Journal of Computers Vol. 28, No. 6, 2017, pp. 288-300
doi:10.3966/199115992017122806026

Research on Extraction and Application of Weak Signals Based on Wavelet Transform

HuaiXiu Wang[1], CongLei Zhang[1*] and XiaoLi Nie[2]

[1] University, School of electrical and information engineering, Beijing University of Civil Engineering and Architecture, Beijing, China
wanghxiu@126.com, zclzjh@163.com

[2] University, School of electrical and information engineering, Beijing University of Civil Engineering and Architecture, Beijing, China
1076450723@qq.com

Received 24 July 2017; Revised 19 September 2017; Accepted 19 October 2017

Abstract. In recent years, mine earthquake disasters occurs frequently and has brought great harm. Analysis and Research of mine earthquake weak signals have great significance to reduce casualties and property losses. This paper based on the wavelet transform uses actual mine earthquake signals as the analysis object, and determines wavelet basis function as Sym8 and wavelet decomposition layer as 3 for de-noising processing of actual mine earthquake signals through a lot of MATLAB simulation experiments. At the same time, this paper introduces Birge-Massart threshold acquisition method, and implements effective de-noising of mine earthquake signals combined with the improved threshold function, so that it provides a good condition for the research and prediction of mine earthquake signals.

Keywords: MATLAB wavelet toolbox, threshold de-noising, wavelet transform, weak signal de-noising

1 Research Status of Wavelet Transform

1.1 Introduction to Wavelet Transform

Journal of Computers is a high quality journal in computer and information technology. The editor in chief is Prof. Chin Chen Chang. Welcome submissions of information engineering, information science, and information management. Wavelet transform (WT) is a new analysis method, which inherits and develops the localization thought of short-time Fourier transform (STFT), and overcomes the problem of immutable time-frequency window and other shortcomings. Wavelet transform provides a time-frequency window which changes with the frequency. Wavelet transform has adaptive adjustment of temporal resolution and frequency resolution characteristics, therefore it is also called “digital microscope”. Wavelet transform is the ideal tool for signals’ time-frequency analysis and processing.

1.2 Research Status of Wavelet Transform in Signal De-noising

The application field of Wavelet transform is very broad because of its extensive and perfection application. It is the most commonly used method in signal processing and image field, and is often used in signal compression, signal filtering, extracting signal feature information and others. Since the wavelet analysis has put forward, it is quickly used for signal extraction. The earliest use of wavelet analysis in signal processing is the modulus maxima method, then, spatial correlation filtering method, signal de-

* Corresponding Author

noising threshold algorithm (soft and hard threshold method), translation invariant de-noising method and other methods appear.

In recent years, along with the increasing maturity of wavelet theory, the weak signal extraction based on wavelet transform has been well used in many practical problems. Many domestic scholars also use the wavelet de-noising method in the study of rock materials' acoustic emission and microseism. In 2006, Kui Zhao and other persons put forward the separation method of signal and noise in point Kaiser based on wavelet transform. At the same year, GengFeng Wang puts forward the wavelet packet de-noising method based on energy threshold by applying wavelet de-noising technique to rock acoustic transmitting indoor signal. In 2007, JieFang Jin and others sums up that db4 function in the Daubechies wavelet functions can satisfy conditions in the processing of rock acoustic transmitting signal, according to the analysis of rock acoustic transmitting signal and characteristics of the matching wavelet base. In 2008, DaWei Xu used wavelet de-noising method in the rock-burst signal filtering preliminarily, and put forward that the pretreatment of microseism signal can use this method. In 2010, JiePing Yuan used wavelet de-noising technique in microseism signal de-noising through simulation experiments. Therefore, it is feasible applying wavelet transform to mine earthquake signal de-noising.

2 MATLAB and MATLAB Wavelet Toolbox

2.1 Introduction to MATLAB

MATLAB is a software which is easy to study and have powerful functions. MATLAB mainly consists of MATLAB part and simulation part, containing graphical visualization, numerical and symbolic computation three functions, and also provides special toolboxes for more than 30 fields.

The data unit of MATLAB is matrix, and the form of mathematics and engineering application is very close to METLAB instruction expression. Compared with C and FORTRAN language, MATLAB algorithm is more convenient. Compared with traditional programming language MATLAB has the following advantages: practical publishing platform and program interface, simple programming language, friendly programming environment and working platform, strong scientific computing ability, good graphics processing ability, convenient application software developing environment and reliable module set kit. MATLAB has powerful features so that it is widely applied to engineering applications.

2.2 MATLAB Wavelet Toolbox

Wavelet toolbox is one of the MATLAB toolboxes. Directly inputting wave menu in the MATLAB command line can start wavelet analysis toolbox. In wavelet toolbox the signals can be imported and processed by calling the various commands directly, then the code is generated after processing, which is convenient for calling. MATLAB wavelet analysis toolbox contains the following functions: wavelet function, one-dimensional wavelet transform function, two-dimensional wavelet transform function, image and signal compression and de-noising function, input and output function of wavelet analysis, operation function, etc. MATLAB wavelet toolbox has study and analysis of wavelet's characteristics, designing continuous wavelet transform, discrete wavelet transform and wavelet packet transform, compression and de-noising for signal and image and other functions [1].

