

Seismic Signal Analysis and System Development Based on Wavelet Analysis

Fan Yongkai* and Wang Chunhai

Department of Computer Science and Technology, China University of Petroleum, Beijing, China

Abstract: The Fourier Analysis has two distinguished characteristics: 1) has higher frequency resolution and lower temporary resolution in the low frequency part, and 2) has the opposite characteristics in the high frequency part, so it has a strong ability showing local characteristics of signal. The paper takes use of wavelet decomposition and reconstruction function to decompose and reconstruct seismic signal, then extract local characteristics as we want. In order to simplify the process at the same time, we use MATLAB as our analysis tool and realize the result visualization display base on the C# language programming. The result shows that this is not a new way but a very efficient way in the process of seismic signal analysis.

Keywords: MATLAB program implementation, seismic signal, signal analysis, wavelet analysis.

1. INTRODUCTION

With the development of national economy, the amount of the demand for oil and natural gas in China increases continuously. In 2013, China's apparent consumption of crude oil is 4.88 billion tons, domestic production is 2.08 billion tons, and the foreign dependency rate has reached 57.39% at the same time. The high degree of dependence on oil and gas brings a negative impact on the national energy security, China is facing a severe problem of petroleum and natural gas [1]. As people's demand for oil and natural gas resources is increasing, we should take more attention to the complex subtle reservoir, for example, small fault, wave layer. Seismic exploration is the main method in search for oil and natural gas, it finds out the underground geological structure through the measurement and analysis of seismic waves excited by the artificial, and study seismic wave propagation in stratum based on the rock elastic. In summary, earth exploration work is mainly composed of three parts: data acquisition, data processing and analysis, geological interpretation. Among them, data processing and analysis as the middle part connecting data acquisition and geological interpretation is very important [2, 3].

Scientists can recognize the underground rock stratum's geological structure from the seismic wave, and infer the location of oil and gas field. The characteristics of the seismic signal is caused by rock physical characteristics and changes, formerly people always ignore the information of physical property of rock, reservoir saturation and fluid composition, hiding in seismic signals due to a variety of interference, but now people gradually extract and analysis those information with the development of seismic

exploration technology and seismic data processing technology [4]. Wavelet transform can multilevel decompose seismic wave signal because of its good time-frequency analysis capability, multi resolution characteristics and basis function selection diversity, thus it has become a new method of seismic wave optimization process and is widely used [5].

In this paper, we develop a software through the mixed programming of C# and MATLAB, that can makes full use of the powerful function of MATLAB's mathematical calculations characteristics and the wavelet function can be called easily in the C# program. In order to improve the running efficiency of the program, we call the analysis result from the the C# program and use graphic user interface to show the outcome, this way will greatly facilitates the use of wavelet analysis in processing of seismic data interpretation.

2. BASE THEORY OF WAVELET ANALYSIS

2.1. Wavelet Decomposition

The principle of wavelet analysis is Mallat algorithm [6]. The Mallat algorithm is expressed as follows:

Here, we assume that $f(t) \in L^2(R)$ and in the resolution of 2^{-j} cases, its rough imaging is $A_j f \in V_j$, $\{V_j\}_{j \in Z}$ is $L^2(R)$'s multi resolution analysis, therefore we can deduce $V_j = V_{j+1} \oplus W_{j+1}$, it can also be expressed as $A_j f = A_{j+1} f + D_{j+1} f$.

In it, $A_j f = \sum_{k=-\infty}^{\infty} C_{j,k} \psi_{j,k}(t)$, $D_j f = \sum_{k=-\infty}^{\infty} D_{j,k} \psi_{j,k}(t)$, so we can develop that

*Address correspondence to this author at the Department of Computer Science and Technology, China University of Petroleum, Beijing, China; Tel:010-89733797; E-mail:fanyongkai@cup.edu.cn

