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Applications of Various Time-Frequency Analysis Methods to Earthquake Accelogram Records

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SUMMARY

The most commonly used signal analysis method is Fourier Transform (FT) that assumes the time signal in study is stationary. FT method is only suitable for signals whose frequency contents do not change over time and not able to show how the frequency contents develop over time. Therefore unsuitable for examining earthquake records, because this records are non-stationary signals. Recently, Time - frequency analysis (TFA) methods have been developed and this methods are used for the representation of those records. TFA contains those techniques study a signal in both the time and frequency domains at the same time. That is TFA converts to one dimension signal into two dimension signal both time domain and frequency domain and comprises several different methods. In this study, five various time- frequency analysis methods that Short-Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), Smoothed Wigner-Ville Distribution (SPWVD), Choi-Williams Distribution (CWD) and Reduced Interference Distribution (RID) were applied and compared three component (N-S, E-W and Vertical) earthquake accelograms. As a result, RID method is the most eligible one with a reasonably good time- frequency resolution and put down a undesirable events for this analysis of earthquake accelogram records.

Introduction

To better understand the structure of the seismic signals, not only is enough to examine changes at time domain, frequency domain also is shows a component characteristics of the signal considerably. The Fourier Analysis is converts to frequency domain from a signal time domain. However, this method does not give information about the frequency values, which correspond to the time periods. Commonly used signal analysis methods based on the Fourier Transform cannot denote basic characteristic of the time- frequency locality of the non-stationary signal. Different from Fourier transform, Time-Frequency Analysis (TFA) includes time information for the frequencies. Time-frequency analysis a one dimensional signal into a two-dimensional function of time and frequency, and illustrate how the spectral content of the signal changes with time.
Time-Frequency Analysis is suitable for non- stationary signal analysis and processing. The seismic waves that observed in earthquake records distinctive non-stationary typical. Therefore, recent years researcers have used alternative time-frequency analysis methods their studies (Huerta-Lopez et al., 2000, Demetriu and Trandafir, 2003, Fan and Dong, 2009).
In this study, different time-frequency analysis methods which are used Short-Time Fourier Transform (STFT),Wigner Ville distribution (WVD), Choi-Williams distribution (CWD), Reduced interference distribution (RID) and Smooth Pseudo Wigner-Ville distribution (SPWV) are used to compare those method's features and applied in a earthquake accelograms recorded on three component.

Method and Application

Time -frequency domain consists of three dimensions where the first dimension is time, the second dimension is frequency and the third dimension is the value as a function of energy, of a signal at corresponding time and frequency. The time-frequency distribution ideally describes how the energy is distributed, and allows to estimate the fraction of the total energy of the signal at time (t) and at frequency (ω) (Huerta-Lopez et al., 2000).Time-Frequency Analysis (TFA) is suitable for non-stationary signal analysis and processing. Therefore, several types of time- frequency analysis have been developed and used. The time-frequency distributions fall into two categories. These categories are classed linear distributions and quadratic distributions (Cohen, 1995, Hlawatsch and Boundreaux-Bartels, 1992). The difference between linear and quadratic methods is that the linear transform can be inverted to reconstruct the time signal. Thus, the linear transform is suitable for signal processing, such as noise reduction and time-varying filtering. On the other hand, the quadratic methods describe the energy distribution of a signal in the time-frequency domain, which is useful to analyze, classify, and detect features of the signal. In the linear time-frequency analysis methods, the short-time Fourier transform (STFT). The basic concept in STFT method is to divide the signal into small segments of the same width and perform Fourier analysis on each of them to get the frequencies present in each segment (Cohen, 1995).
The amplitude distribution is define by STFT through the linear integral,

$$STFT_x(t, f) = \int_{-\infty}^{\infty} x(\tau).h(\tau - t).e^{-i2\pi f\tau} dt \qquad (1)$$

STFT is the local spectrum of signal $x(t)$ around time t, selected by localization window $h(t)$ (Gabor, 1946). Quadratic methods includes Cohen's general class (Cohen,1986) which are Wigner Ville (WV), Smoothed Pseudo Wigner-Ville (SPWV), Reduced Interference (RI) and different kernels Choi- Williams (CW). The general requirements of an appropriate time-frequency distribution are time and frequency marginal, instantaneous frequency, group delay, time and frequency support and time and frequency shift properties (Cohen, 1995). Cohen's class time- frequency analysis P(t,w) is described by the shift-immutable quadratic transformations.

