Adoption of Distributed Optical Fibre Sensing Technology in Geological Engineering under Three-dimensional Visualization Environment

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Abstract. To better solve the problem of data noise caused by the application of optical fibre sensing technology in geological engineering, the overall design of geological engineering monitoring system in three dimensional (3D) visualization environment is firstly carried out in this study, and the data processing module of distributed optical fibre sensing system is designed in detail. Then feature compression algorithm is proposed for the smooth de-noising of geological monitoring data feature. Finally, through the comparison of the data smoothing de-noising of geological engineering with the compression algorithm proposed in this study, the desiccating effect is verified by using three indexes of signal-to-noise ratio, mean square error, and smoothness. The results show that the feature compression algorithm has a good effect on the smooth de-noising of geological monitoring data. At the same time, more unnecessary information is omitted in the adoption of geological engineering, and the smoothness of curves is taken into account, which greatly promotes the widespread application of distributed fibre optic sensing technology in geological engineering. keywords: 3D visualization; fibre optic sensing technology; geological engineering; feature compression algorithm

1. Introduction

Fibre optic sensing technology is a new monitoring technology developed in the 1980s. With the development of optical fibre and fibre optic communication technology, this technology is widely applied to the monitoring and detection of various geotechnical engineering [1]. Compared with the traditional monitoring technology, optical fibre sensing technology has the advantages of distribution, long distance, low cost, good tolerance, high sensitivity, and high precision. With the progress of science and technology, optical fibre sensing technology becomes perfect, and is gradually applied to the monitoring and detection research of many engineering geological problems, such as slope, ground crack, composite base, and tunnel [2, 3].

The application of distributed fibre optic sensing technology is extensive. However, due to the characteristics of long-distance measurement and multi-point sampling of the fibre optic monitoring, complex monitoring data is emerged, and the traditional data processing and analysis system can’t meet the needs [4]. The needs of distributed optical fibre mass monitoring information processing were satisfied by scientific computing visualization. However, in the monitoring process of some geological engineering, massive geological monitoring data is still brought by the distributed measurement
characteristics of distributed optical fibre sensing technology. Besides, there are all kinds of noises in the data, both periodic and random. Thereby, before the process of the monitoring data of geological engineering, de-noising is carried out firstly [5, 6]. Nowadays, there are very few processing technologies and software analysis for distributed monitoring data of some geological problems, and relevant researches are conducted by a few scholars [7-9]. These research results can smoothly de-noise the distributed fibre optic monitoring data to a certain extent, but various methods have poor pertinence on fast processing of distributed optical fibre monitoring data. And the treatment effect is not satisfactory, especially in some geological problems, such as ground fissure geological problems. Therefore, the promotion and application of distributed optical fibre sensing technology in geological engineering under 3D visualization environment is seriously affected by the lack of distributed monitoring system and the unsatisfactory data smooth de-noising.

In summary, to solve the problem that the de-noising of monitoring data in geological engineering is not ideal, the smooth de-noising processing method of monitoring data on the construction of distributed fibre optic sensing system is proposed in this study. Moreover, theoretical support is provided for the in-depth study of distributed fibre optic monitoring data processing and system construction.

2. Methodology

2.1. The overall design of three-dimensional visualization system in geological engineering
The purpose of the 3D visualization optical fibre detection system in geological engineering is to establish the optical fibre monitoring information based on the 3D model of the structure and realize the function of interactive observation. Therefore, the system is designed in five parts: the model building of geological engineering, process of geological engineering monitoring data, optical cable layout and registration of geological engineering, display of geological engineering, and interaction of geological engineering.

Modelling of geological engineering: the main information is obtained to build the model, and it was converted into the model data structure. On this basis, open graphics library (OpenGL) is adopted to build the 3D visualization model of geological engineering.

Dispose of the geological engineering monitoring data: through the analysis and extraction of useful information from the optical fibre monitoring data of geological engineering, the data is obtained and meshed, thus the cloud map of monitoring data of geological engineering is finally drawn.

Distribution and registration of optical cable in geological engineering: the distribution information of geological optical cable is registered with the space of monitoring cloud map and model monitoring area, thereby the optical cable and monitoring cloud map is displayed in the corresponding position of the model.

Mapping and display of geological engineering: the integrated model of the mapping optical fibre monitoring information is exhibited on the computer screen.

Interaction and drawing of geological engineering: through the drawing model, the mouse and keyboard is used to zoom in, zoom out, rotate the model, move and roam the perspective, then man-machine interaction is achieved. Omni bearing observation of the integrated model of optical fibre monitoring information in geological engineering is realized.

2.2. Design of distributed optical fibre sensing system in geological engineering
The design of distributed optical fibre sensing system in geological engineering is divided into login interface and function module design of sensing system. The login screen is the first window when the user starts the software. To ensure the use of the software system is more concise and intuitive, basic system information is contained in the system login interface, such as the name of the system, version information. Since the construction of fibre optic network and the processing subsystem of fibre optic data is included in the fibre optic monitoring system of geological engineering, the corresponding module interface is laid out. After entering the login interface, the selection of the corresponding functional interface for operation is facilitated. As shown in Figure1, the system is divided into several
sub-system modules, and then detailed module division is carried out for each sub-system. Finally, each subsystem module is devised independently, after the design is completed, according to the feedback information, the function of each sub-system is optimized. When these subsystems are integrated into one system through coordination, the needs of users are met.