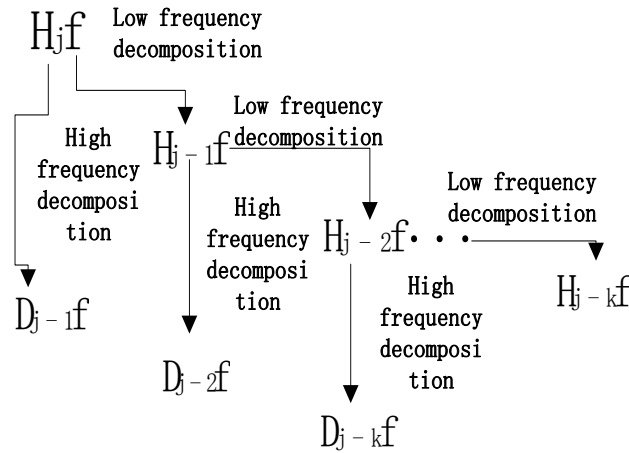


Fig. (1). Process of decomposition graph of different frequency band signal.

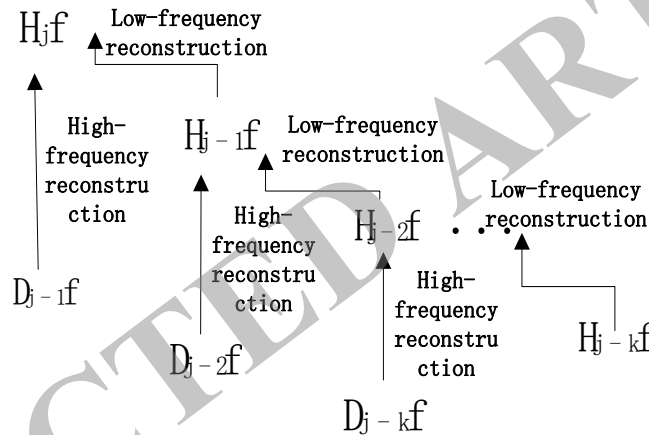


Fig. (2). Process of reconstruction graph of different frequency band signal.

$$\sum_{k=-\infty}^{\infty} C_{j,k} \phi_{j,k}(t) = \sum_{k=-\infty}^{\infty} C_{j+1,k} \phi_{j+1,k}(t) + \sum_{k=-\infty}^{\infty} D_{j+1,k} \psi_{j+1,k}(t)$$

The next step, we obtain $\phi_{j+1,m}(t) = \sum_{k=-\infty}^{\infty} h(k-2m)\phi_{j,k}(t)$ as first expression from scale function's two scale equation, and $\langle \phi_{j+1,m}, \phi_{j,k} \rangle = h(k-2m)$ as second expression from scale function's orthogonality, at the same time, $\langle \psi_{j+1,m}, \phi_{j,k} \rangle = g(k-2m)$ as third expression from wavelet function's two scale equation. Immediately, we infer $C_{j+1,m} = \sum_{k=-\infty}^{\infty} C_{j,k} h^*(k-2m)$ as fourth expression, $D_{j+1,m} = \sum_{k=-\infty}^{\infty} C_{j,k} g^*(k-2m)$ as fifth expression and $C_{j,k} = \sum_{m=-\infty}^{\infty} h(k-2m)C_{j+1,m} + \sum_{m=-\infty}^{\infty} g(k-2m)D_{j+1,m}$ as sixth expression from the previous expression.

Meanwhile, we introduce infinite matrix $H = [H_{m,k}]_{m,k=-\infty}^{\infty}$

and $G = [G_{m,k}]_{m,k=-\infty}^{\infty}$, among them, $H_{m,k} = h^*(k-2m), G_{m,k} = g^*(k-2m)$, so we can get $\begin{cases} C_{j+1} = HC_j \\ D_{j+1} = GC_j \end{cases} \quad j = 0, 1, \dots, J$, $C_j = H^*C_{j+1} + G^*D_{j+1}$ $j = J, J-1, \dots, 1, 0$ from previous expression. Among it, H^*, G^* are H and G 's conjugate transpose of the matrix.

At last, we summarize the process of wavelet decomposition and reconstruction as shown in Fig. (1).