3 Extraction Methods of Weak Signal

3.1 Introduction to Weak Signal De-noising

Assuming that the length of noise signals is n, the expression is as follows: De-noising refers to maximizing to find the optimal approximation function of function f from noise signals x. The main goal of de-noising is to separate actual useful signal and noise, retain the original signal, remove noise and realize the de-noising at last. Some often appeared noise obeys to Gaussian distribution, so e generally stands for Gaussian noise. Now the research on Gaussian noise is quite mature, but the research on non-Gaussian noise still need a lot of explorations. Therefore, this paper should choose the appropriate method for noise removal after fully analysis of the actual mine earthquake signal's characteristics of mine earthquake signal processing.

It is the mainly used mathematical method that converting signals from time-domain to frequency-domain to solve the signal de-noising problem, and commonly used methods are Fourier transform, wavelet transform and others. The wavelet transform of noise signal consists wavelet transform of invalid signal and wavelet transform of effective signal. The general idea of wavelet de-noising: after processing noise signal with wavelet transform, the low-frequency wavelet coefficients is occupied by the active components of the signal, and the wavelet coefficient in high-frequency part is noise. Under different decomposing scales, set or solve the threshold, and then return wavelet coefficient which is smaller than the selected threshold to 0, retain the wavelet coefficient which is larger than the selected threshold. At last, the purpose of removing noise and restoring effective signal is reached after these treatments.

3.2 Commonly Used Wavelet De-noising Methods

Wavelet de-noising technique is the key of the current research. In general, the wavelet de-noising technology mainly depends on the following features of wavelet transform.

Low entropy. The sparsely distributing wavelet coefficient makes the entropy of the signal after wavelet transform decrease.

Multi-resolution analysis feature. Because wavelet transform uses multi-resolution analysis, the non-stationary characteristics of signal (peak, edge, discontinuous points, etc.) can be characterized well.

Getting Rid of the Correlation: This feature can highlight the superiority of time-domain de-noising.

Flexible basis function selection. According to different objects and applications, wavelet transform can choose different wavelet basis functions in order to achieve the best denoising effect.

At present, wavelet transform is the widely used de-noising tool. Table 1 summarizes the advantages and disadvantages of five kinds of commonly used wavelet de-noising methods.

Table 1. Five kinds of wavelet de-noising methods

Method	Advantage	Disadvantage
wavelet decomposition and reconstruction method	①simple algorithm ②The computing speed depends on the length of the signal.	①small application area ②high requirement to noise and signal frequency band ③It is not suitable for white noise de-noising.
modulus maximal method	①It can suppress the oscillation of singular point.	①strict requirement for scale ②slow calculation speed
Wavelet threshold method	①It effectively suppresses the noise. ②The signal processed through soft threshold is smooth. ③The best original signal can be got through hard threshold processing.	①There exists constant deviation between wavelet coefficients in Soft threshold method. ②The signal got from hard threshold method has large oscillation and is discontinuous.
translation invariant de-noising method	①It can suppress Pseudo-Gibbs phenomenon. ②It improves the signal-to-noise ratio.	①Computing speed is slower, and the longer the length of signal is, the slower computing speed is.
multi-dimension relevance method	①It is easy to implement. ②The de-noising effect of high signal-to-noise signal is good.	①The amount of calculation is large, and it is necessary to iterate.

Through comparison, this paper chooses the threshold method to deal with the noise of mine earthquake signals.

Wavelet threshold de-noising method is put forward by professor Donoh and professor Johnstone in 1992, which can maximize to restore the true signal. The basic principle is that remove the correlation of data by wavelet transform, some limited large wavelet coefficients are occupied by the energy of effective signals, and noise irregularly and randomly distributes in the wavelet domain. So after the first step of threshold de-noising (decomposition of wavelet coefficient), The difference between corresponding coefficient’s amplitude of the signal and noise will be highlighted, and the signal’s coefficient is large, the noise’s coefficient is small. That is, the signal with large wavelet coefficient is valid signal, so de-noising can be achieved by shrinking processing the signal with small wavelet coefficient [2].

The paper takes mine earthquake signal de-noising as the example to introduce steps of threshold de-noising method. Fig. 1 shows the flow chart.

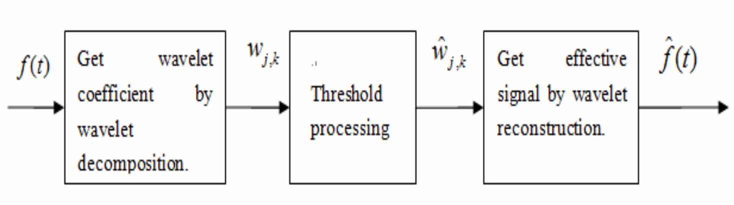

Fig. 1. Flow chart of wavelet threshold de-noising

Firstly, wavelet coefficient is obtained through wavelet decomposition. In this paper, the first step is to analyze the characteristics of mine earthquake signal, and then choose suitable wavelet basis function and decomposition layer n, at last get the wavelet coefficient matrix by using wavelet transform.

