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Application of the Haar wavelet transform to detect microseismic signal arrivals

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Abstract

A discrete wavelet transform is applied for the time-scale representation of raw seismic data and subsequent identification of events of interest. The wavelet transform properties such as localization, which is essential for the analysis of transient signals, provide a filter to extract characteristics of interest such as energy and predominant time scales. This information is subsequently exploited for microseismic events detection. The sample sum of squares is partitioned on a scale-by-scale basis and analysed across the time scales to emphasise the signal phase arrival, retaining the scales at which the seismic events have larger energy. The orthonormal decomposition of the signal energy estimated by the wavelet variance into the retained scales provides a useful means of describing the change in the signal magnitude associated with the triggering events. This type of analysis discriminates between signal phase arrival and spurious signal triggering by the different magnitude of local relative energy, which is much smaller in the latter case. The relative energy across the scales also changes, with greater magnitudes at coarser resolutions in the pattern expected in a trace decomposition with only a random noise component.

Keywords: Microseismic data; Microearthquake detection; Localization; Wavelet transform; Filtering

1. Introduction

Theoretical research on wavelet analysis has produced important contributions to different scientific areas, and has motivated the diverse use of wavelet analysis in recent years. Results and implementations have been published in an already enormous body of literature on this technique. References such as Hubbard (1998) and Mulcahy (1996) provide a nice introduction to the subject. A detailed formalisation of wavelet theory can be found in, among others, Chui (1997) and Daubechies (1992).

Early wavelet applications were motivated by geophysical exploration (Goupillaud et al., 1984; Grossman and Morlet, 1984). So far one of the most successful application areas is image compression

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(Mulcahy, 1997). Wavelets have properties such as localization. This is essential for the analysis of nonstationary and transient signals. Other properties are orthogonality, multirate filtering or space–scale analysis, which make this tool attractive for many application fields. Wavelets allow representation of general functions at different scales and positions in a versatile and sophisticated way, yet are simple to implement. This has motivated their exploitation in the analysis of real processes. Wavelets are therefore becoming increasingly popular for signal and image processing in the disciplines of science and engineering in areas such as medical research, climate change, industrial applications, astrophysics, etc., and a wider range of wavelet applications is expected in the future.

In this paper we explore the potential of wavelet transforms for analysis and information extraction from a microseismic trace. The main scientific objective of the work is to examine the wavelet representation as a matching filter for processing important features across time-scales to extract characteristics of interest such as energy and predominant time scales. This information can subsequently be exploited for microseismic event detection and elimination of spurious signals. Some recent work related to analysis of seismic data with other objectives is discussed, for example, by Yomogida (1994) and Chakraborty and Okaya (1995).

The organisation of the paper is as follows. In Section 2 some concepts of the discrete wavelet transform and its properties are introduced. Sections 3–6 describe the seismic data set and discuss the application of wavelet analysis for exploring their main features. Finally, in Section 7 some concluding remarks are presented.

2. The wavelet transform

The discussion in this section reviews the necessary information on wavelet transforms (WT) for the decomposition and detection of temporal structures such as the transient features contained in the one-dimensional raw seismic data that we analyse. For a complete and more comprehensive treatment of wavelet transform theory see the references Chui (1997) and Daubechies (1992).

Time series with time-varying frequencies can be found in many real problems, i.e. acoustic signals, seismic signals, non-stationary geophysical processes, etc. The study of such processes aims at transforming and representing the raw signal so that the frequency content can be obtained locally in time. Windowed Fourier and WT are two methods which allow this type of analysis to be performed. The windowed Fourier transform achieves location in time by windowing the data at various times and then taking the Fourier transform. In this procedure however, precision in time and frequency are fixed in the chosen window function and therefore arrival time detection of transient components with different scales is not possible.

On the other hand, WT are essentially applied to extract information and as a basis for signal representation. The choice of the basis function determines the information to be extracted from the process and allows the study of different signal structures, such as non-stationary short-time transient components, features at different scales or singularities. The process representation using wavelets is provided by a series expansion of dilated and translated versions of the basis function, also called the “mother” wavelet, multiplied by appropriate coefficients. For processes with finite energy the wavelet series expansion gives an optimal approximation to the original series (Chui, 1997).

Discrete wavelet transforms are suitable for processing real data in which the signal $f(t)$ is known only at sampling points with spacing dependent on the sampling rate. The WT in this case has discretized scale λ and location u parameters. Using a logarithmic uniform spacing in the discretization of the scale and location domains provides an orthonormal wavelet basis which characterises completely N signal observations with N wavelet coefficients (Daubechies, 1992, p. 10). In many applications values of the scale parameter λ are restricted to be powers of 2. That is, in the basis function $\psi_{\lambda,u}(t)=\frac{1}{\sqrt{\lambda}}\psi\left(\frac{t-u}{\lambda}\right)$, the parameters are $\lambda=2^j$ and $u=2^j i$. The index j defines both the scale and the transform level.

Many different wavelet bases can be used in the transformation attaining the proprieties above. The selection of a basis function is motivated by the data features to be extracted. Alternative functions move different characteristics of the raw data set between