The signal can take reconstruction algorithm of reconstruction after decomposition using Mallat algorithm. Reconstruction algorithm is similar to decomposition algorithm, the reconstruction process as shown in Fig. (2):

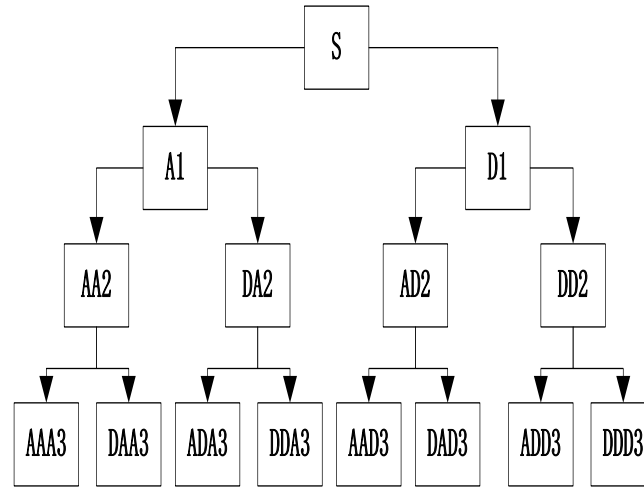


Fig. (3). Wavelet analysis tree.

2.2. Wavelet Packet Decomposition

Multi-resolution analysis of wavelet can make effective time-frequency decomposition to signals, but because of its scale function is based on the binary system, it's resolution is poor in the high frequency section, so it can only divide signal's frequency band into equal intervals in index level. Wavelet decomposition packet can provide a more precise analysis method for signals, which can make further decomposition to high frequency part and select adaptively the corresponding frequency band based on the characteristics of signals for the purpose of matching the signal spectrum and improving time-frequency resolution, so it has wide application scope.

Coifman put forward wavelet packet analysis based on wavelet analysis. It divides all sub of each layer into two parts, and then transmits to the lower layer, so each layer covers all frequency of primary wave. We can decompose signal into any levels and select to use subs flexibly, so wavelet packet analysis is a kind of accurate analysis method that can further decompose details wave. The following is the wavelet packet decomposition formula and process:

Supposing $\begin{cases} U_j^0 = V_j \\ U_j^1 = W_j \end{cases}$, $j \in Z$, and defining the subspace U_j^n is function $w_n(t)$'s closure space, the subspace U_j^{2n} is function $w_{2n}(t)$'s closure space, making it satisfy the following two scale equation:

$$w_{2n}(t) = \sqrt{2} \sum_k h(k) w_n(2t-k)$$

$$w_{2n+1}(t) = \sqrt{2} \sum_k g(k) w_n(2t-k)$$

In the above expression, $g(k) = (-1)^k h(1-k)$ and it can also be expressed as $U_{j+1}^n = U_j^{2n} \oplus U_j^{2n+1}$, $j \in Z, n \in Z_+$.

For example, we decompose signal S using wavelet packet decomposition of three layers, and its wavelet analysis tree is shown in Fig. (3).

The expression of wavelet packet decomposition is as follows:

$$S = AAA3 + DAA3 + ADA3 + DDA3 + AAD3 + DAD3 + ADD3 + DDD3$$

3. REALIZATION OF SYSTEM

In order to use the function calls in MATLAB to realize the analysis of seismic data, we use Visual Studio 2010 as our development environment, and design the wavelet analysis system in Windows platform using C# language under the VS2010 IDE. It's achieved by using the core algorithm of wavelet analysis and wavelet packet analysis to improve the resolution of seismic data and adapt to the degree of automation requirements. In the process of development, we strive to make software simple, practical and good human-computer interaction.

3.1. Structure of System

The structure of system mainly consists of four parts: data import module, Fourier transform module, wavelet analysis module, graphical results and comparison module. Data import module mainly imports data into system by the way of database or Excel; Fourier transform can transform the import data and select frequency band to wavelet analysis; wavelet analysis module can make wavelet transform or wavelet packet transform on appropriate wavelet basis function and the appropriate scale; graphic display module can display the results and compare the different results of different wavelet basis functions, scale and wavelet transform or wavelet packet transform, and save the results to a specified format.

