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The Application of Wavelet De-noising in the DTS Temperature Measurement System

Feng Zhou¹,²  Jianjun Gan³*  HuanLv²  Ligang Cui²

¹Water conservancy and civil engineering infrastructure safety key Laboratory, Nanchang Institute of Technology, Nanchang, China, 330099
²Civil and Architectural Engineering School, Nanchang Institute of Technology, 330099 Nanchang, China
³School of water conservancy and ecological engineering, Nanchang Institute of Technology, 330099

E-mail: 251230177@qq.com

Abstract: The DTS system is widely used in the fields of temperature warning, fire warning and so on. In recent years, it is often used in the civil engineering field to monitor the temperature field and temperature stress caused by the mass concrete. The monitoring range is mostly in the range of 10km, which is mainly limited to the high loss characteristics of the optical signal in the multimode fiber. If we want to increase the measurement range of the system, analysis method and signal denoising algorithm are the focus of research. In view of this, this chapter uses OTDR theory and Wavelet Threshold De-noising to filter and analyze the noise of high noise echo signal, and has achieved good results. The temperature measurement in the domestic temperature measurement system is less than 5km, and the temperature measured in this paper is about 10km.

1. Introduction
Nowadays, it is urgent to pay attention to the change of temperature field in the field of engineering monitoring. Such as the monitoring of the internal temperature of the generator; the early fire warning of a short distance oil pipeline or voltage wire; the distribution and change of the temperature in a small building and so on. Especially for some dangerous occasions where human beings are not suitable for close range survey temperature, the physical variable optical fiber sensor[1] must be used for space layout instead of the ordinary ones.

By the experimental study of interaction of photons and molecules, the scientist Ramanathan found a new spectral line at both ends of the incident light, thus suggesting the phenomenon of Raman scattering in 1923; by the temperature identification which was succeeded by J.P.Dakin[2] in using the OTDR light time domain scattering technique, the optical fiber temperature measurement technology began to be popular in 1980s. In the end of 80s, the British YORK company studied the distributed optical fiber temperature measurement system with the detection distance of 2km, the temperature precision of 1℃, and the spatial resolution precision of 7.5m by the improved DTS system algorithm. Based on the Raman scattering principle[3], many famous universities in China analyzed the Distributed fiber Raman scattering
technology and produced a monitoring system with temperature measurement capability in 1988. In the same year, China Jiliang University also developed an automatic temperature alarm system, which can be used for temperature detection in coal and tunnel[4]. In 2007, Zhang Lixun[5] of Chengdu University of Electronic Science and technology of China used OTDR temperature demodulation technology to improve the accuracy of the space temperature measurement of distributed temperature optical fiber sensing system to 1m. According to the DTS optical fiber system, the temperature field can be measured. Compared with Brillouin temperature measurement, the DTS system has low cost and the detection technology is different from it, but the shortcoming is that the effective distance of monitoring is short. Therefore, it is suitable for low budget and short distance monitoring.

Wavelet de-noising is a popular denoising method in recent years. It can not only make up for the lack of signal recognition in low frequency, but also greatly save the response time of the system, and play a good de-noising effect. Unlike traditional spectral analysis methods, wavelet analysis is a[6] method of spectral analysis with moveable positions and variable windows. In 80s, there were a large number of articles and works about the wavelet analysis method[7], of which the breakthrough theory was the Mallat[8] algorithm; the book "wavelet and operator" published in 1989, and in 1991 Mallat established the wavelet singularity theory. In 1991, Mallat set up the theory of wavelet singularities, proposed a new method of wavelet denoising: wavelet modulus maxima processing method. In 1994, Donoho proposed nonlinear transformation threshold denoising method from the widely used signal denoising effect. In 1996, Coifman proposed the method of translation invariants in the process of wavelet analysis is from threshold analysis method[10], based on this, the base pursuit denoising method and multiwavelet theory has been applied to some extent. In this paper, combined with the characteristics of wavelet denoising method, wavelet denoising method is used to denoise noise in DTS system.

2. Experimental section

2.1 Raw materials and instruments
The part of the DTS test system is illustrated in Figure 1. The low temperature test box of it ranges from 0 C to -30 C and the high temperature device can be heated to 300 C. The constant temperature water bath is mainly between 0 C and 100 C, and the temperature resolution of the device reaches 1 C. Since the DTS system needs to control the temperature precision reached to centigrade, it is necessary to collect the data after the temperature is stable when the temperature control device is used.

(a)Constant temperature water bath (b)Low temperature test box
2.2 Experimental method
The structure of the DTS optical fiber system is shown in Figure 2. Choose a fiber about 10km, keep the ambient temperature about 20℃. Then use the front as a reference fiber, and put the 8790-8890m of it in a constant temperature water bath to heat up to 40, 50, 60, 70, 80, and then cooled to -20℃. The temperature coefficient can be calculated by these data. Using the relation of temperature coefficient, temperature and light intensity ratio, combining the wavelet denoising and traditional fitting method, analyzing the data of 40℃, 60℃ and -20℃ collected by the acquisition card, and the corresponding temperature can be obtained.

