P PHASE AND S PHASE DETECTION USING THE DAUBECHIES WAVELET TRANSFORM (DWT) TO MINIMIZE THE NOISE AT THREE COMPONENT SEISMOGRAMS DISPLACEMENT RECORDS

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ABSTRACT

The wavelet transform is one of the important methods that are used to minimize noises and to analyze signals. The choice of wavelet and its associated scaling function are very important to obtain the most useful wavelet transforms. In the present work, it was investigated that the easy obtaining of the P and S phases by minimizing the noise at the three-component seismograms displacement records using Daubechies Discrete Wavelet Transform. The after shocks of the earthquake that occurred at the Afyon-Sultandağ (Turkey) on 03-04 February 2002 were used as real data. This work shows that the Daubechies Discrete Wavelet Transform gives very successful results at determining the P and S seismic phases without deforming the main characteristics of the required signal, thus making the data more comprehensible.

Keywords: Daubechies Discrete Wavelet Transform, P-S seismic phases

1. INTRODUCTION

A seismic signal consist of several different phases, which characterize the type of considered seismic signal. In these phases, P and S phases are the most important and they can determine easily. The arrival time of the S phase can be calculated by a three-component seismogram if the P phase arrival time is known [8]. Determining the arrival time of S phase depends on some physical differences between P and S phases [5]. The arrival time is the first one of these differences. The seismic events show that S phase arrives to the surface of the earth later than P phase. The S phase arrival time is determined in a three component seismogram, representing motion on a ground detector in three mutually orthogonal directions[3]. These are two in horizontal plane (x-y plane) and one vertical direction (z-axis). P phases are longitudinal waves and propagate along the direction of seismic activity; on the other hand S phases are transverse waves and propagate perpendicular to the direction of seismic activity. When the frequency spectrums of both phases are compared it can be seen that P phase takes place at the higher frequencies than S phase.

Identification of phases becomes harder when the seismic signals contain noise. Band-pass filters are used to analyze the broadband seismic data for increasing the signal/noise ratio by minimizing low and high frequency noises [1]. But this is not possible for all conditions. Generally, the background noises at the seismic signals have a certain frequency band. These noises are made up of the repeated reflections and refractions at the interfaces of the shell and at the regions where the conversion occurs from the body waves (P, S) to the surface waves in the non-homogenous media. Band-pass and polarization filters are used to determine compressional and shear phases. Seismograms are composed of polarizations at all frequencies and superposition of different types of waves that have dissimilar phases. Unfortunately, these filters are not useful for all conditions since they assume that all wave shapes in all or most frequencies have same polarization [1]. So the use of discrete wavelet transform becomes important in detection of real time seismic signals and reduction of noise effects.

There are some applications of wavelet transform about phase determination in three-component seismogram analyze in the literature [6, 7, 8, 9]. Furthermore, the most important property of this study is to enable obtaining the phases at the noisy seismic signals whose P and S phases are too difficult to determine.

2. METHOD

2.1. Discrete Wavelet Transform

A wavelet, in the sense of the Discrete Wavelet Transform (DWT), is an orthogonal function which can be applied to finite group of data. Functionally, it is very much like the Discrete Fourier Transform, in that the transforming function is orthogonal, a signal passed twice through the transformation is unchanged, and the input signal is assumed to be a set of discrete time samples. Both transform are convolutions.

A wavelet equation has a form that is similar to the well-known Fourier series. But to introduce these functions two parameters are used.

$$\mathbf{f(t) = \sum k \sum j a_{j,k} \Psi_{j,k}(t)}$$

Where j and k are integers and $\Psi_{jk}(t)$ is wavelet function that is generally orthogonal. The expansion coefficient $a_{jk}(t)$ which has two parameters is called as discrete wavelet transform (DWT) coefficient of f(t). This coefficient is given as

$$\mathbf{a}_{j,k} = \int \mathbf{f}(\mathbf{t})\Psi_{j,k}(\mathbf{t})\mathbf{dt}$$