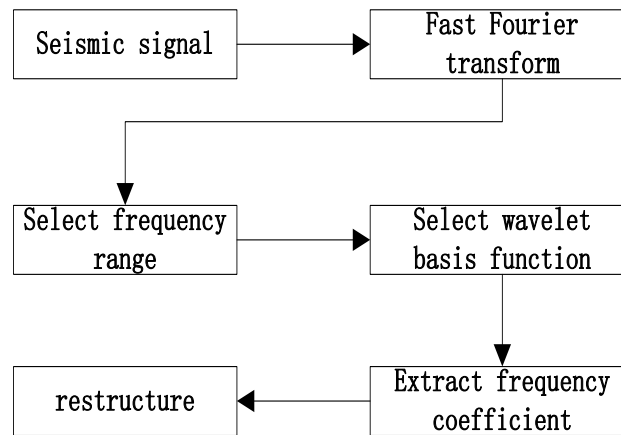


Fig. (4). Wavelet analysis flow diagram of seismic signal.

3.2. Characteristics of System

Firstly, it has the same style with Windows system's user interface, and encapsulates the wavelet analysis function of mathematical software MATLAB, user can easily learn and use the system.

Secondly, it can be convenient to carry out wavelet analysis of seismic data, making the wavelet analysis methods together basically. We can use it to make Fourier transform and obtain spectrum on appropriate wavelet function and appropriate scale, what's more, we also can select different layers' approximation coefficients and detail coefficients to reconstruction, thus analyze and compare results.

Thirdly, it can be easy to maintain and extend. The system is developed with C# language and object-oriented thinking, which make sure the software evolution easily to new ideas and methods for seismic data in the further.

3.2. Implementation with Mixed Programming of C# and MATALB

There are two ways to achieve making cross compiler and mixed programming of C# and MATLAB. One is use the deploy-tool to generate the dynamic link library DLL for C# calls, but this approach has a limit which is that MATLAB source M file must be a function of documents; the other way is based on the COM interface by which you can call MATLAB script command. Usually, we use cross compiler to call special function and toolbox in MATLAB, or drawing function to display results. In consideration of the MATLAB code's size is not large, so we use the latter approach to implement the C# and MATLAB cross compilation of mixed programming rather than the first one.

The first step we followed is to introduce Matlab Application Type Library in COM style to project, and the we add two references MathWorks: MATLAB.NET.Arrays and MathWorks.MATLAB.NET.Utility.The following steps give us the basic rule to realize the utilization: stating a MAppClass object to realize the MATLAB call, and writing MATLAB's adding data, calling wavelet analysis

function and rendering results into a string, executing function to perform, at last saving the rendering results into the specified path and display it by Picture Box control.

Because the storage mode of seismic data signals may be a text document, Excel or database, we realize data import function for each storage mode. Importing data in text documents and Excel is simply by calling the MATLAB's Load function and Xlsread function, and only passing the parameters of path. Importing data in database need connection string, for example, supposing that database is SQL sever 2005,it's connection string is:

```
url='jdbc:sqlserver://localhost:1433;databaseName=testdata\';driver='com.microsoft.sqlserver.jdbc.SQLServerDriver\';
```

Then use exec function to access the database connection, get the data by SQL statement and finally through the setdbprefs function to format the data to numerical type.

4. WAVELET DECOMPOSITION AND RECONSTRUCTION OF SEISMIC DATA

In order to extract relatively weak information in the seismic data effectively , firstly we should convert the seismic signal in time domain into frequency domain, then select the effective information frequency band and make wavelet decomposition, so the original signal is decomposed into some frequency bands and we can reconstruct specific bands. This process is shown in Fig. (4).

4.1. Examples of Wavelet Decomposition

In this section, we take the actual logging data of an oil well's gamma curve as an example to make wavelet analysis, mainly using the wavelet toolbox function in the mathematical software MATLAB. Firstly, we obtain spectrum by fast Fourier transform, as shown in Fig. (5).