Secondly, process the threshold of wavelet coefficient. Low-frequency coefficient does not need procession, and each layer of the high-frequency coefficient need corresponding procession according to threshold rules. Then, a new wavelet coefficient matrix is gotten.

Thirdly, make wavelet reconstruction for the signal after de-noising. Make reconstruction based on the wavelet decomposition structures after threshold processing. The mine earthquake signal after de-noising can be gotten by reconstructing the unprocessed low-frequency in the highest level and all high-frequency coefficient processed by threshold.

3.3 Evaluation Standard of De-noising Effect

SNR (signal-to-noise ratio) and RMES (root mean square error) are two commonly used conditions of evaluating de-noising effect. Generally, it is necessary to comprehensively analyze both the values of SNR and RMES when you consider the de-noising performance. Suppose that is the original signal, and is the signal after de-noising, so the SNR is defined as Equation (1).

$$SNR = 10\log\left(\frac{\sum_{n=1}^{N} x^2(n)}{\sum_{n=1}^{N} x^2(n) - \sum_{n=1}^{N} \tilde{x}^2(n)}\right). \tag{1}$$

RMES is defined as Equation (2).

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left[x(n) - \tilde{x}(n)\right]^2}. \tag{2}$$

4 MATLAB Simulation Experiments on Threshold De-noising of Actual Mine Earthquake Signal

4.1 Mine Earthquake Signal

Under the action of source's force, all sorts of media vibrate because of the interaction with each other, then the vibration spreads to the surrounding area and forms seismic waves. In mines with different structure and depth, there are a series of refraction and reflection transformations, so the mine earthquake signal collected by mine earthquake recorder is meaningful.

It is the precondition of mine earthquake signal de-noising knowing the features of mine earthquake signal. The features of mine earthquake signal is mainly decided by the characteristics of the source, the rock and the distance from monitoring position to the source. The apparent characteristics is as follows: random mine earthquake signals, no fixed period, wide frequency band, different waveforms and large difference of energy.

In the actual problem, there are a lot of interference signals in the mine earthquake signal. Currently in the mine earthquake signal gathering area, main noise are mechanical vibration, blasting, wind, rain and lightning interference, etc.

4.2 Acquisition of Mine Earthquake Signal

In this experiment, microseism collecting system based on FPGA is used for data collection. Microseism collecting system consists of sensors, collecting station and the upper machine, and Fig. 2 shows the system.

Fig. 2. Microseism collecting system

The system uses 24 sampling channels to collect one-day's data. The sampling interval is 1 ms, and a total of 1.92 million data points are collected.

The system's collecting process is as the following steps: collecting mine earthquake signal through sensors, realizing the transformation from vibration signal to the analog, realizing the preliminary screening of useful signal by using anti aliasing filtering circuit, realizing the amplification processing of analog signal through programmable amplifier, realizing the final sampling process of signals and uploading the data to the upper machine.

Then the collected data are imported to MATLAB after format conversion and channel integration. Fig. 3 shows a part of the imported data, the first column represents the sampling channel, the second column represents the sampling time interval, the third column represents the number of mine earthquake signal data points, and the last few columns stand for mine earthquake signal amplitude of the corresponding sampling channel.

1	1	0	0.001958	-0.000218	0.000153	0.000233	-0.00022	0.000104	-0.000072	0.000064
1	1	1	0.001904	-0.000209	0.00012	0.000252	-0.000187	0.00008	-0.000047	0.000063
1	1	2	0.001916	-0.000193	0.000096	0.0002	-0.000192	0.000147	-0.000115	0.000093
1	1	3	0.001933	-0.000177	0.000055	0.000302	-0.000196	0.000107	-0.000082	0.000093
1	1	4	0.001912	-0.000146	-0.000017	0.000369	-0.000148	0.000071	-0.000019	0.000091
1	1	5	0.001888	-0.000185	-0.000017	0.000373	-0.000194	0.00012	-0.000037	0.000088
1	1	6	0.001884	-0.000155	0.000004	0.000402	-0.000283	0.000137	-0.000089	0.000076
1	1	7	0.001928	-0.0001	0.000006	0.000406	-0.000345	0.000072	-0.000021	0.000089
1	1	8	0.001932	-0.00005	0.000035	0.000376	-0.000336	0.000083	-0.00003	0.000114
1	1	9	0.001966	-0.000038	0.000093	0.000239	-0.000419	0.000075	-0.000053	0.00019

Fig. 3. Part actual acquisiting data of mine earthquake signal

4.3 Processing of Mine Earthquake Signal

Draw the time-domain curve of mine earthquake signal after importing data to MATLAB. Then get frequency-domain curve by Fourier transform in order to analyze main frequency and frequency of noise and useful signal.

This experiment adopts 24 sampling channels, and there are too many images, so this article only takes one-channel's data as an example. Fig. 4 stands for the overall time-domain curve of mine earthquake signal. Fig. 5 shows the overall frequency-domain curve after Fourier transform. Fig. 6 represents partial enlarged frequency-domain curve after Fourier transform.