Wavelet functions are the family functions. They have two parameters and they are expressed in term of $\Psi(t)$ named as mother wavelet.

$$\Psi_{j,k}(\mathbf{t}) = 2^{j/2}\Psi(2^{j}\mathbf{t}-\mathbf{k})$$

Where k is the translation and j is the dilation or compression parameters. Thus wavelet functions are obtained from a unique wavelet by translation and scaling. In addition, there is no unique or universal mother wavelet function. At analysis, mother wavelet function must have satisfactory qualities even the smallest parts and must be typically chosen according to the signal analysis problem type. Nearly all useful wavelet systems are quite satisfactory in multi-resolution conditions [4]. So by minimizing the noise and expanding the desired f(t) signals with a chosen mother wavelet function, the same f(t) function can be obtained by a successful approach again [10].

2.2. Daubechies Wavelet Transform

Daubechies wavelet transform is one of the mother wavelet transforms. This transform signal is defined by the scaling and wavelet functions that are expressed in terms of α and β coefficients, respectively.

Scaling function V and coefficients α are defined as [2]

$$\alpha_1 = \frac{1+\sqrt{3}}{4\sqrt{2}} \qquad \alpha_2 = \frac{3+\sqrt{3}}{4\sqrt{2}} \qquad \alpha_3 = \frac{3-\sqrt{3}}{4\sqrt{2}}$$

$$\alpha_4 = \frac{1-\sqrt{3}}{4\sqrt{2}}$$

$$\mathbf{V}_1^1 = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, 0,0,0,...)$$
$$\mathbf{V}_2^1 = (0,0,\alpha_1, \alpha_2, \alpha_3, \alpha_4, 0,0,...)$$
$$\mathbf{V}_{N/2}^1 = (\alpha_3, \alpha_4, 0,0,...,0,\alpha_1, \alpha_2)$$
$$\mathbf{V}_{\mathbf{m}}^1 = \alpha_1\mathbf{V}_{2\mathbf{m}-1}^0 + \alpha_2\mathbf{V}_{2\mathbf{m}}^0 + \alpha_3\mathbf{V}_{2\mathbf{m}+1}^0 + \alpha_4\mathbf{V}_{2\mathbf{m}+2}^0$$
$$\mathbf{V}_{\mathbf{m}}^2 = \alpha_1\mathbf{V}_{2\mathbf{m}-1}^1 + \alpha_2\mathbf{V}_{2\mathbf{m}}^1 + \alpha_3\mathbf{V}_{2\mathbf{m}+1}^1 + \alpha_4\mathbf{V}_{2\mathbf{m}+2}^1$$

Wavelet function W and coefficients β are given as

$$\beta_1 = \alpha_4 \quad \beta_2 = -\alpha_3 \quad \beta_3 = \alpha_2 \quad \beta_4 = -\alpha_1$$

$$\mathbf{W}_1^1 = (\beta_1, \beta_2, \beta_3, \beta_4, 0,0,0,...)$$
$$\mathbf{W}_2^1 = (0,0,\beta_1, \beta_2, \beta_3, \beta_4, 0,0,...)$$
$$\mathbf{W}_{N/2}^1 = (\beta_3, \beta_4, 0,0,...,0,\beta_1, \beta_2)$$
$$\mathbf{W}_{\mathbf{m}}^1 = \beta_1\mathbf{W}_{2\mathbf{m}-1}^0 + \beta_2\mathbf{W}_{2\mathbf{m}}^0 + \beta_3\mathbf{W}_{2\mathbf{m}+1}^0 + \beta_4\mathbf{W}_{2\mathbf{m}+2}^0$$
$$\mathbf{W}_{\mathbf{m}}^2 = \beta_1\mathbf{W}_{2\mathbf{m}-1}^1 + \beta_2\mathbf{W}_{2\mathbf{m}}^1 + \beta_3\mathbf{W}_{2\mathbf{m}+1}^1 + \beta_4\mathbf{W}_{2\mathbf{m}+2}^1$$

