Interference identification and removal of seismic precursor observation data based on singular spectrum analysis method

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Abstract. The singular spectrum analysis (SSA) method has the characteristics that it is not affected by the noise spectrum distribution, and is superior to the traditional denoising method. Moreover, it has been commonly used in signal analysis in the fields of oceanography, machinery, and electronic technology. This paper systematically introduces the basic principle and implementation process of singular spectrum analysis method. Then the singular spectrum analysis method is applied to the interference identification and removal of seismic precursor observation data. Taking deformation data and geoelectric field observation data as an example, the results show that the singular spectrum analysis method can effectively separate the rainfall interference in deformation observation data, and has important guiding significance for the subsequent removal of rainfall interference. In addition, the singular spectrum analysis method can be used to extract and remove the interference of HVDC and subway from the geoelectric field observation data, and the effect is obvious, which can effectively improve the data quality and better serve the earthquake analysis and prediction.

1. Introduction

Earthquake prediction has always been a research hotspot in the world. As the two important observation methods for earthquake prediction, the quality of deformation and geoelectric observation data is very important.

Deformation observation is sensitive to rainfall, especially heavy rain. Rainfall affects the observation of cave deformation mainly through rainfall infiltration and load changes, which can have a greater impact on the shape and trend of the observation data, and cause substantial distortion of the earth tide curve. Theoretically, when the rainfall rate is greater than the infiltration rate, part of the rainfall flows along the ground surface to the stagnant water area, imposing additional loads on the stagnant water area, and then affecting the tilt change of the observation pier; when the rainfall rate is less than the infiltration rate, rainfall mainly causes irregular deformation of the ground surface in the form of infiltration, which affects the instrument observation pier through the transmission of stress. Therefore, the identification of rainfall disturbance is very important for obtaining reliable precursor change information from deformation observation data[1].

As another important means of predicting and monitoring seismic activity, geoelectric field observation undertakes a very important task, but it is extremely susceptible to interference from the surrounding environment. The main interferences in current observations include electrode polarization, high-voltage direct current transmission, subway operation, lightning and rain and other natural phenomena, and factory operation. Among them, the relatively common ones are high-voltage
direct current transmission and subway operation interference.

In this paper, the Singular Spectrum Analysis (SSA) method is applied to the interference identification and noise reduction of seismic precursor observation data such as deformation and geoelectric field, aiming to improve the data quality of earthquake precursor observation data, enhance data availability and reliability, and better serve the identification of earthquake anomalies and earthquake prediction. The SSA method was first proposed in 1978 in oceanography and then widely used in many fields such as meteorology, geodesy, seismology\cite{2-5}. Compared with the traditional denoising method\cite{5-7}, the SSA method is not affected by the noise spectrum distribution, and can achieve the effect of adaptive noise reduction.

2. Methods

SSA is a kind of principal component analysis method which basic principle is to decompose one-dimensional time series \( x = (x_1, x_2, \cdots, x_N) \) into a number of interpretable and independent components and then reconstruct it. The specific process is: (1) select a lag window \( M \), calculate the trajectory matrix; (2) perform singular value decomposition and arrange the eigenvalues in descending order: the eigenvalues are \( \lambda_1, \lambda_2, \cdots, \lambda_M \) and \( \lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_M \geq 0 \); (3) group and average diagonally to get a reconstructed time series.

During the application of the SSA method, it is important to pay attention to the choice of two parameters: the lag window \( M \) and the reconstruction order \( P \). The \( M \) should not be too large or too small and there is no uniform standard for its selection. When dealing with different types of data, the choices are also different. In this paper, for the oblique strain observation data which main component is the solid tide, \( M \) is generally selected as an integer multiple of the period of the solid tide. Generally, \( M = 120 \sim 160 \) can basically meet the requirements\cite{8}; for data with large interference such as geoelectricity, \( M = N/2 \) can be selected (when \( N \) is not an even number, the last data point is discarded, and the final result is not affected)\cite{9}, when \( M = N/2 \), the corresponding singular value will get the maximum value.

The selection of reconstruction order \( P \) (the number of singular values in the grouping process) is another important parameter in the application of the SSA method. There is also no universal standard for its selection method. The more commonly used method is the inflection point method: the singular spectrum of noise obtained by singular value decomposition has the characteristics different from the useful signal. The singular values of the noise are of the same size, the singular spectrum tends to be flat, and a noise plateau appears. At this time, the rate of change of the corresponding singular value drops suddenly, resulting in an inflection point\cite{8}.

3. Results and Discussion

3.1. Rainfall interference identification of deformation observation data based on SSA method

The singular spectrum analysis method can realize the effective decomposition of periodic signal and aperiodic interference, and the influence of rainfall belongs to low-frequency aperiodic interference. Therefore, theoretically, the separation of deformation observation data and rainfall interference can be achieved through the singular spectrum analysis method.