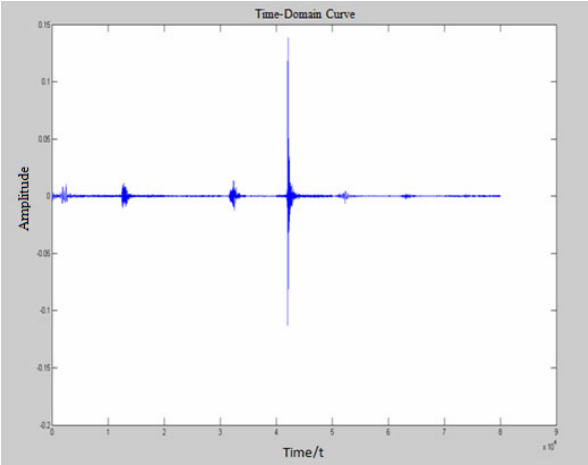

Fig. 4. Overall time-domain curve of channel 1 mine earthquake signal

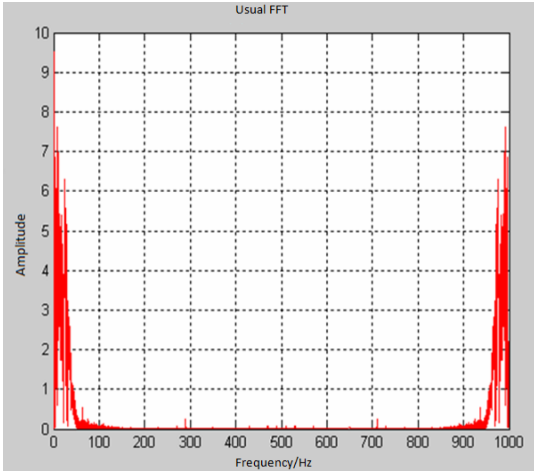

Fig. 5. Overall frequency-domain curve of channel 1 mine earthquake signal

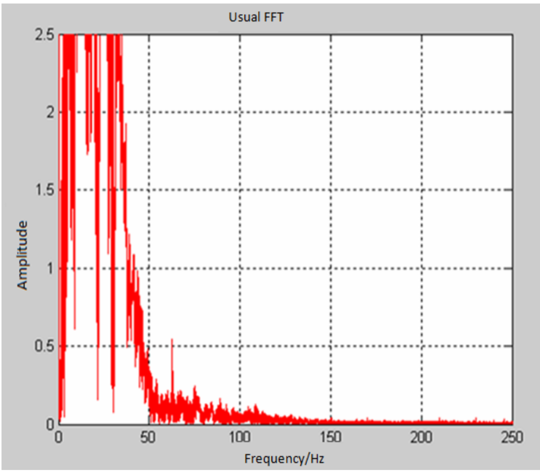

Fig. 6. Partial enlarged frequency-domain curve of channel 1 mine earthquake signal

According to the analysis of main frequency, it is known that the frequency of main earthquake is 50 Hz through analysis of the main frequency. This part plays a key role in the next step of signal and noise separation.

4.4 Wavelet Basis Function and Its Selection

Mainly used wavelet basis functions. There are six kinds of commonly used wavelet basis functions as the following.

(1) Haar wavelet is a kind of orthogonal function set, with orthogonality, symmetry, compactness and high time resolution, but its frequency-domain localization ability is poor [3].

(2) Daubechies wavelet functions (DbN) have no symmetry, but have orthogonality [4]. N represents the number of wavelet basis function, and the value of N is usually 1-10.

(3) Symlet wavelet is a kind of orthogonal wavelet, with symmetry. Symlet wavelet is an improvement of db wavelet, and are basically similar to Daubechies wavelet, but has better symmetry than Daubechies.

(4) Coiflet wavelet has orthogonality, symmetry, and the characteristic of quasi linear phase.

(5) Morlet wavelet is a kind of single frequency sine function, with no orthogonality and double

orthogonality. But this wavelet has symmetry, so it is often used in continuous wavelet change, and the application range is very big.

(6) MexicanHat wavelet has no orthogonality, but have good localization ability.

The selection of wavelet basis function. The appropriate selection of wavelet basis function is one of the factors affecting the effects on signal de-noising, and there will be different results even process the same signal by using different basis functions [5]. In the process of signal de-noising, it is hoped that the wavelet base function used is orthogonal wavelet, that is the wavelet used has symmetry, smoothing and compact support. Symmetry maintains a certain linear phase shift, and effectively avoids the signal distortion. Smoothing keeps the high and low of frequency resolution. Compact support makes the spatial local characteristic of wavelet base good. But the above three properties are mutually restricted, and can't meet at the same time.

In this paper, according to the experience of previous scholars, compromise method is adopted to implement a certain symmetry, smoothing and compact support for the selection of wavelet basis function. Sym wavelet and db wavelet generally meet the above requirements through analysis. At the same time, this paper dose a lot of experiments under the scale 2~10 by MATLAB wavelet analysis toolbox and MATLAB programming, and mainly carries out de-noising experiments under the scale 2. Because that the de-noising effect is not ideal when the scale is larger than 5, so this paper only gives the de-noising numeric values under scale 2-5. The specific data are shown in Table 2 to Table 4.