As A is the low frequency signal component and D is the high frequency signal component, f(t) signal is calculated using [2]

$$\mathbf{f} = \mathbf{A}^{\mathbf{m}} + \mathbf{D}^{\mathbf{m}} + \mathbf{D}^{\mathbf{m}-1} + ... + \mathbf{D}^2 + \mathbf{D}^1$$
$$\mathbf{A}^{\mathbf{m}} = (\mathbf{f}\mathbf{V}_1^{\mathbf{m}})\mathbf{V}_1^{\mathbf{m}} + ... + (\mathbf{f}\mathbf{V}_{\mathbf{N}/\mathbf{m}}^{\mathbf{m}})\mathbf{V}_{\mathbf{N}/2^{\mathbf{m}}}^{\mathbf{m}}$$
$$\mathbf{D}^{\mathbf{m}} = (\mathbf{f}\mathbf{W}_1^{\mathbf{m}})\mathbf{W}_1^{\mathbf{m}} + ... + (\mathbf{f}\mathbf{W}_{\mathbf{N}/\mathbf{m}}^{\mathbf{m}})\mathbf{W}_{\mathbf{N}/2^{\mathbf{m}}}^{\mathbf{m}}$$

In this study, real data recorded by three-component STS-1 broadband 0.01-20Hz sampling seismometer, which is situated at the Earthquake Research Center of Suleyman Demirel University, were used. 20Hz-sampling records were chosen from whole data. The effects of the instrument are removed using a FORTRAN program.

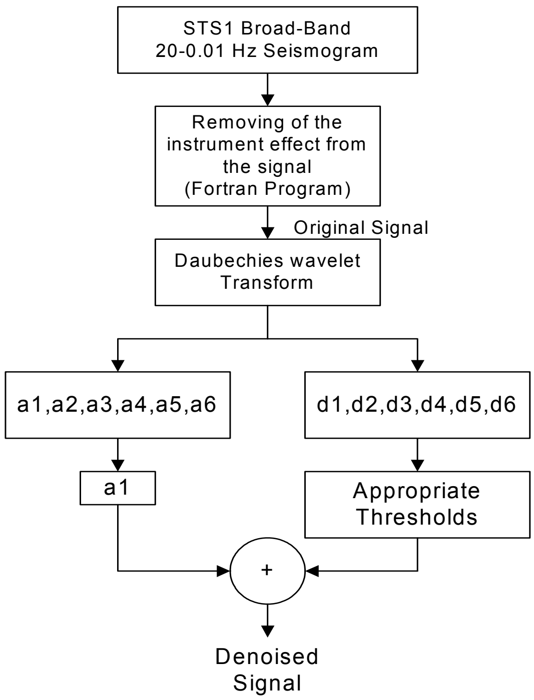

Fig.1. The block diagram of the applied algorithm for solution

The obtained data were separated to 5 high frequency components and 5 low frequency components using Daubechies Discrete Wavelet Transform. Appropriate thresholds were adjusted for each one. Desired denoised data were obtained using these thresholds.

3. Data

In this study, the data obtained from the three after shocks of the earthquake that occurred in Afyon-Sultandağ in Turkey on 03-February-2002. The after shocks occurred on 03-February-2002 at 09.11-13.30 and on 04-February-2002 at 02:44. Three components of these after shocks (E-W, N-S, Z) were analyzed using the explained method. The results are given in the following figures. In these figures P indicates longitudinal wave phase and S indicates transverse wave phase. The difficulty in determining P and S phases from the original seismogram records were removed seriously with made noise reduction.

