

ESTIMATION OF POLARIZATION ON TIME-SCALE PLANE FOR SEISMIC WAVE SEPARATION

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ABSTRACT

Wave separation is a main issue in seismic signal processing. Two waves having different polarizations can be separated if the polarization of each wave is known. This is performed by an oblique polarization filter. This technique developed recently has a crucial issue. It requires the estimation of the polarization of each wave, which can be a difficult task. This paper presents the use of the time-scale plane to estimate the polarization of the waves. The module of the continuous wavelet transform allows to detect the different waves, and the phase wrapping matrix enables to detect the interferences between waves. The algorithm is illustrated on synthetic data and successfully tested on real seismic data. It succeeds in separating two waves overlapping on the time-scale plane.

1 INTRODUCTION

This paper deals with the problem of wave field separation for geophysical signals. Wave separation is a major issue in seismic signal processing [8]. It makes the interpretation of the data easier. (better SNR and wave-field characterization). The presented method uses the principle of the oblique polarization filter introduced recently by Glangeaud *et al* in [6]. Using basic transformations such as phase shifts, rotations and amplifications, this algorithm can separate two waves having different polarizations. The innovation in our technique consists in using the continuous wavelet transform to obtain a better detection. Becquey *et al* in [2] have already used some properties of the time-scale plane to build a polarization filter. Chakraborty [3] used the fine properties of the time-scale plane to decompose non stationary signals such as seismic signals.

Firstly the modelisation of the data is presented, followed by a short recall on the continuous wavelet transform. Then, the algorithm is presented and illustrated in presence of two synthetic chirps. Finally, it is tested and validated on real seismic data.

1.1 Modelisation of the data

We consider waves propagating in different directions and recorded by a sensor array with two components (2C). Such a sensor is for instance able to record the vibration in the horizontal and vertical planes separately. It leads to record two signals : s_h and s_v . If one single wave is recorded, making the standard assumptions (plane wave, band limited spectrum, constant polarization over the bandwidth, and statistical independence of the source signal, see [1]), the recorded signal can be modeled by :

$$S(t) = \begin{bmatrix} s_h(t) \\ s_v(t) \end{bmatrix} = \frac{1}{\sqrt{1+\rho^2}} \begin{bmatrix} 1 \\ \rho e^{j\theta} \end{bmatrix} z(t), \quad (1)$$

where ρ and θ determinate the polarization state and can be respectively assimilated to the modulus ratio and the phase shift of the wave recorded by the two components of the sensor. $z(t)$ is the analytic signal (of the wave) received by the horizontal sensor.

When two recorded waves have two different polarizations, it is possible to isolate each wave on each component s_h and s_v [6]. This filtering is performed by a combination of phase shifts, rotations and scalar amplifications. The crucial issue is the estimation of the polarization state (ρ and θ) of both waves. It is usually done by choosing a convenient time windowing. This step can be very difficult, or even impossible when the waves appear in the same time interval. To solve this problem, we propose to represent the signal in the time-scale plane in order to estimate the polarization on a time-scale region rather than on a time window.

1.2 Wavelet transform

The Continuous Wavelet Transform (CWT) has shown good properties for the representation of seismic signals in the time-scale plane [3]. It has a good time resolution for high frequency components, and a good frequency resolution for low frequencies. This enables a fine detection of the waves present in the signal. It also allows many kind of processings [7], [4] [9]. The CWT of a

signal s at a scale a and a time b is given by :

$$CWT(s)(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-b}{a}\right)^* dt. \quad (2)$$

ψ is called the “mother wavelet”. It is a bandpass filter which characterizes the time-scale resolution. In our study Morlet’s wavelet is used. It offers *optimum* localization properties (exponential decay in time and in frequency), and is symmetric so that the phase of the signal is left unchanged. Besides, we use the analytic wavelet in order to have access to the phase information :

$$\psi(t) = (\pi t_0)^{-1/4} \exp\left[-\frac{1}{2}\left(\frac{t}{t_0}\right)^2 + 2i\pi f_0 t\right] \quad (3)$$