3. Experiment and discussion
The ratio of the light intensity ratio to the temperature and the two path signals is Formula 1:

\[
\frac{1}{T} = \frac{1}{T_o} - \frac{K}{h\Delta_s} \ln \left( \frac{P_{as}(T)/P_s(T)}{P_{as}(T_o)/P_s(T_o)} \right)
\]  

The ratio of light intensity to the actual temperature and the temperature of the thermostat, \( K \) is Boltzmann constant \( 1.380 \times 10^{-23} \, J \cdot K \), \( h \) is Elementary quantum \( 6.626 \times 10^{-34} \, J \cdot s \), \( \Delta_s \) is \( 1.32 \times 10^{13} \, Hz \). In actual tests, knowing the actual temperature and the light intensity ratio of the thermostat, we can get the actual temperature of the fiber through formula 1.

The Raman scattering map collected by the DTS system (Figure 3) can be found that the intensity
The ratio of 60 to 8800-8900 is larger than that of 40 at 0.1. So it conforms to the working conditions.

Figure 3 Two temperature Raman scattering contrast diagram

Using sym4 wavelet to the threshold de-noising. Calculate the ratio of anti-Stokes and Stokes intensity and use sym4 to process the threshold de-noising. The result is shown in figure 4:

Figure 4 The ratio of anti-Stokes to Stokes intensity before and after denoising.

From Figure 4, we can see that the amplitude of the ratio of anti-Stokes to Stokes decreases from 0.0015 to 0.0005, and the noise reduction effect is obvious. The data with temperature information can be obtained after smoothing the light intensity ratio of the noise reduction. In the compensation process, data fitting of light intensity ratio is needed and the fitting formula is 2:

\[ y = a \cdot e^{(bx)} \]  

The fitting effect is shown in Figure 5:

Figure 5 fitting effect diagram

The compensation leveling is carried out by the original data and the fitting formula 2, shown in figure 6:
The average data is obtained by averaging the five heating stage data, as shown in Table 1.

Table 1: Relation table of temperature and scattering intensity ratio

| Temperature (℃) | Temperature variation (℃) | \( \frac{V_{AS}(i)}{V_S(i)} \) | \( \Delta \frac{V_{AS}(i)}{V_S(i)} \) |
|-----------------|---------------------------|-----------------------------|-----------------------------|
| 20              | 0                         | 1.0120                      | 0                           |
| 40              | 20                        | 1.0301                      | 0.0190                      |
| 50              | 30                        | 1.0893                      | 0.0773                      |
| 60              | 40                        | 1.1503                      | 0.1383                      |
| 70              | 50                        | 1.2076                      | 0.1956                      |
| 80              | 60                        | 1.2699                      | 0.2579                      |

Fitting drawing 7 through table data and we can get the relation number of

\[
T = \frac{V_{AS}(i)}{V_S(i)}; a=0.005961; b=-0.1008
\]

We can analyze the data of theoretical temperature of 40, 60, and -20 by the calculation coefficients a, B and formula 3:
Thresholding denoising of -20 C using DB4 and sym4 wavelet functions respectively and five layers of wavelet decomposition are carried out by wavedec in there. Next, finding the threshold of the coefficients of each layer through ddencmp. Finally start the threshold denoising by wdencmp, the result is shown in figure 8:

(a) Db4Wavelet threshold de-noising  
(b) Sym4Wavelet threshold de-noising

Figure8 De-noising effect of different wavelets

By contrast figure 8, we can see the range of temperature error in sym4(b) is 2 centigrade while the error in db4(b) is 4 centigrade. Temperature before and after noise reduction by using sym4 is shown as chart 2.

Table2 Temperature values before and after noise reduction

| Theoretical temperature (℃) | Analysis of temperature before de-noising (℃) | Analysis of temperature after de-noising (℃) |
|-----------------------------|-----------------------------------------------|---------------------------------------------|
| 40                          | 38                                           | 39                                          |
| 60                          | 61                                           | 59                                          |
| -20                         | -22                                          | -21                                         |

The calculated temperature is drawn in Figure 9, and the effect map before and after noise removal at -20 C is drawn in figure 10, as shown below.

Figure9 Temperature curve
It can be found by Table 2 and Figure 9 and 10 that the evenness of red curve is higher than the blue, and from Table 2, it can also be found that the accuracy of temperature identification after de-noising is higher than before de-noising. The temperature measured by the OTDR technology is basically the same as the actual temperature, so the method is suitable for measuring the temperature.

4. Conclusion
By combining the wavelet threshold denoising algorithm with the traditional curve fitting algorithm, this chapter draws the conclusion about the DTS system based on OTDR technology, data collection and analysis:

1) Comparing with before de-noising, the accuracy of temperature identification after wavelet threshold de-noising improves to ±1℃. And the algorithm can help the DTS temperature measurement system more than 15km, while the traditional temperature measurement system has a distance of only about 5km.

2) In this paper, the principle of DTS system temperature measurement is studied. By comparing the filtering effect of each wavelet family, it is concluded that the sym4 wavelet function is more suitable for the wavelet threshold de-noising of the system.

3) Using the combination of C language and MATLAB and SQL database, the software of DTS temperature measurement system is compiled which realizes the recognition of the temperature from data acquisition and analysis.

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