Then we select the frequency band to make wavelet decomposition. Because that the effective information exist in the low frequency, so we select 0~100Hz to make wavelet decomposition. By using the wavedec function to decompose

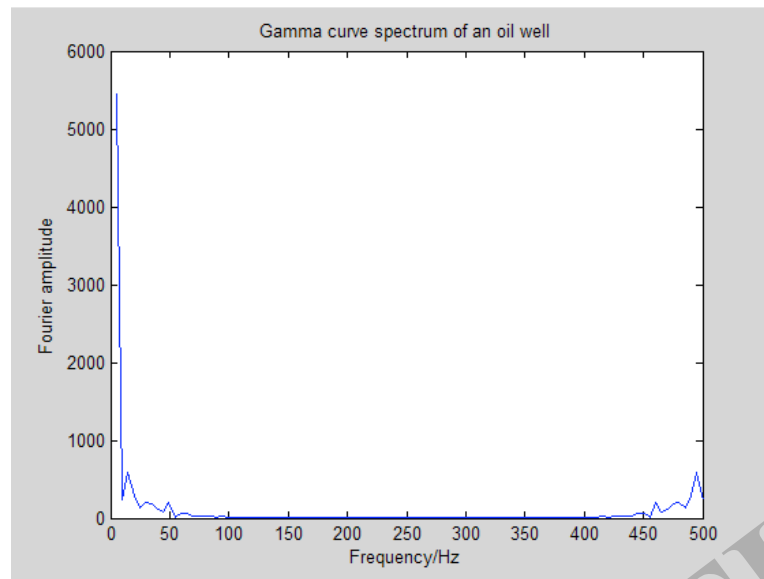


Fig. (5). Gamma curve spectrum of an oil well.

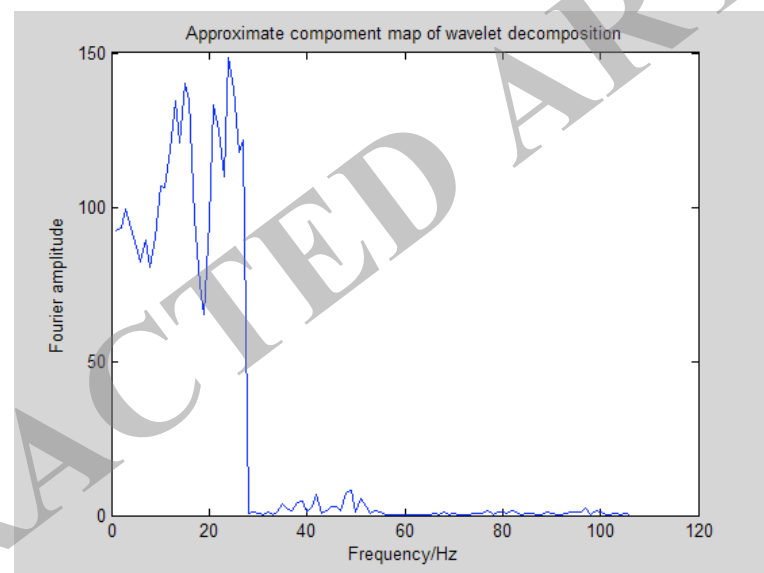


Fig. (6). Approximate component map of wavelet decomposition.

with the wavelet basis function of DB2 and scale of 2, we get the approximate component map shown in Fig. (6).

Supposing that the information we need is in 25~50Hz as the figure shown in Fig. (5), we just need to extract the high-frequency coefficients of two layer after wavelet decomposition according to the principle of wavelet decomposition. We use the function `decoef` in MATLAB to extract the detail component and reconstruct it by using the `wrcoef` function, the results are shown in Fig. (7).

4.2. Examples of Wavelet Packet Decomposition

Similarly, we make wavelet packet decomposition to the data decomposed in the 4.1 section. Firstly, we make fast

Fourier transform and select bandwidth, and carry on the wavelet packet decomposition. Here, we use the function `wpdef` in the MATLAB with the wavelet packet basis function of DB2 and scale of 2, at last get the wavelet packet tree shown in Fig. (8).

We use the function `wpcoef` in MATLAB to reconstruct and select the second nodes in the second layer of the wavelet packet decomposition tree. The results are shown in Fig. (9).