According to Table 2 to Table 4, SNR (signal-to-noise ratio) and RMES (root mean square error) are two commonly used conditions of evaluating de-noising effect [6-7]. Generally, the bigger SNR is, the better the de-noising effect is, and the smaller the RMES is, the more similar reconstructed signal and useful signal are. Therefore, this experiment eventually chooses Sym8 as wavelet basis function for this mine earthquake signal de-noising based on MATLAB experiment data and comprehensively analysis analyzing SNR and RMES two evaluation standards.

Table 2. De-noising numerical table of db function under different scales

function scale	db1	db2	db3	db4	db5	db6	db7	db8	db9	db10
2SNR	34.68248	39.14560	40.40543	40.87119	41.09498	41.20034	41.30155	41.35680	41.41058	41.44690
2RMSE	0.003221	0.003223	0.003223	0.003223	0.003223	0.003223	0.003223	0.003223	0.003223	0.003223
3SNR	30.40090	34.77450	35.94921	36.34234	36.62830	36.72297	36.81962	36.86113	36.93921	36.87412
3RMSE	0.003216	0.003221	0.003222	0.003222	0.003222	0.003223	0.003223	0.003223	0.003223	0.003223
4SNR	26.11056	29.60706	30.81808	31.47930	31.53111	31.79868	31.93180	31.76139	31.96859	31.92423
4RMSE	0.003200	0.003212	0.003215	0.003215	0.003217	0.003217	0.003216	0.003218	0.003217	0.003217
5SNR	21.68412	23.96905	25.08489	25.56847	25.97420	26.30991	26.39309	26.65658	26.60361	26.69175
5RMSE	0.003166	0.003183	0.003189	0.003191	0.003194	0.003197	0.003194	0.003199	0.003198	0.003196

Table 3. De-noising numerical table of sym function under different scales

function scale	Sym2	Sym3	Sym4	Sym5	Sym6	Sym7	Sym8
2SNR	39.1456	40.40543	40.86636	41.09298	41.19271	41.3094	41.35948
2RMSE	0.003223	0.003224	0.003224	0.003224	0.003224	0.003224	0.003224
3SNR	34.7745	35.94921	36.36711	36.57589	36.67916	39.81849	41.87457
3RMSE	0.003221	0.003222	0.003223	0.003223	0.003223	0.003223	0.003220
4SNR	29.60707	30.81808	31.30132	31.57508	31.68749	31.94379	32.00034
4RMSE	0.003212	0.003216	0.003217	0.003217	0.003217	0.003217	0.003217
5SNR	23.96905	25.08489	25.82569	26.06006	26.32737	26.44454	26.68674
5RMSE	0.0031183	0.003189	0.003191	0.003197	0.003194	0.003196	0.003196

Table 4. De-noising numerical table of db and sym function under scale 2 in MATLAB

function	db1	db2	db3	db4	db5	db6	db7	db8	db9	db10
SNR	37.7621	40.8277	41.3859	41.5878	41.6913	41.7492	41.8205	41.8295	41.8527	41.9112
RMSE10-5	4.17	2.93	2.75	2.69	2.66	2.64	2.62	2.61	2.61	2.59
function	Sym1	Sym2	Sym3	Sym4	Sym5	Sym6	Sym7	Sym8	Sym9	Sym10
SNR	37.7621	40.8277	41.3859	41.5751	41.6853	41.7396	41.8036	41.8759	41.8758	41.8854
RMSE10-5	4.17	2.93	2.75	2.69	2.66	2.64	2.62	2.91	2.60	2.60

4.5 The Selection of Largest Decomposition Layer

In the process of actual signal de-noising, decomposition layer affects the de-noising effect. Generally the best decomposition layer J takes 3-5 in the processing signal. However, in actual problem, particular analysis of SNR is needed for the choice of decomposition layer.

In the mine earthquake signal processing, SNR is too small and de-noising effect is not ideal when decomposition layer is greater than 5 through MATLAB wavelet analysis toolbox and MATLAB programming experiments, so decomposition layer 2-5 is considered to choose.

The paper shows wavelet decomposition coefficient in the form of image. Fig. 7 shows the wavelet decomposition coefficient which exists in the form of matrix. The paper shows the change characteristics wavelet decomposition coefficient through MATLAB programming and wavelet toolbox two forms. It is known from Fig. 7 that a lot of noise will be filtered with the increase of decomposition layer, and the signal of low-frequency coefficient is closer to the actual signal.

At the same time, according to Table 5, SNR is the maximum in decomposition layer 3. Secondly, two evaluation standards and calculation problem are considered. At last, this paper chooses decomposition layer 3 for mine earthquake signal de-noising.