2 ILLUSTRATION ON TWO CHIRPS

2.1 Interference detection

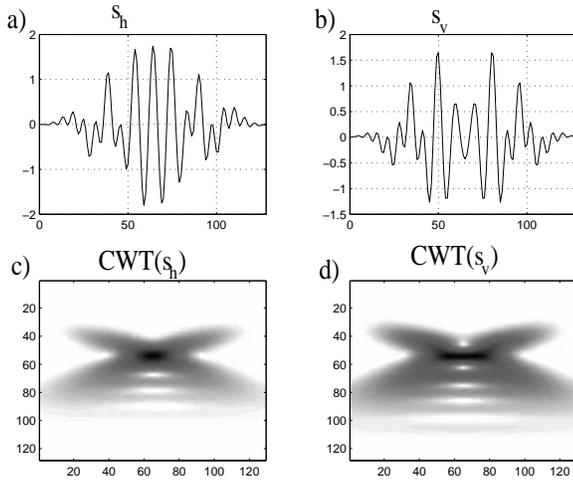


Figure 1: *Synthetic recording of two chirps and their continuous wavelet transform*

To illustrate the proposed method, the case of two crossing chirps recorded by a 2C sensor is considered. Each component (horizontal s_h and vertical s_v) is the sum of the two chirps. Their polarization is elliptic. Both traces s_h and s_v are respectively represented figures 1(a) and (b). The modules of the corresponding continuous wavelet transforms are represented figures 1(c) and (d). Those two module images give an *a priori* information on the localization of existing waves on the time-scale plane. Note that, both chirps can be recognized. But since the corresponding patterns overlap on the time-scale plane, they cannot be separated, neither by a time filter, nor by a frequency filter, nor even by a time-scale filter. Figure 2(a) presents an interesting information : the phase wrapping between the wavelet coefficients of each component. This can be seen as the instantaneous phase wrapping at each scale: $\text{angle}(CWT(s_h(a,b)) \cdot (CWT(s_v(a,b)))^*)$ where *

stands for complex conjugate. The irregularity of the phase wrapping points out the presence of interferences. On the opposite, the lower left quarter and the higher right one (resp. lower right and higher left) have the same value. This is because they belong to the same wave (the same chirp). Therefore, they have the same polarization and thus the same phase wrapping. To detect those interferences free regions, the local variance of this image is estimated for each pixel, using a 5x5 filtering window. Figure 2(b) shows the result of this “variance” matrix.

For the legibility of the images, the interferences regions appear in black. Note that the very central interferences region is not correctly detected since it mostly corresponds to a positive interferences region.

At this step, using the module images, the phase image and the interference image, we have an understanding of the distribution of the energy and we know *a priori* where to find some non interfered isolated wave regions. In the next section those regions will be used to estimate the polarization.

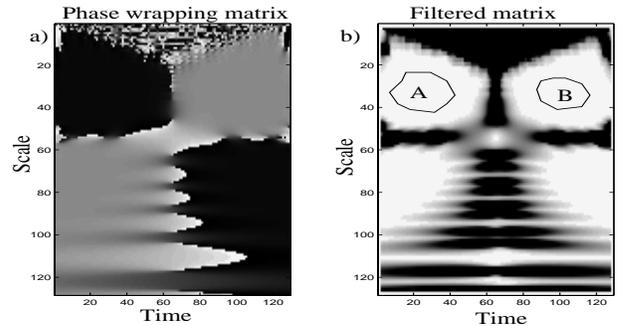


Figure 2: (a) *Phase wrapping between wavelet coefficients*, (b) *image processed by a variance filter*

2.2 Separation of the two chirps by the oblique polarization filter

The oblique polarization filter is a supervised method which can be decomposed in three main steps.