4.3. Comparison of Results

Similarly, we make wavelet decomposition on the data used in 4.2 section, only the wavelet basis function changes

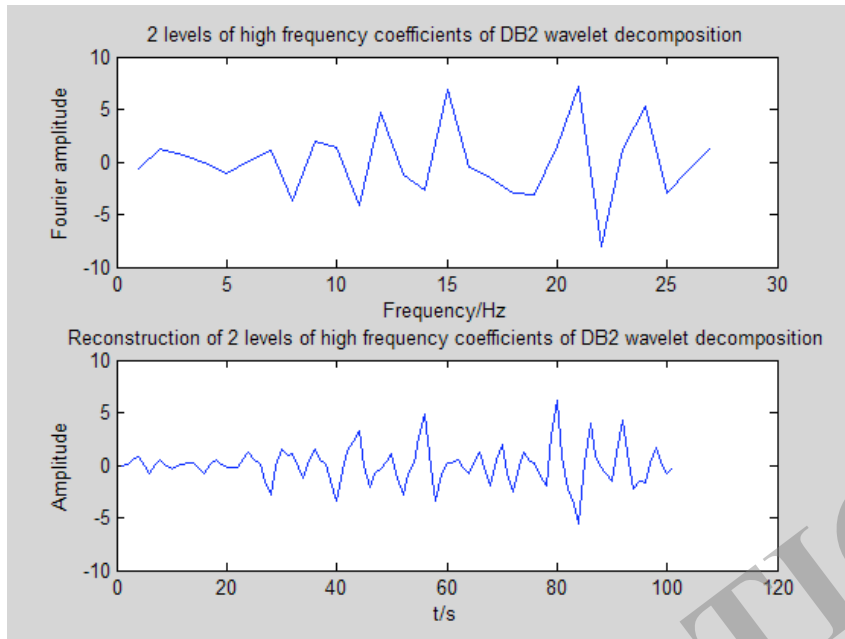


Fig. (7). 2 levels of high frequency coefficients of DB2 wavelet decomposition.

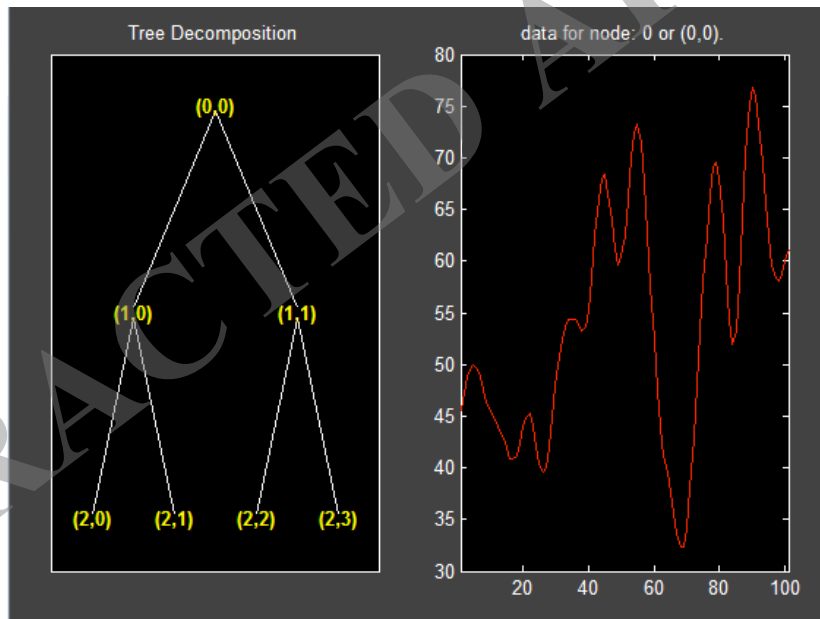


Fig. (8). Wavelet packet decomposition tree of DB2.

to DB10, here we make comparison and obtain the results shown in Fig. (10).

