Investigation on an application of emergency rescue in the initial natural earthquake by wavelet analysis

Majun Peng, Cheng Wei*
China Nonferrous Metal (Guilin) Geology And Mining Co. Ltd, Guilin, 541004, China
*Corresponding author’s e-mail: blackfire513@126.com

Abstract. Earthquake brings great harm to humans. In order to achieve the desired effect and mitigation effectiveness of early warning, it must reduce the time of rapidly assessing earthquake location and processing seismic and other data. Seismic phase identification based on the wavelet analysis is a powerful and widely spread method in identifying the initial earthquakes. We can get the signals’ recognition factor of S wave and P wave in different scale. Then according to these recognition factors, we can determine the positioning function of primary earthquake of S wave and P wave. Next through the positioning function, we can easily pick up the first arrival of P wave and S wave. The wavelet packet analysis is a more precise analysis method of signal, which makes the frequency band multi-level division, and further decomposes the high-frequency part. Also, the wavelet analysis does not subdivide, and according to the characteristics of analysis-signal, the adaptive-select the corresponding frequency band is matched by the frequency spectrum of the signal, improving the time-frequency resolution. This paper mainly investigated the applications of initial earthquakes identification on emergency rescue, and it can be a useful theoretical reference for further relevant research.

1. Introduction

The identification of seismic waves in the initial earthquakes is a great significant problem encountered in the research of modern seismology. According to the principle of identification, initial earthquakes identification consists of two parts, manual identification and automatic identification[1]. However, traditional manual identification often depends on the experience of the one who makes the judgment and identification. It is not only time-consuming but also has artificial errors, reading errors, and so on, which will all affect the identification precision. Thus, it is necessary to develop and research for obtaining a stable, practical and efficient automatic identification method and system[2].

Wavelet theory is capable of application on the earthquake emergency and has been developed rapidly during the past several years. In this theory, energy is decomposed based on scales from time series. The multiresolution analysis decomposes the signals into different frequency bands, each of which is still a signal changed with time. Therefore, it is the excellent time-frequency characteristic of the wavelet transform that makes it a powerful tool to analyse the mutational signals and more suitable for detecting the arrival time of abnormal waveform[3]. In this paper, the author comprehensively analysed the natural seismic signals by the application of wavelet packet transform and wavelet transform, and verified the validity and accuracy of this method for the identification of actual natural earthquake, which demonstrates that the method provides a reference for the effective identification of initial natural earthquakes.
2. Theory of initial earthquake identification based on wavelet packet transform signal

The identification of the first arrival of the signals by using the wavelet packet transform is quite useful. Wavelet packet transform \( c_{n,j}^k \) refers to a signal as the superposition of the basic unit \( 2^{k/2}W_n(2^kt-j) \). Just as the Fourier transform regards the signal as the superposition of trigonometric functions, any wavelet packet basis function \( 2^{k/2}W_n(2^kt-j) \) can be obtained by binary translation, expansion and contraction of \( W_n(t) \). The window centre of \( W_n(t) \) is \( (t_n, \omega_n) \). \( \Delta t_n \) and \( \Delta \omega_n \) respectively, represent the time window and frequency window width. It can be proved that the window corresponding to the wavelet packet basis function is \( \left[ 2^h(t_n - \Delta t_n + j), 2^h(t_n + \Delta t_n + j) \right] \times \left[ 2^{-h}(\omega_n - \Delta \omega_n), 2^{-h}(\omega_n + \Delta \omega_n) \right] \). The wavelet packet decomposition transform represents that the size of the window area equals the internal energy of \( 4\Delta \omega_n \times \Delta t_n \), where \( W_n(t) \) is the generating wavelet function, \( k \) is the scale parameter, and \( j \) is the translation factor. With the change of \( k \), the window area does not change, while its time window length and frequency window height are continually adjusting. When \( k \) becomes higher, the time window becomes narrower, that is, the time resolution increases \(^{(4)} \). This characteristic contributes to demonstrating the local features of mutational or gradient earthquake signals resulted from the generation of new seismic phase. Therefore, it is feasible to use wavelet packet decomposition transform to identify the initial earthquake of unsteady seismic signals, which is the basis for identifying the initial earthquake of signals \(^{(5)} \).