2.2.1 Time-scale region design, phase shift, rotation

Usually, to look at the polarization, the plot (a) of figure 3 is used. This is the plot of amplitude s_v versus amplitude s_h . In our example (two crossing chirps), it is impossible to find a good time window enabling a good estimation of the polarization because both waves are present in the same time interval. So, we select the region on the time-scale image corresponding to one single chirp with no interference (region A figure 2(b)). The figure 3 (b) plots the real part of the wavelet coefficient (present in the region A) from s_v versus those from s_h . Then applying a phase shift on the s_h leads to linearised polarization (figure 3(c)). Note that the phase wrapping at this moment is null on the region of the figure 2(a).

This is followed by a rotation which allows to make one chirp disappear from the vertical component due to the fact that the polarisation pattern of the selected wave is now orthogonal to one axis.

2.2.2 Phase shift on the vertical component

A second region is needed for the second chirp (region B figure 2(b)). The $*$ correspond to the coefficients in the region A , and the $+$ correspond to the ones in B . Then, using a similar technique, a phase shift gives a linear polarization for the region B (the $+$). The $*$ are not altered since it already disappeared from this component. This lead to figure (e) where both chirp are linearly polarized on the component, but not orthogonal.

2.2.3 Amplification and rotation

Finally one of the components is amplified to make both waves orthogonal. At the end, a rotation isolates each chirp on a different component (figure f).

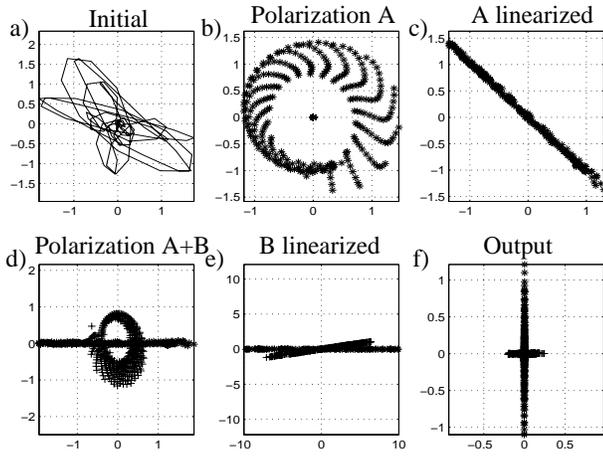


Figure 3: *Separation process in 3 step and 6 images*

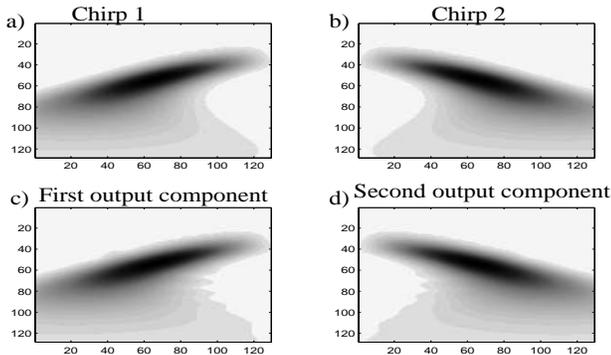


Figure 4: (a) and (b) initial chirp and (c) and (d) output of the filter

Figures 4(a) and (b) present the initial chirps and figures 4(c) and (d) the result of the filtering process. Both

chirps have been isolated. We used the great properties of the wavelet decomposition for the wave detection. Furthermore the use of the phase information (which is often hard to interpret and seldom used) is well suited to the presented method.

3 RESULTS ON REAL DATA

The method has also been tested and validated on real data. Figures 6(a) and (b) represent the initial 2C profiles where one highly energetic wave can be seen on each component. This wave is almost the only visible propagation. Those data are difficult to process by classical filters such as f-k, SVD or τ -p [8] because this energetic wave is dispersed along the different sensors. To process

