Wavelet Transform Filtering Method of Optical Fiber Raman Temperature Sensor

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ABSTRACT

The traditional wavelet filtering threshold de-noising method is widely used in the optical fiber Raman sensor temperature measurement, but the weakly spontaneous Raman scattering signal is easily submerged by optical noise and random noise. So the method has a low efficiency. In order to increase the efficiency of signal denoising in the process of temperature measurement, we proposed a new method combine default threshold and the given threshold based on the traditional method. The experimental data of 25Km fiber Raman sensor is filtered by the new method and the results show that the new threshold method can eliminate the noise in the signal, and also preserve the information of temperature variations.

Keywords: *Distributed optical fiber Raman temperature sensor; Wavelet denoising; Threshold value; Temperature measurement error*

1. INTRODUCTION

Distributed optical fiber Raman temperature sensor (DTS) based on the optical fiber Raman scattering effect is the advanced technology and it is used to measure the space temperature field in recent 20 years. The system has reliable temperature resolution and temperature metrical precision. It has been widely used in many occasions because it's inherent advantages, such as small volume, low cost, electromagnetic radiation resistant, corrosion resistant and rapid response. In the DTS system, the temperature of optical fiber is obtained by the ratio of anti stokes and stokes. The uneven medium and the the backward scattering effect will bring in light noise, and the process of photoelectric conversion and signal amplification will import random noise, both of them can cause the antistokes signal which is 20 to 30 dB smaller than the incident pump submerged in noise[1]. Therefore, effective denoising in the process of the weak antistokes signal has become an important part of DTS measurement systems[2]. There is a simple method to deal with the noise by using data accumulation average algorithm. But the method has several shortcomings and defects comparing to the current various methods. It takes a long time to calculate, thus this seriously affected the temperature demodulation in practical application. Wavelet transform is a new signal analysis method based on the Fourier transform, and it can remove the noise in the signal effectively[3][4]. Background elimination method based on wavelet transform is proposed [5], and it has been used to filter the Raman signal background noise. The data accumulation average algorithm and the combination of wavelet transform denoising method is used by Sizu Hou[6], and the method not only improves the signal-to-noise ratio but also shortened the measuring time. Lei Liu [7] proposed a method of using Matlab and VC combined programming and then wavelet transform was applied to the DTS system, causing the temperature measurement error reduced from 3.1℃ to 1.1℃. In the year of 2014, wavelet transform filtering has been used for the Stokes and anti Stokes light in the Raman spectra[8] and get the maximum temperature error range when temperature changes of 25℃ to 295℃.

2. WAVELET THRESHOLD DENOISING

Wavelet threshold denoising method is also called wavelet shrinkage. Its definition content is to perform threshold processing on the wavelet coefficients in each layer after the signal is decomposed. The smaller absolute value will be returned to zero and larger wavelet coefficient absolute value will be retained or shrinked[9]. Finally the signal will be reconstruced after denoising [10].

One dimensional signal with noise can be expressed as[11] :

$$W(K)=U(K)+A*V(K) \quad K=0\cdots,n-1 \qquad (1)$$

The W(K) above is a noisy signal. U(K) performs as a useful signal. V(K) is noise. A is noise intensity. Wavelet threshold denoising is to maximize the efficiency of the useful signal U(K) contained within the noisy signal W(K). The task consists of the following steps:

(1) One dimensional signal wavelet decomposition. Choose a wavelet basis and determine the decomposition layer and then decompose the wavelet. The selection of wavelet basis depend on actual needs. According to the previous experiments we know that the best denosing effect in the Raman optical fiber sensor system is db5. Signal senosing effect will be better with the increase of decomposition layer. But when the decomposition layers rech 5, the computational cost will increase and denoising effect will not boost significantly[12]. Therefore 5 decomposition layer is choosen in the distributed optical fiber Raman temperature sensor system.

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(2) Wavelet threshold decomposition coefficient quantization. After the signal is divided into 5 layers, hard threshold and soft threshold can be used to process the wavelet coefficients obtained in each decomposition scales. This paper will choose soft threshold because it has high-quality image smoothing degree than hard threshold[13].
(3) Wavelet reconstruction. It is to reconstruct the coefficient after decomposition and denoising.

The threshold(T) is the key in the process of extracting useful signal U(K) from noisy signal W(K). It is directly related to the senoising quality in a way. If the threshold (T) is too small, the signal will still contains a lot noise, but if it is too big, some useful components will be easily filtered out as noise, leading to distortion.

3. THRESHOLD ACQUISITION METHOD

During the process of temperature measurement in the DTS system, the temperature changed in a low speed. The useful temperature signal U(K) in the formula(1) performs as stable low frequency components. Therefore, we should try to save the low-frequency components.

Using the wavedec function in the matlab software, selecting db5 wavelet, making wavelet decomposition layer 5. The low frequency coefficient is a5 and the high frequency coefficients are d5, d4, d3, d2 and d1. The wavelet decomposition threshold of the low frequency coefficient is defaulted. High frequency coefficients contains a default threshold and a given threshold method. The methods of obtaining these two thresholds are as follows:

Method one. High frequency coefficient of each layer will use the default threshold during the denoising process. This method is realized by using the wden function in matlab as formula (2) .

softdn=wden(dn,'tptr','s','scal',5, 'db5') (2)

Where dn represents for the high frequency coefficients of each layer after discrete wavelet decomposition.The tptr means four kinds of thresholds. And s indicates that the soft threshold is employed. There are three options for scal. Function wden will automatically decide the threshold applied to each wavelet decomposition layer according to the parameter selection.