$$P(t,w)=\frac{1}{4\pi^2}\iint A(\theta,\tau)\Phi(\theta,\tau)e^{-j\theta t-j\tau w}d\theta dt$$

where $A(\theta,\tau)$ is the symmetrical ambiguity function of the signal $x(t)$ and is given by

$$A(\theta,\tau)=\int x(t+\frac{\tau}{2})x^*(t-\frac{\tau}{2})e^{j\theta t}dt$$

$\Phi(\theta,\tau)$ is the kernel of the time frequency distribution, and θ and τ are frequency and time dummy variables of integration.
The forms of the transformation kernel $\Phi(\theta,\tau)$ for some distributions used in applications (Hlawatsch and Boudreaux-Bartels, 1992; Hlawatsch et al.,1995) are shown in Table 1.

Table 1. Different forms of the transformation kernel $\Phi(\theta, \tau)$

Distribution Name	KERNEL $\Phi(\theta, \tau)$
Wigner-Ville (WVD)	1
Smoothed Pseudo Wigner-Ville(SPWV)	$\eta(\frac{\tau}{2}).\eta^*(-\frac{\tau}{2}).G(\nu)$
Reduced interference distribution (RID)	$s(\tau\nu)$
Choi-Williams Distribution (CWD)	$\exp(-\frac{(2\pi\tau\nu)^2}{\sigma}),\sigma\in(0.1,1)$

WVD is computed by correlating the time signal with a modified version of the time signal itself, but does not estimate time waveform into segments. This distribution satisfies large number of desirable mathematical properties. The WVD is always real valued, it preserves time and frequency shifts. Disadvantages of the WVD include the cross-terms that affect the time-frequency resolution, and the negative values that the distribution can take (Cohen, 1995). SPWV is an example of such a development. To eliminate interference terms, Gaussian functions are used in the time and frequency smoothing operations. CWD overcomes the WVD limitation repressing in great amount the cross-term interference, but some timefrequency resolution is lost and computation is very slow. RID overcomes these problems to a significant extent, even though some small synchronisation and cross terms may be present. For these reasons and the increment in the time-frequency resolution.

Time- Frequency Analysis of Earthquake Accelograms

The earthquake accelogram records used for time-frequency analysis where recorded 24.03.2010 Elazığ Kovancık in Turkey (Ml is 5.0 and depth is 22.57 km) in a three component (North-South, East-West, Vertical) of the ground motion. The accelogram records are obtained National Strong-Motion Network of Turkey. The time- frequency analysis was centered on using five of the most well known and generally used TFA. Those are; Short Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), the Choi-Williams Distribution(CWD), Smoothed Pseudo Wigner-Ville (SPWV) and the Reduced interference distribution (RID). Some of the following results were obtained using the time- frequency toolbox developed in Matlab (Auger et al., 1996).
Figure 1 shows that the time domain and frequency domain distributions of the accelerations recorded during the 2010 Elazıg earthquake on three component directions (NS, EW, Vertical) are represented and display different TFA methods (STFT, WVD, SPWV, CWD and RID).