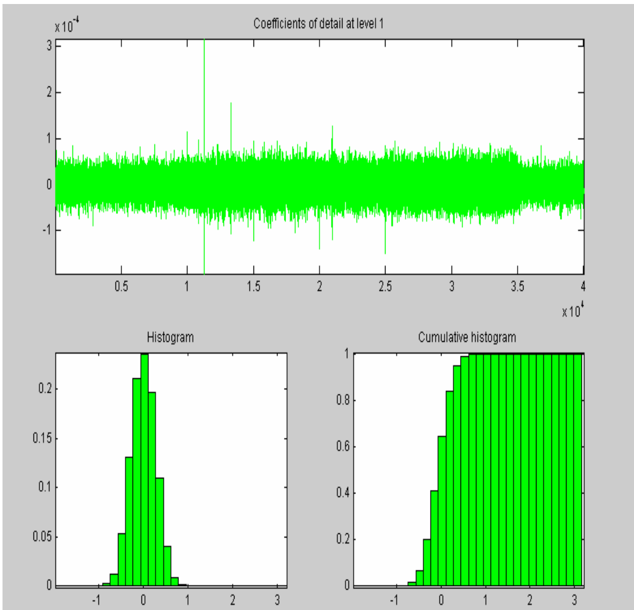

Fig. 7. Detailed image of wavelet coefficient in wavelet toolbox

Table 5. De-noising numerical table of Sym8 under scale 2-5

Sym8	2	3	4	5
SNR	41.8459	42.4554	35.1283	30.9194
RMSE10-5	2.61	3.85	5.65	9.18

4.6 Choice of Threshold Rule

The selection of threshold is an important problem in the process of wavelet threshold de-noising. Several classical threshold rules are as follows: Fixed threshold method is suitable for the signal containing noise which independently and identically distributes. Stein unbiased likelihood estimation threshold belongs to a kind of adaptive threshold on the principle [8]. HeurSure threshold adjust the threshold according to SNR, that is, adjust threshold to fixed threshold if processed signal with large SNR, and adjust the threshold to unbiased estimation threshold if processed signal with small SNR. Mini-max threshold is a kind of threshold selection fixed way, which is got according to the fixed threshold.

In this paper, a large number of MATLAB simulation experiments are done based on four kinds of commonly used threshold rules according to the characteristics of the actual mine earthquake signal, wavelet basis function Sym8 and decomposition layer 3. The specific de-noising numeric value is shown in Table 6. In this experiment the signal is random, and SNR and RMS (root mean square) appear the opposite condition. So this experiment considers using Rigrsure threshold de-noising through comprehensively considering the reasons such as the amount of calculation.

Table 6. De-noising numerical table under four kinds of threshold rules

Threshold Rule	Heursure	Rigrsure	Minimax	Sqtwolog
SNR	41.2989	42.3231	38.4554	37.9363
RMSE (10-5)	2.78	3.97	3.85	4.09

This experiment takes channel 8 as an example to show de-noising effect of using Rigrsure threshold rule. Table 7 shows de-noising numeric value of channel 8 mine earthquale signal processed by Rigrsure threshold rule.

Table 7. De-noising numerical table of channel 8 mine earthquake signal processed by Rigrsure threshold rule

Rigrsure Threshold Rule	SNR	RMES (10-5)
Channel 8	41.9523	2.73

Fig. 8 shows the signal contrast figure before and after using Rigrsure threshold de-noising rule. The blue line stands for original signal, and the red line represents the signal after de-noising.

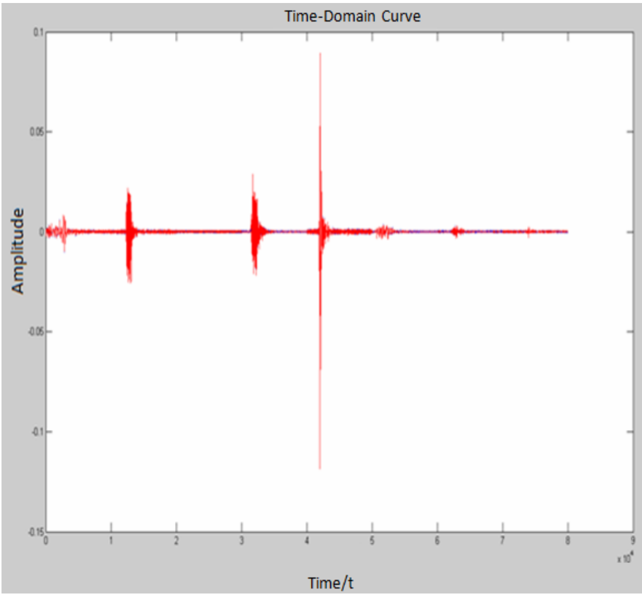

Fig. 8. Channel 8 signal contrast figure before and after using Rigrsure threshold de-noising rule

In the experiment Birge-Massart method is also tried to get the threshold of one dimensional wavelet transform, which is a kind of adaptive threshold Equation (3) shows the Birge-Massart threshold which is obtained by minimization standard.

$$c(t) = \sum_{k \le t} m^2(k) + 2\sigma^2 t(\alpha + \ln\frac{n}{t}), t = 1,2,\cdots,n \quad \textbf{(3)}$$

In Equation (3), stands for the wavelet coefficient whose storage is in form of decreasing absolute value. stands for the adaptive threshold. represents adjustment factor. is the number of coefficient. is the standard deviation of noise, and its computation formula is shown in Equation (4).

$$\sigma = median(|W_{h,v,d}|)/0.6745 \quad \textbf{(4)}$$

In Equation (4), respectively represents the high-frequency coefficients in level, vertical and diagonal three directions. The function of is filter. Because Equation (3) is a function of t type, so the corresponding threshold will obtain maximum and minimum value when t takes the maximum and minimum value. Appropriate Birge-Massart threshold can be obtained by adjusting the specific signal parameter.

