is lost, and the data curve has the lowest similarity with the original data curve after denoising. The analysis of the airspeed data denoising effect of the hard threshold function shown in Figure 4 shows that although the denoising SNR is slightly lower than the soft threshold function, it has a lower error and the curve similarity is increased to 0.988. The denoising performance is generally superior to the soft threshold function; however, this method does not have continuous processing characteristics, and the smoothness is poor. It can be intuitively seen through the denoising curve diagram that the data still has a glitch point, causing data oscillation, especially between data points 40-70 and 80-100. The data value mutation phenomenon is more serious.

Figure 6 is a graph showing the effect of the wave function on the denoising of the airspeed data after the threshold is improved. Comparing Figures 4, 5 and 6, it can be seen that the improved threshold method is used to denoise the airspeed data, and the denoising curve is smoother than the hard threshold function, which significantly improves the data glitch compared to the hard threshold function, especially at 80-100 data points between. The soft threshold function is oversmoothed between 40 and 60, while the improved threshold rule improves the problem. Combined with Table Ⅰ, it can be seen that the data denoising with the improved threshold wavelet method can not only effectively preserve the variation characteristics of the original data, and the similarity with the original data curve is as high as 0.990, and the influence of the error is also reduced. It also reduces the sum of squared errors after denoising to 2477.4. The denoising performance of this method is significantly better than the other two wavelet threshold methods.

In order to verify the applicability of the improved threshold function wavelet method in the data processing of telemetry system, the method is applied to the denoising processing of data such as engine speed, cabin temperature and humidity of telemetry aircraft. It is known that the signal-to-noise ratios of the three parameters after noise addition are -3.11989db, -0.7004db, 9.8033db, and the value of the variable n in the threshold function is still 3.5, and the interference signal is decomposed, and the number of layers is 2 layers. It can be found that the sum of the squares of the denoising errors for the four kinds of telemetry data and the value of the curve similarity are shown in Table Ⅱ.

TABLE II. IMPROVED THRESHOLD FUNCTION WAVELET CONSTRUCTION METHOD EXPERIMENTAL EFFECT EVALUATION FORM

Algorithm evaluation index	Engine Speed	Airspeed	Temperature Data	Humidity Data
SSE	462060	24774	24.682	21.835
NCC	0.998	0.989	0.978	0.810

From the value of the denoising effect evaluation index in Table Ⅱ. It can be seen that the wavelet method with improved threshold can effectively deal with the data noise, and the similarity of the denoising fitting curve to have strong applicability.

In order to improve the denoising accuracy of telemetry parameters, this paper studies the wavelet threshold method. The matlab simulation shows that the improved Garrote threshold wavelet is superior to the traditional threshold function in denoising performance, and compares the processing results of the airspeed data with the three algorithms mentioned above. The result shows that the denoising effect of the improved algorithm is effectively improved. Finally, in order to verify the applicability of the improved Garrote threshold wavelet method in the denoising of telemetry data, this paper applies the algorithm to the processing of many kinds of telemetry parameters. Through the denoising effect diagram and the denoising performance evaluation index, it is concluded that the algorithm can be better applied to the data processing of telemetry system. In order to effectively remove the data noise, make the measured value closer to the true value, and better maintain the aviation flight safety, the article deeply studies the effectiveness of wavelet transform in the denoising processing of telemetry data. The application characteristics of different thresholds and threshold functions in data denoising are mainly studied. This paper improves the defects of traditional soft and hard threshold functions in data denoising. A wavelet function construction method with improved threshold is proposed. The results show that the improved threshold function has better denoising effect than the commonly used soft and hard threshold functions, and it can improve the data hopping phenomenon of hard threshold function and the excessive smoothing and denoising error of soft threshold function; and it can effectively remove multi-class telemetry data noise, with the highest measurement accuracy, the overall curve similarity is up to 80%, with good measurement accuracy and applicability.

VI. CONCLUSION

In order to ensure the flight safety of the aircraft, it is necessary to collect all kinds of parameters on the aircraft during flight test and transmit them to the ground acceptance equipment in real time for fault analysis by ground inspectors to ensure the flight safety of the aircraft. Because the remote sensing parameters of aircraft will be disturbed by various kinds in the process of acquisition and transmission, the measurement data will inevitably be affected by noise, such as spikes, burrs and other phenomena, which reduces the efficiency of fault analysis of ground detection. In order to avoid the interference caused by data noise, make the data display closer to the real value, and ensure the flight test safety of aircraft, this paper studies the denoising algorithm of telemetry parameter data, reduces the influence of error, and makes the measured value closer to the real value.

Firstly, the least squares method, five-point cubic algorithm and median filtering algorithm are studied. Through matlab simulation technology, the denoising of telemetry parameter signals is processed. It is concluded that the denoising of telemetry parameter signals has great limitations, it's fitting speed is slow, and the denoising effect is poor. Five-point cubic algorithm has certain effect on burr and cusp smoothing, and it can be used to a certain extent. Removal of data noise, but because of the discontinuity of smoothing function, there will be jumping phenomenon between different groups of data points, and the data curve can not be displayed smoothly. When the smoothing window is too small, the trend of data curve changes is quite different from the original data, and almost can not achieve the effect of drying. The bigger the window value, the smoother the curve will be, but it will be destroyed. The authenticity of the data and the denoising effect of the median filtering algorithm are general for the space velocity data with drastic changes.

ACKNOWLEDGMENT

This research is partially funded by the Project funds in Shaanxi province University Student Innovation and Entrepreneurship Fund Project (S S202110702080) and the Project funds in engineering laboratory project (GSYSJ2018013).

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