For a N-point discrete signal, the phase plane can be used according to the time-frequency characteristics of the signal since the window in the phase plane corresponds to the coefficient \( c_{n,j}^k \) obtained by wavelet packet decomposition. When the energy of signal in the window is relatively strong, it is represented by a high chromaticity in the phase plane; on the contrary, it is represented by a lower chromaticity. The position of the window along the frequency axis is determined by \( j \) \(^{(6)} \). If the signal amplitude of each decomposition coefficient filled in the corresponding window with the corresponding chromaticity, a phase plane chromaticity map can be obtained. When the new seismic phase arrives, it will cause a mutational or gradient change of the original signal, and the frequency and energy of the signal will change abnormally in high values. Therefore, the mutational change characteristics of the time-frequency distribution of the signal can be introduced by the distribution of the phase plane chromaticity diagram. Then the time of the seismic phase arrival can be obtained \(^{(7,8)} \).

In conclusion, since different scales own different time and frequency resolutions under wavelet decomposition, wavelet decomposition separates signals contained in different frequency intervals, combining with the time-frequency intuitive diagram of the signal the method used can identify the seismic phase at the corresponding frequency.

3. Verification of analogue signal identification

To verify the signal identification method mentioned before, a more characteristic analogue signal is used for the following research. By processing the analogue signal, the corresponding first-arrival position is identified and compared with the real signal characteristics, and then verifying the validity and accuracy of the identification method.

3.1 Gradient analogue signal and identification results

The gradient signal can be simulated by a combination of functions. In this paper, the simulation of the gradual signal is composed of several sine functions. It is assumed that there are five sine waves with

\[
\sin \frac{\pi}{20}(t-t_{i0})s\cdot H(t-t_{i0}) , \quad \sin \frac{\pi}{10}(t-t_{i0})s\cdot H(t-t_{i0}) , \quad \sin \frac{\pi}{5}(t-t_{i0})s\cdot H(t-t_{i0}) , \quad \sin \frac{2\pi}{5}(t-t_{i0})s\cdot H(t-t_{i0}) ,
\]

the form of

\[
\frac{\sin \frac{\pi}{20}(t-t_{i0})s\cdot H(t-t_{i0})}{\sin \frac{\pi}{10}(t-t_{i0})s\cdot H(t-t_{i0})} , \quad \sin \frac{\pi}{5}(t-t_{i0})s\cdot H(t-t_{i0}) , \quad \sin \frac{2\pi}{5}(t-t_{i0})s\cdot H(t-t_{i0}) ,
\]


and 

\[ \sin \frac{\pi}{2} (t - t_{01}) \ast s \ast H(t - t_{01}) \]

and all the amplitude is 1, which does not change with time. The length of the discrete data is 512 points, and the sampling rate is \( s = 40 \) points/second, where \( H \) is step function, \( t_{01} = 0 \), \( t_{02} = 2.5s \), \( t_{03} = 5s \), \( t_{04} = 7.5s \), and \( t_{04} = 10s \). The sine waves as mentioned above are successively superimposed to form the gradient analogue signal used in this paper [2]. If these signals are discretely considered as points, then the first signal always exists from point 0, while the second signal emerges from 100, and the third, the fourth and the fifth signal appears from 200, 300, and 400, respectively.

Figure 1 shows an analogue gradient signal formed by the superposition of the above five sine waves. In Figure 1, the x-coordinate represents the number of points, and the y-coordinate represents the amplitude. From the figure, we can see the gradient characteristic of the signal.

![Figure 1 The gradual change](image)

Figure 2 presents chromaticity diagram of the phase plane generated by conducting two-layer decomposition of the db6 wavelet packet on the signal. The best wavelet base uses logarithmic energy entropy. In this diagram, the x-coordinate is the points of the signal, and the coloured bar represents the frequency of the signal. It can be seen from the distribution of the coloured chromaticity with the points in the figure that when each new signal arrives, there will appear a mutational signal with high frequency. The first arrival position of the signal is the coordinate position of the four black points in the figure, which are 101, 201, 301 and 401 respectively. The position of the first black spot is the initial moving position of the second signal, the position of the second black spot is the initial moving position of the third signal and, so forth. The identification result is basically the same as the actual initial position of the signal (100, 200, 300, 400). The corresponding initial movement times were
2.525s, 5.025s, 7.525s, and 10.025s, which are essentially in agreement with the actual initial movement times.

3.2 Mutational analogue signal and identification results
The gradient signal described above is the superposition of five sine waves, while the mutational analogue signal is changing the sine wave to the corresponding cosine wave, and then superimpose the five cosine waves one after another, as shown in Figure 3. The following is the method used to identify the gradual signal and here to identify the mutational signal and verify the identification effect of the method on the mutation signal.

As can be seen from figure 4, the initial moving positions of the mutation signal are 101, 201, 301 and 401, respectively, and the corresponding first arrival time is 2.525s, 5.025s, 7.525s, and 10.025s, respectively, which are basically consistent with the real initial motion time.