Table 8 gives the de-noising numerical value of Birge-Massart threshold rule under soft and hard threshold function. Fig. 9 shows the partial enlarged contrast figure of mine earthquake signal before and after processed by Birge-Massart threshold de-noising (The blue line represents original signal, and the red line represents the signal after de-noising).

Table 8. De-noising numerical table of Birge-Massart threshold rule under soft and hard threshold function

Birge-Massart	Hard Threshold Function	Soft Threshold Function
SNR	49.8363 48.5374	48.5374 48.5374
RMSE (10-5)	3.29	3.82

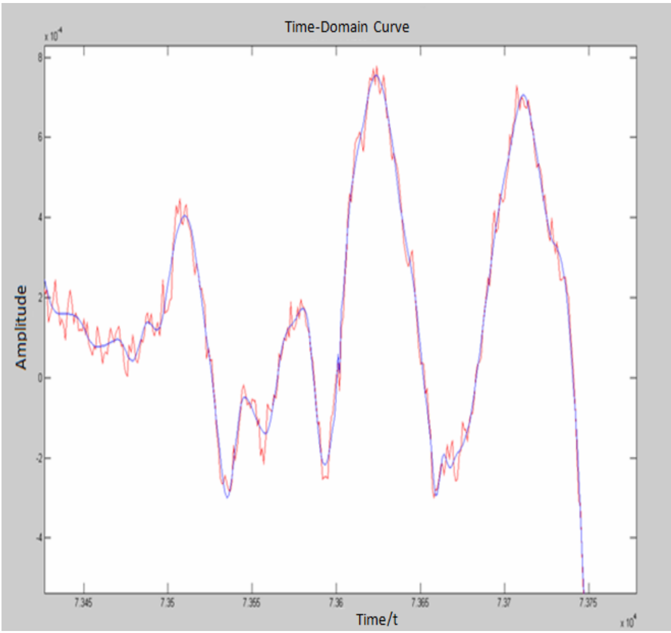

Fig. 9. Partial enlarged contrast figure of mine earthquake signal before and after processed by Birge-Massart threshold de-noising

According to the comparison between Table 7 and Table 8, and the comparison between Fig. 8 and Fig. 9, under the same experimental conditions, both SNR and RMSE are improved when using Birge-Massart method for de-noising, and the Birge-Massart method de-noising effect is better than the Rigrsure rule de-noising effect. Therefore this paper chooses Birge-Massart adaptive threshold method for mine earthquake signal de-noising.

4.7 Improvement of Threshold Function

It is available from Table 8 that hard threshold function has high SNR, and soft threshold function has small RMSE. So in order to achieve better de-noising effect, it is necessary to combine hard and soft threshold functions (compromise thought). That is using the improved threshold function deals with the noise.

Equation (5) shows the traditional hard and soft threshold compromise method.

$$\hat{w}_{j,k} = \begin{cases} \operatorname{sgn}(w_{j,k})(|w_{j,k}| - a\lambda), |w_{j,k}| \geq \lambda \\ 0, |w_{j,k}| < \lambda \end{cases} . \quad \textbf{(5)}$$

In Equation (5), stands for the wavelet coefficient of point k under scale j, is symbol function, represents threshold, and represents adjustment factor. The ideological source of this method is to make estimating wavelet coefficient more close to effective signal's wavelet coefficient, that is the minimum. So hard and soft threshold tradeoff method is carried out. But in this method the function will be continuous only when is equal to 1, which will lead to volatility of the reconstructed signal. So this paper adopts a new threshold function to deal with the noise of mine earthquake signal.
Equation (6) shows the new threshold function.

$$\hat{w}_{j,k} = \begin{cases} \operatorname{sgn}(w_{j,k})\left[\left| w_{j,k} \right| - \dfrac{\lambda}{\exp(\frac{\left| w_{j,k} \right|}{N})} \right], \left| w_{j,k} \right| \geq \lambda \\ 0, \left| w_{j,k} \right| < \lambda \end{cases} \quad (6)$$

In Equation (6), exp () stands for index function, and N represents the number of actual signal's sample point.

There lacks a process of transition when using commonly used hard and soft threshold function to process wavelet coefficient, which directly returns wavelet coefficient that is less than the threshold to zero or to the shrinkage threshold. New threshold function does a smooth transition processing. It is known according to Equation (6) that new threshold function not only overcomes the problem of constant deviation in the traditional soft threshold function, but also solves the oscillation problem of hard threshold function.

4.8 New Threshold de-noising Method

This experiment adopts new threshold function and Birge-Massart threshold rule and de-noises mine earthquake signals of 24 channels, which greatly improves the SNR and RMSE level and confirms the advantages of new de-noising method this paper studies. Because there are too many pictures, this paper chooses channel 8 as an example to display the de-noising effect, as shown in Fig. 10 and Table 9.