Taking the observation data of the north-south component hourly value of the horizontal pendulum tiltmeter in Xiyang Seismological Station of Shanxi from July to August 2018 as an example, it can be seen from Figure 1(a) that the original curve dropped sharply around August 3. Reconstructing the data with the SSA method can isolate the corresponding rainfall interference in the corresponding time period (Figure 1(b)). Compared with the actual rainfall during this time period (Figure 1(c)), it is sufficient to prove the accuracy of the identified rainfall interference, and the range of interference influence is about 6d.
For data with severe rainfall interference, the SSA method can effectively identify rainfall interference. So, whether the SSA method is still effective for the observation data which rain interference is seriously concealed by the instrument drift. Figure 2(a) shows the hourly data of the north-south component of borehole strain in Xuzhou. It is difficult to see obvious changes from the data morphology. After the SSA method is applied, it can be seen that there are three serious interferences caused by rainfall, namely: August 7th, August 24th, and September 17th, the impact range is about 10-15 days (Figure 2(b)). Compared with the actual rainfall (Figure 2(c)), it confirms the accuracy of our interference identification, indicating that the SSA method can still effectively identify the rainfall interference in the corresponding time period when the observed data morphology does not change obviously.

3.2. Identification and removal of interference from geoelectric observation data based on SSA method

With the rapid development of China’s power grid construction, HVDC transmission technology has been widely adopted due to its characteristics of greatly reducing transmission losses and ultra-long distance transmission, and large-scale network construction has begun. At present, there are 26 high-voltage direct current transmission lines in operation across the country. The interference to the
observation of the geoelectric field is very obvious. As shown in the red curve in Figure 3, when the high-voltage transmission starts and stops to inject into the ground current, the ground electric field produces a large jump, and the interference form appears as a step. In this paper, the SSA method is used to try to identify and remove the high-voltage direct current transmission interference in the geoelectric field of Dabaishi. The result is shown in the blue curve in Figure 3. It can be seen that the singular spectrum analysis method can effectively suppress the high-voltage direct current signal.

Figure 3 Comparison of before and after noise removal of HVDC transmission interference from Dabaishi Geoelectric Field (red: before denoising and blue: after denoising)

On the other hand, with the rapid development of the national economy and the acceleration of urbanization, subway interference has increasingly become one of the disturbances that have a huge impact on the geoelectric field in addition to the interference of HVDC transmission. Taking Chengdu Seismic Station as an example, Chengdu Subway Line 2 has been in operation since June 2013. The closest distance to Chengdu Station is 25km. The operating time is 6:00-23:00 Beijing time. From the geoelectric field data curve (the red curve in Figure 4), it can be seen that around 6:00-24:00, the data noise increases significantly, periodic high-frequency interference appears, and the data curve is distorted. The 0:00-5:00 geoelectric field signal is in a calm phase, there is less free interference, and the signal changes relatively smoothly. After the singular spectrum analysis method is used to identify the interference and de-noise (the blue curve in Figure 4), the "burr" interference of the geoelectric field observation data is reduced, and the useful information is also effectively retained.

Figure 4 Comparison of Chengdu Geoelectric Field Subway Interference before and after denoising (red: before denoising and blue: after denoising)

In summary, the singular spectrum analysis (SSA) method can effectively identify the rainfall interference in the deformation observation data, and can be applied to the identification and removal of the HVDC transmission interference and the subway interference of the geoelectric field observation data. But there are still some problems.

1) Because the influence of rainfall interference on deformation is more complicated, different instruments or different measurement items of the same instrument have different response characteristics to rainfall. The same measurement item will also show different characteristics due to
different rainfall patterns, seasons, or water saturation of underground media. Moreover, the impact of rainfall is not directly superimposed on the deformation curve. It mainly affects the surface deformation through infiltration. There are a series of influencing factors which can cause changes in the deformation observation data, such as the creep effect of underground media caused by heavy rain, the infiltration coefficient, the infiltration flow of groundwater after rainfall, and the load change. Therefore, the removal of rainfall interference requires the establishment of a reasonable mathematical and physical model, and the identification of the impact period of rainfall interference through the SSA method can provide good guidance for the establishment of rainfall interference removal models.

(2) Due to the numerous influence factors and the complex frequency components of geoelectric field interference, and the singular spectrum analysis method itself has subjective constraints in the selection of lag window and reconstruction order, the final denoising effect is not fully achieved an ideal state, a small part of the effective information doped in the interference is removed at the same time, and the retention of effective information has not reached the maximum. This is also the area that needs to be improved and perfected in the future, that is, to improve the method itself, develop an improved singular spectrum analysis method, To achieve a more ideal denoising effect[4][10-11].

4. Conclusions
(1) The singular spectrum analysis method can decompose the signal into simple linear superposition of each basic signal, and realize the effective separation of periodic components and non-periodic components. The actual data processing results show that this method can be used in the analysis and processing of earthquake precursor observation data, identifying rainfall interference from deformation data, identifying and removing high-voltage direct current transmission interference and subway interference from geoelectric field data. The method is effective and provides high-quality data for subsequent seismic anomaly identification.

(2) The selection of lag window and reconstruction order is subjective, and should be analyzed in accordance with the characteristics of the data itself. This restricts the application effect of the singular spectrum analysis method in complex signals which is also the development direction of subsequent singular spectrum analysis methods.

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