CONCLUSION

Wavelet analysis can extract the local feature of seismic signal, and give scientists a great help to interpret of seismic data. While Visual C#.Net has gradually become a mainstream tool of application developed, mathematical software

MATLAB is widely applied due to its powerful calculation, extensive function and drawing function in numerical processing and analysis. In this paper, we use wavelet analysis to do the seismic data analysis which based on mixed programming with C# and MATLAB, and use the wavelet functions of wavelet toolbox in MATAB and powerful visual ability in C# to achieve the final software system. The system is not only achieve good joining C# and MATLAB, but also make wavelet analysis on the seismic data that we can

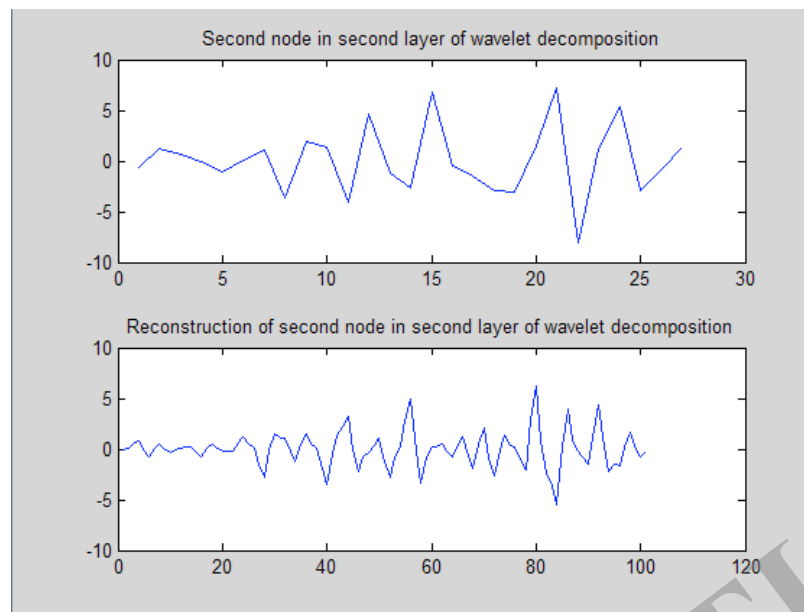


Fig. (9). Second node in second layer of wavelet packet decomposition and reconstruction.

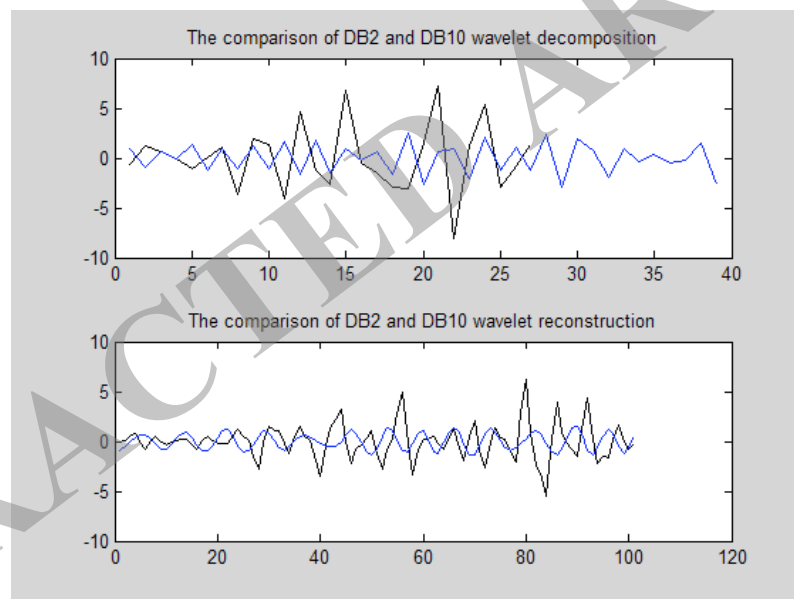


Fig. (10). The comparison of DB2 and DB10 wavelet decomposition.

select wavelet basis function and scale, and what is more, it can display the results clearly in the graphic interface. Thus it provides a great convenience in the analysis of seismic data for the relevant people, and also is the proof of broad prospect mixed programming of C# and MATLAB in various areas, so maybe it has a great significance for popularization using both for technology itself and data interpretation.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This paper is funded by 1) Beijing Higher Education Young Elite Teacher Project and by 2) Science Foundation of China University of Petroleum Beijing (No. 2462015Y Q0514).

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Received: September 16, 2014

Revised: December 23, 2014

Accepted: December 31, 2014

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