Method two. High frequency coefficients of each layer denoising with given threshold. High frequency coefficients can be disposed by the high credibility given threshold. Function of thselect is selected to obtain the threshold.

T=thselect(dn,tptr) (3)

Selecting a threshold form of tptr. Using the function thselect to generate different thresholds for high frequency coefficient dn[14].

Softdn=wthresh(dn,s,B*T) (4)

The soft threshold method is used to process threshold of dn, B is a given constant. The threshold can be changed by B*T.

4. ANALYSIS OF THE RESULTS OF DENOISING

The processing sample is 2000 times cumulative average data produced by 25km raman thermometry product prototype. Due to the fiber end has the worst signal to noise ratio, and the measurement error is also the largest there, we focus on temperature change at the fiber end. Put the last 40m fiber into a thermostat of 75℃, and the rest on the optical disc at room temperature.

In figure 1, the black solid dots is 2000 times cumulative average algorithm data, and the black line is high frequency coefficients of the default threshold after filtering obtained by method one. By comparing two different high frequency coefficients filtering method we found that the filtering effect of method two is much better than method one as shown in figure 3 and figure 4. 1000 sample data are extracted from the background curve at the left of the temperature package. The results through standard deviation calculation show that the temperature error of 2000 cumulative average algorithm is 4.4℃, while the error of method one and two are 3.9 ℃and 1.4℃,respectively.

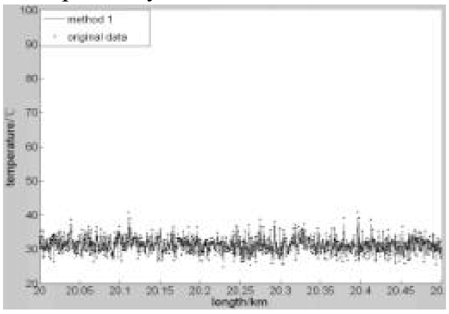

Fig.1. The comparison chart of 2000 cumulative average and denoising method one

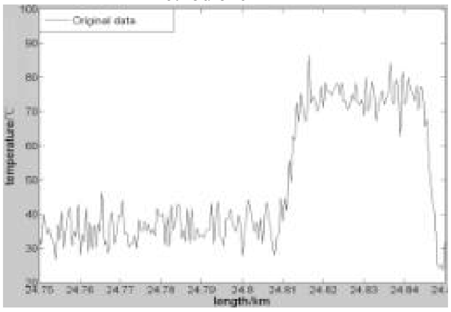

Fig.2. The chart of 2000 cumulative average method

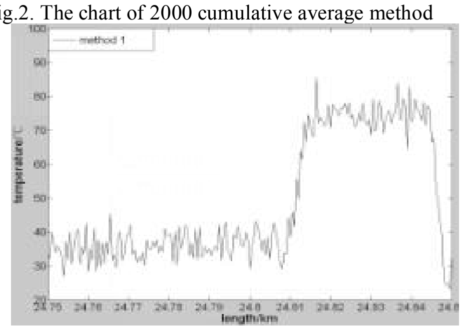

Fig.3. The chart of denoising method one

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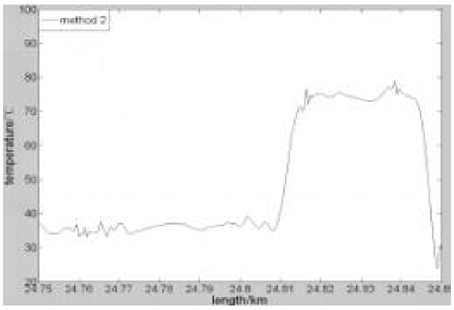

Fig.4. The chart of denoising method two

In order to verify the effectiveness of the method two, the filtering result of method two is compared with 5000 times cumulative average algorithm. The outcome of comparison is shown in figure 5.

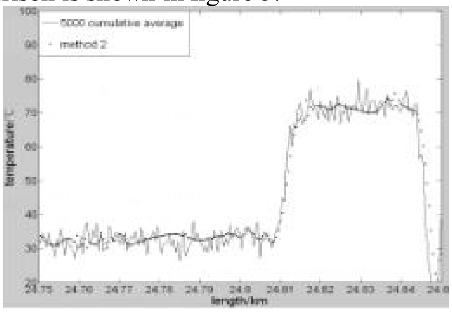

Fig.5. The comparison chart of 5000 cumulative average and denoising method two

The black solid line in figure 5 is 5000 times cumulative average temperature data curve near the temperature package. The black dot is the temperature data after filtering. We can see that the effect of 5000 times average algorithm processing method is not as obvious as method two, and it needs a longer time because of the cumulative frequency increased, thus the practical application of the system is affected. The different temperature error of each method is shown in table 1.

Table 1 Comparative analysis of temperature error data

	2000 times	Method one	Method two	5000 times
Temperature Error(℃)	4.4	3.9	1.4	2.6

From the table above we can get that 2000 times cumulative average denoising effect is better than that of 5000 times averaging, and measuring time is also halved.

5. CONCLUSIONS

In the process of temperature measurement, the effective part of the signal is low frequency signal. A threshold filtering method is proposed, which uses default threshold of low frequency coefficient and given threshold of high frequency coefficients. The standard deviation calculation results show that the temperature error reduced from 4.4℃ to 1.4℃. Experimental results show that the new method is more competitive than the traditional method in the process of temperature measurement in the distributed optical fiber Raman temperature sensor system.

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