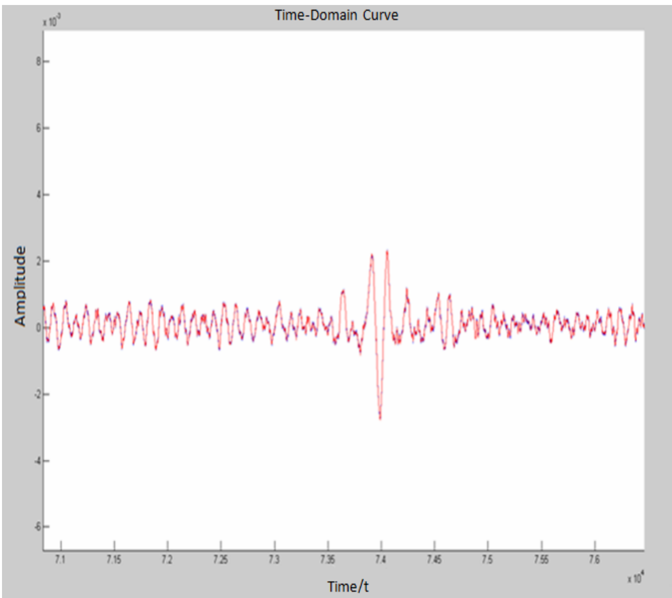

Fig. 10. Partial enlarged contrast figure of channel 8 mine earthquake signal before and after processed by new threshold de-noising method

Table 9. De-noising numerical table of channel 8 under new threshold de-noising method

New Threshold De-noising Method	SNR	RMSE (10-5)
Channel 8	55.6312	4.01

According to the comparison between Table 7 and Table 9, it is known that the SNR rises from 41.9523 to 55.6312, and RMSE also reduces from 4.01(10-5) to 2.73 (10-5) when channel 8 signal processed by the new threshold method. The contrast of de-noising effect is very remarkable, which fully shows the superiority of the new threshold de-noising method.

5 Conclusion

This paper takes the actual mine earthquake signal as research object, deals with more than 1.92 million data, takes MATLAB software as the platform, does lots of experiments in MATLAB programming and wavelet toolbox, and gets the following important conclusions at last.

The image of mine earthquake signal is obtained by modeling in the MATLAB, and get that the main frequency of mine earthquake signal is around 50 Hz through Fourier transform analysis.

The paper chooses wavelet basis function as Sym8 by analyzing the characteristics of the commonly used several wavelet basis functions, the characteristics of mine earthquake signal, experimental data and the evaluation criterion of de-noising effect.

The paper determines the best decomposition layer as 3 to get better de-noising effect through a lot of MATLAB simulation experiments. The corresponding data also illustrates the superiority of de-noising effect.

The paper does detailed analysis and experiments on several commonly used threshold rules, and finds that Rigrsure threshold rule has better de-noising effect than other methods, but Birge-Massart threshold which is an adaptive threshold method shows great superiority in the de-noising of mine earthquake signal.

The paper makes a detailed research on hard and soft threshold functions and the improved method, overcomes their shortcomings by putting forward a new threshold function, and also proves the good de-noising effect of new threshold function through the simulation experiments.

Due to the limitations of time and experiment platform, more study and work need to be further explored.

The problem of wavelet basis function needs to be further studied, especially the n value problem of db wavelet. Why does not n take larger than 10? In the future, these kinds of wavelet base functions and the corresponding de-noising effect need to be further researched and explored.

It is one of the goals in the future study to find an adaptive algorithm which applies to all mine earthquake signals and can reach the second a better de-noising effect.

References

[1] Z. Gao, Matlab Wavelet Analysis Toolbox Principle and Application, National Defend Industry Press, Beijing, 2004.

[2] X.M. Li, L. Chen, The Application of Wavelet Threshold De-noising in Image De-noising, Modern Computer, 2006.

[3] H.Y. Shen, QC. Li, Seismic wave fields separation and noise Attenuation in frequency domain via SVD, in: Proc. 2009 SEG Annual Meeting, 2009.

[4] I. Daubechies, The wavelet transform, time-frequency localization and signal analysis, IEEE Transaction on Information Theory 36 (1990) 961-1005.

[5] Shi, Y.B. Du, M.B. Zhang, S.J. Cheng, L.D. Gan, L.D. Gao, Z.H. Yao, M.C. Li, Seismic acquisition with digital point receivers and prestack reservoir characterization at China's Sulige gas field, The Leading Edge 28(3)(2009) 324-331

[6] Y.P. Wang, Y.L. Cai, The application of wavelet analysis in signal processing, Radio Engineering 24(8)(1994) 11-18.

[7] C.H. Hu, System Analysis and Design Baesd on MATLAB－Wavelet Analysis, Xian University Press, Xian, 2000.

[8] R.L. Lv, Performance analysis of wavelet threshold de-noising and the research of wavelet threshold denoising method based on energy Yuan, [dissertation] Zhejiang: Zhejiang University, 2003.