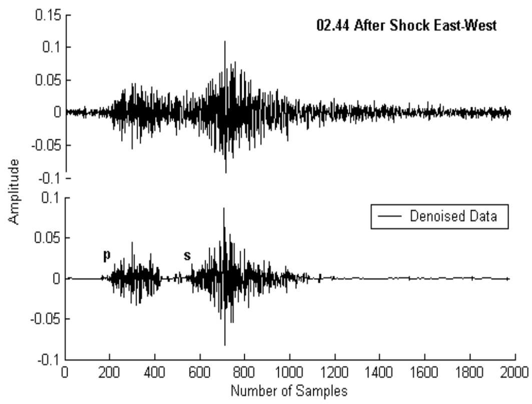

Fig.2. The 100s/20Hz sampling original records of East-West component of the after shock that occurred at 02.44 and determining P and S phases by removing the noise

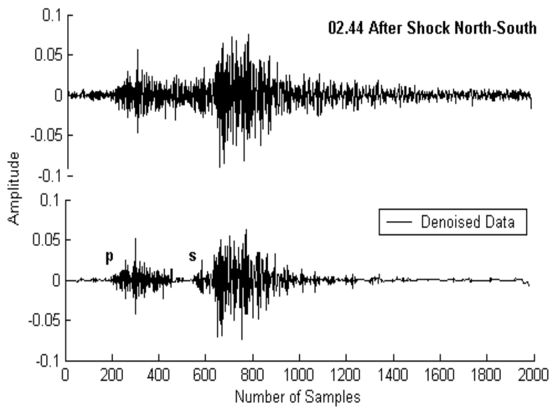

Fig.3. The 100s/20Hz sampling original records of North-South component of the after shock that occurred at 02.44 and determining P and S phases by removing the noise

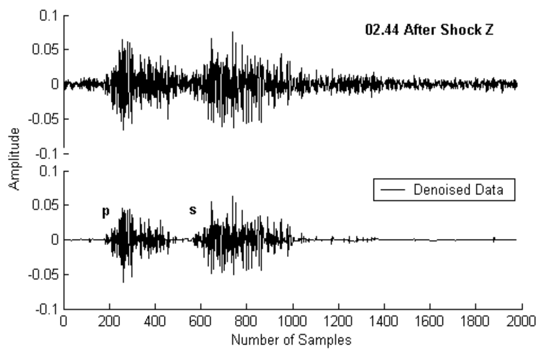

Fig.4. The 100s/20Hz sampling original records of Z component of the after shock that occurred at 02:44 and determining P and S phases by removing the noise

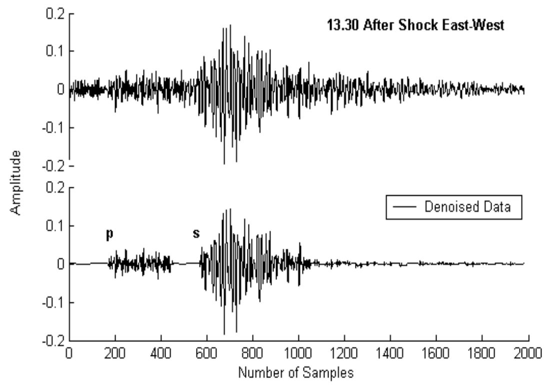

Fig.5. The 100s/20Hz sampling original records of East-West component of the after shock that occurred at 13:30 and determining P and S phases by removing the noise

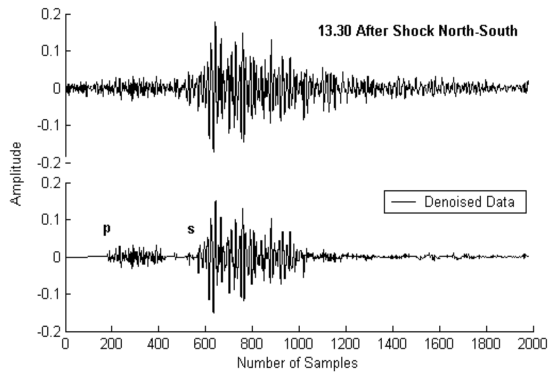

Fig.6. The 100s/20Hz sampling original records of North-South component of the after shock that occurred at 13:30 and determining P and S phases by removing the noise