In terms of the identification effect of analogue signals, the combination of wavelet packet transform and discrete wavelet transform can identify the first arrival time of non-stationary signals more accurately. It shows that this method can be applied to the identification of initial earthquake waves.

4. Identification of initial earthquake in actual seismic signals
It is found that wavelet packet transform combined with wavelet transform is an effective method to recognize the initial motion of the signal through previous analysis. Based on the experience and knowledge of analogue signal recognition, we used the method mentioned to identify the actual natural seismic signals of the aftershock of the Wenchuan earthquake. The identification results are as follows:
The south-to-north natural seismic record of the aftershocks during the Wenchuan earthquake is shown in Figure 5, in which the sampling rate of 50 Hz. This paper took the actual natural seismic data as an example to identify the initial earthquake.

Due to the complexity of seismic signal components, there exits plenty of noise in the recording process, and thereby, the initial seismic signal identification need to deal with several scales of coefficient energy distribution for the overall analysis.

It can be seen in Figure 6 that the coordinate of the first initial motion position of the seismic signal is at point 591, and the corresponding time is 11.82s. The coordinate of the second initial motion position of the seismic signal is at the point 1271, and the corresponding time is 25.42s. The coordinate of the third initial motion position of the seismic signal is at the point 2811, and the corresponding time is 56.22s. The coordinate of the fourth initial motion position of the seismic signal is at the point 11830, and the corresponding time is 236.6s. Thus, the location and time of several initial seismic points in the seismic signal can be captured.
Figure 7 is the detailed signal distribution diagram of the seismic signal in five layers decomposed by the db6 wavelet transform. The distribution of the highest frequency in the signal is $d_1$, and the higher up the value, the lower the frequency. It can be seen from the frequency distribution in the figure that the highest frequency part of the seismic signal arrives first. The distribution of the lower frequency part of the seismic signal is represented by $a_5$ and $d_5$. According to the acknowledge we known, the first arrived is the P wave of the high-frequency component, followed by the S wave of the intermediate frequency part, then the surface wave (Love Wave) of the low-frequency part, and finally the aftershock.

Combined with the results of the two analyses, the first arrival time of P wave and S wave are 11.82s and 25.42s, respectively. The first arrival time of surface wave (Love Wave) is 56.22s. The initial arrival time of the aftershock is 236.6s.

5. Conclusion and suggestion

This paper discussed applying wavelet analysis technology to the emergency rescue for the initial natural earthquake. The main conclusions obtained are as follow:

1) The wavelet packet decomposition transform possesses a "mathematical microscope" function, which can automatically use different resolution time windows according to different frequency components of the signal. When a specific type of seismic wave arrives, the recorded waveform will make gradient change or mutational change; in other words, the abnormal high-frequency component will emerge. Wavelet packet decomposition will automatically use a short window to improve the temporal resolution, which means the method will focus on the new signal to accurately identify and measure the new seismic waves.

2) At low frequency, the wavelet functions with large-scale value and long period are used while small-scale values and short-period wavelet functions are used at high frequencies. The above transformation characteristics are particularly suitable for the demonstration and processing of seismic signals.

3) There are abundant high-frequency components when the initial of the signal arrives. Thus, it is obviously inappropriate to use low-frequency wavelet to detect the initial arrival of the signal, and in this case, high-frequency wavelet should be employed.

4) The maximum amplitude of waveform recorded is usually not the arrival of the seismic phase. In fact, the corresponding actual arrival of the maximum amplitude should be ahead of the seismic phase. For situations with high signal noise, picking up arrival time according to the maximum amplitude will not cause high errors, but for cases with low signal noise, this treatment will bring large errors. The research in this paper reveals that wavelet packet picking of seismic phases is a quite effective method and can be applied for earthquake emergency rescue and relevant work.
Hence, according to the characteristics of the earthquake-affected area, the following emergency rescue measures are recommended:

(a) Distribute the relevant documents of emergency rescue work to the residents threatened by the natural earthquake;
(b) Divide the influence area of groundwater activity and set up warning zones and warning signs around the earthquake (and the affected) area;
(c) Monitor the water level changes and earthquake activity characterization phenomena, especially the signs and changes of the existing phenomena and the scope of influence, so as to exercise emergency evacuation and avoidance for the residents within the potential affecting area of the earthquake;
(d) Notify the electric power authority the situation about the earthquake threatening the safety of transmission, and ask the authority to make corresponding protection measures and emergency plans;

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