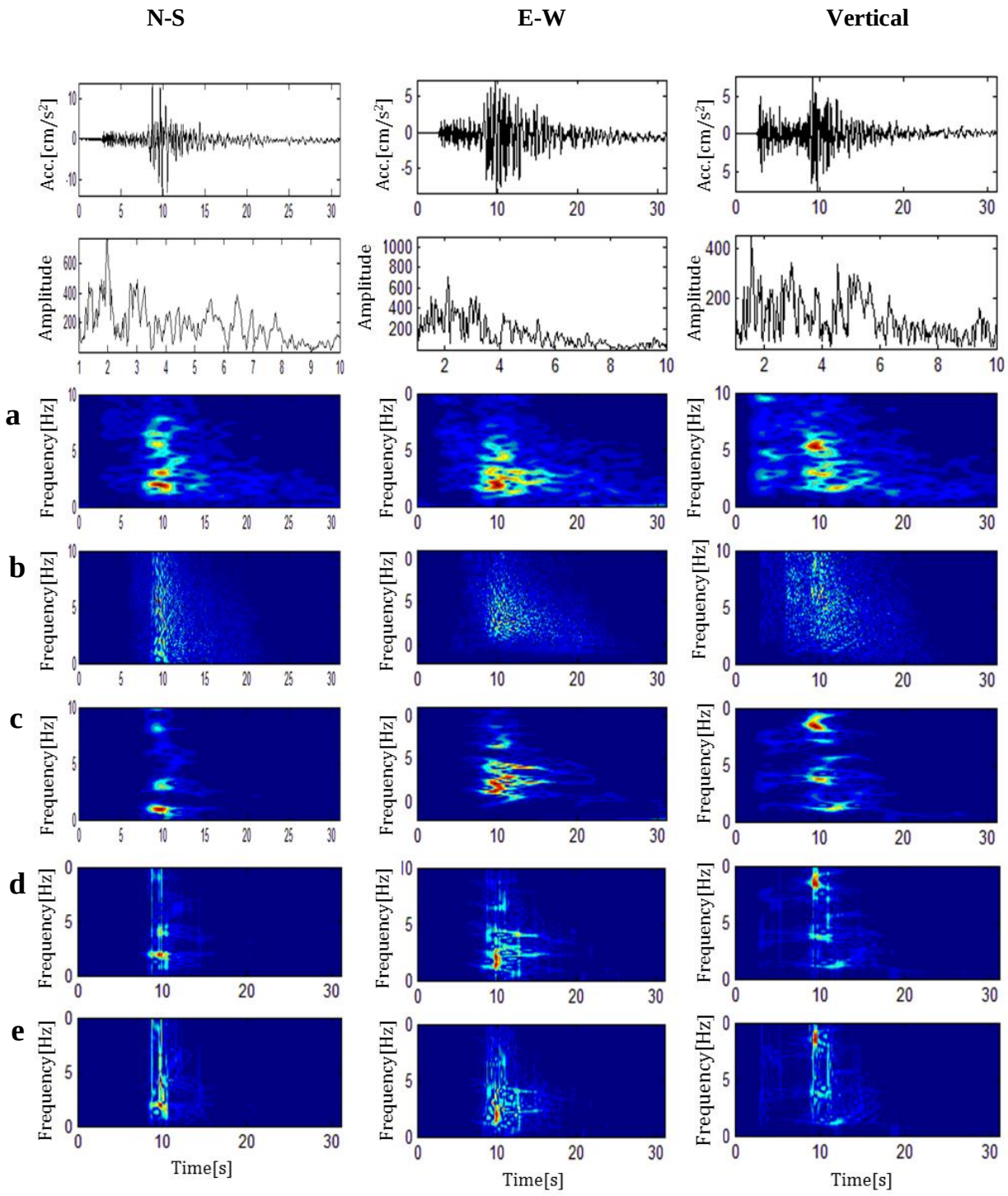

Figure 1. *Time domain, frequency domain and different time-frequency analysis representation forN-S, E-W and vertical components of accelograms recorded during the 2010 Elazıg earthquake. a)STFT, b)WVD, c)SPWV, d)CWD, e)RID*

Conclusion

In this study, examined the time-frequency analysis distributions. Short-time fourier transform (STFT) lacks time resolutions, although the dominant frequencies are fairly well defined. Wigner- ville distribution (WVD) has significant time-frequency resolution but the information that the TFD display is blurred by the interference cross-terms. This state difficulties for any well-supported and interpretation of the time-frequency characteristics of the different earthquake waves. Smooth Pseudo Wigner-Ville distribution (SPWV) allows localization with enough clarity their sensitive being determined by time and frequency resolution. Choi- Williams distribution (CWD) can reduce the interference caused by some particular kind of cross- term, can be seen that time- frequency resolution is lost. The RID enable the identification of time and frequency components of the seismic waves, even though a small synchronisation effect is still present for some components of the signal. It is now possible toevidence some seismic signals which exhibit frequency dispersive characteristics. Also, particular frequency components can be identified with the respective times that match with the maximum amplitudes in the time domain of the earthquake record.

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