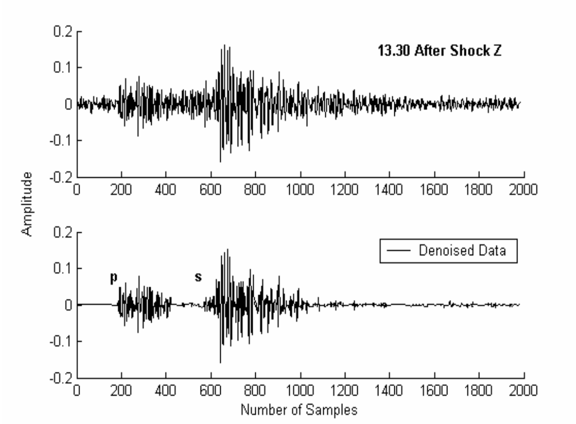

Fig.7. The 100s/20Hz sampling original records of Z component of the after shock that occurred at 13:30 and determining P and S phases by removing the noise

4. Results and Discussion

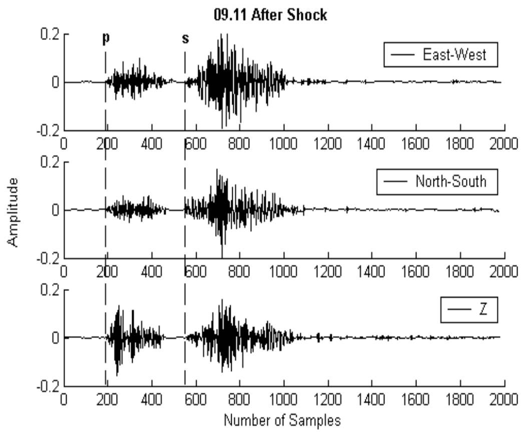

Fig.8. All three components of 09:11 after shock

The investigated signals in this study were local earthquake signals. The separation of the signals to their low and high frequency components by Daubechies Discrete Wavelet Transform supplied understanding of the signal without applying any denoising process. The thresholds could be applied to the chosen regions of signals and this property makes the process easier. The boundaries of the signal that thresholds would apply can be determined by first wavelet separations. So the user only needs to determine the appropriate threshold values. Noise minimization can be made more sensitively than the noise separation processes that were made by known band-pass filters and it can be made without causing loss of the phases that are wanted to seen in the main signals. In the denoised signals that were obtained by wavelet transform, when three components were investigated together it can be seen that P and S phases were determined nearly at the same points (Fig.8). So it is clear that there were no phase shift during the noise reduction. This method can be improved for the seismic refraction and seismic reflection besides the other real data.

5. References

[1] Du, Z., Foulger, G.R., Mao F., Noise reduction for Broad-band three-component seismograms using data-adaptive polarization Filters, Geophys. J.Int. 2000, 141, 820-828

[2] Daubechies, I., Ten Lectures in Wavelets, Series in Applied Mathematics, Philadelphia, 1992, 357pp.

[3] Botella F., Rosa-Herranz, J., Giner J.J., Molina S., Galiana-Merino J.J., A real Time Earthquake Detector with prefiltering by wavelets, Computers & Geosciences, 2003

[4] Vetterli M., Kovacevic, J., 1995. Wavelets and Subband Coding. Prentice-Hall, Englewood Cliffs, NJ, 488 pp.

[5] Aki, K., Richards, P.G., Quantitive Seismology, Freeman and Company, San Francisco, 1980

[6] Anant, K., Dowla, F., Wavelet Transform Methods for Phase Identification in Three-Component Seismograms, Bull. Seism. Soc. Am., 87(6), 1598-1612, 1997.

[7] Olmo, G., Lo Presti, L., Applications of Wavelet Transform for Seismic Activity Monitoring, in Wavelets: Theory, Algorithms, and Applications, Chui, C., Montefusco, L., Puccio, L., Academic Pres, London, 1994.

[8] Oonnicx, P.J., Automatic Phase Detection in Seismic Data using the Discrete Wavelet Transform, Report PNA-R9811, CWI, 1998.

[9] Cichowicz, A., An Automatic S-Phase Picker, Bull. Seism. Soc. Am., 83(1), 180-189, 1993

[10] Rioul, O., Vetterli, M., Wavelets and Signal Processing, IEEE Sig. Proc., 8, 14-38, 1991