![System design module diagram](image)

**Figure 1. System design module diagram**

### 2.3. Smooth de-noising method for monitoring data

Distributed optical fibre sensing technology is used to monitor geological phenomena in geological engineering. Sensing fibre is not only a sensor but also a transmission medium, and a lot of monitoring data is obtained by it. At the same time, considering the influence of various random and non-random factors, a large number of monitoring data is mixed with different levels of noise. To reduce the influence of noise, a series of dispose such as smoothing and de-noising are carried out on the data collected by the distributed optical fibre monitoring of geological engineering before the analysis of the geological monitoring data.

Three functions are included in data visualization of geological engineering: data import, data overall display, and selection display. Data import refers to the selection of the specified file, and the data is imported into the subsystem. According to the existing integration file browsing dialog box, the check, and selection, and import work is performed. Data is displayed integrally for the convenience of users to observe the overall trend of the data. Firstly, all the file data are imported and displayed uniformly in a window, then the coordinate axis corresponding to the engineering geology monitoring information is drawn by users in the drawing control. And the data is exhibited correspondingly. Data is selected and displayed to facilitate users to view or edit the monitoring data they need.

Through the reduction of the noise doped in data, the signal is restored. Thereby, the smooth de-noising of geological monitoring data is realized. The representation of a noisy one-dimensional signal model is shown in Eq. 1.

$$s(i) = f(i) + e(i), i = 0, 1, ..., n-1$$

In this equation, $s(i)$ is the noisy signal, $f(i)$ is the real signal, $e(i)$ is the noise. The de-noising problem of geological data is to find a suitable algorithm $F : R → R$.

$$F(s(i)) = f(i)$$

The methods of smoothing and de-noising geological data include mean de-noising, median de-noising, and wavelet analysis de-noising. In this study, the feature compression algorithm is introduced to find a smooth de-noising method.

The characteristic point is the strain point with obvious transition in the monitoring data curve, feature point compression is a method to find feature points in the monitoring data curve. The main idea of this method is: take the line of two points on the curve in each order is taken, and the maximum vertical distance $d$ between all points and the line is calculated. And it is compared with the threshold value $\Delta$. If $d < \Delta$, all the points in the middle are removed; if $d \geq \Delta$, the maximum perpendicular
distance point is retained and used as the new curve segmentation point, and then the whole piece of data is removed and processed until the end of this line.

To obtain a better smoothing effect, the smoothing effect of wavelet analysis, mean value, median value, and eigenvalue is determined under different parameter values from three aspects of mean square error, signal-to-noise ratio (SNR) and smoothness.

The expression for the mean square error is shown in Eq. 3.

\[
MSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} [x(i) - \hat{x}(i)]^2}
\]  

(3)

The expression of signal-to-noise ratio is shown in Eq. 4.

\[
SNR = 10 \log \left( \frac{\sum_{i=1}^{N} [x(i)]^2}{\sum_{i=1}^{N} [x(i) - \hat{x}(i)]^2} \right) \text{ (dB)}
\]  

(4)

The expression of smoothness is shown in Eq. 5.

\[
r = \frac{\sum_{i=1}^{N} [\hat{x}(i+1) - \hat{x}(i)]^2}{\sum_{i=1}^{N} [x(i+1) - x(i)]^2}
\]  

(5)

In this equation, N is expressed as data points, \(x(i)\) and \(\hat{x}(i)\) represent raw data and processed data, respectively.

3. Results and discussion

3.1. SNR analysis of several de-noising methods in geological engineering

![Figure 2. Comparison of SNR indexes of several processing methods](image)

If the obtained SNR is higher after smooth de-noising, then the effect is good. As shown in Figure 2, the compression algorithm (cubic) and the median method have the best SNR, while the SNR of other methods is same. In the data detection of geological engineering, the least proportion is occupied by noise in the original data signal.
3.2. Mean square error analysis of several de-noising methods in geological engineering

![Mean square error analysis](image)

**Figure 3.** Comparison diagram of mean square error index of several processing techniques

Mean square error (MSE) and SNR are the physical quantities of the detection data in geological engineering, which describe the detail differences in de-noising data. Moreover, the mean square error is smaller after smooth de-noising, which indicate that the effect of smooth de-noising is very good. As shown in Figure 3, the mean square error of the median algorithm is the smallest, followed by the compression algorithm (three times). Although the compression algorithm (quadratic) is consistent with the data, the coincidence is worse than the compression algorithm (cubic).

3.3. Smoothness analysis of several de-noising in geological engineering

![Smoothness analysis](image)

**Figure 4.** Comparison diagram of smoothness index of several processing methods
The smoothness after smooth de-noising processing is small, thus the smooth de-noising effect is good. From the perspective of smoothness parameters, as shown in Figure 4, compression algorithm (primary) and compression algorithm (secondary) are the best, median method is the worst, and other methods are in between. To keep the curve smooth, information is eliminated in the application process of geological engineering, and this is reflected in the first two parameters. However, the inflection point of the median between two relatively gentle data segments is changed, which affects the smoothness of the curve. The smoothness of the curve is taken into account by other manners during the process of de-noising.

4. Conclusion
This study aims to solve the problem that the smooth de-noising effect of geological engineering monitoring data under distributed fibre optic sensing technology is not ideal. Based on the distributed optical fiber monitoring system, a feature compression algorithm is constructed by monitoring the obvious turning strain in the data curve. And it is compared and analysed form the MSE, SNR and smoothness. The results show that the compression algorithm (primary) and the compression algorithm (secondary) have better effects on data smoothing and de-noising, but the two methods have different emphases. The former focuses on smoothing data under the constraint of feature points, while the latter concern about the de-noising under the constraint of feature points.

Although good results in data de-noising of geological engineering is achieved by the feature compression algorithm, the application of the optical fiber sensing information system based on the algorithm is rare. Therefore, it is necessary to better verify the application effect of the sensing system in geological engineering and further optimize the design of the system.

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