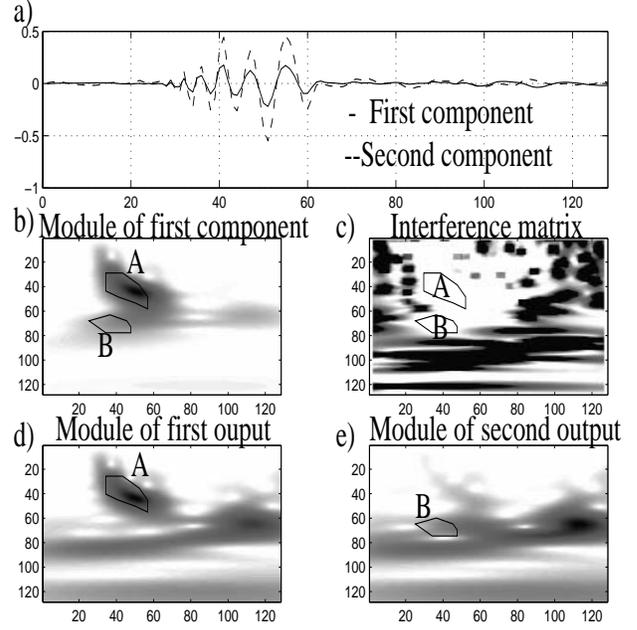


Figure 5: *Focus on time-scale plane of a real signal*

those data, we focused on one trace (remember that our filter is for 1D signals so far). Figure 5(a) presents the two components. The CWT of one component is presented on figure 5(b), and the filtered phase wrapping matrix on figure 5(c). We considered two regions (A and B represented on figure 5(c)) A is a region corresponding to the main energetic wave alone, and B corresponds to a hidden wave detected on the module image. According to the wrapping image, there are no interferences in those regions.

Figures 5(d) and (e) present the module image of each component at the output of the filter. In figure 5(d), the hidden wave has been totally removed. No small wave interferes anymore with the energetic one. In figure 5(e), the small wave still interferes with the other small waves, but the energetic one has been totally removed. Note that we could have considered two other waves. We chose those ones because the energetic one can now be

totally removed. This is done using the filtering in the time-scale plane explained in [9]. Since the wave is well isolated on the time-scale plane from the other waves, it will be perfectly removed.

Then, since the polarization parameters are almost constant over the whole profile, the same rotation, phase shift, have been applied to all the traces. It leads to isolate two waves on each component. By nulling one component and inverting the filter, each wave can be re-projected in its initial configuration. Figure 6(c) and (d) present the highly energetic wave on each component, and on 6(e) and (f) the other small waves. Many new propagations that were not visible before, can now be seen.

After this separation, in order to visualize the new propagations and to show the possibilities offered by the method, we applied the time-scale filtering detailed in [9]. Figure 7 presents one component of the obtained results. Thanks to the pre-processing, the pattern of each wave on the time-scale plane are well isolated, so the separation without interference is possible. This is a fine validation of the proposed tool. Actually, according to the study made by geophysicists, this method has better other classical methods. This is mostly due to the good detection properties of the CWT.

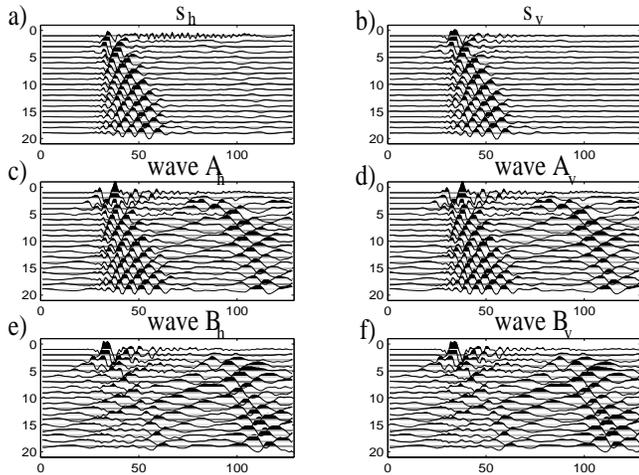


Figure 6: Real profiles from CGG [5]

4 CONCLUSION AND PERSPECTIVES

The supervised algorithm proposed in this paper improves the oblique polarization filter. It has been illustrated on synthetic data, and validated on real data. This filtering also joins the time-scale filtering of [9] since it allows a separation of interfering waves, which was the main trouble of the initial method.

We showed the good properties of the time-scale representation. And the phase wrapping matrices appeared to be nicely adapted to the study of the signal. As a per-

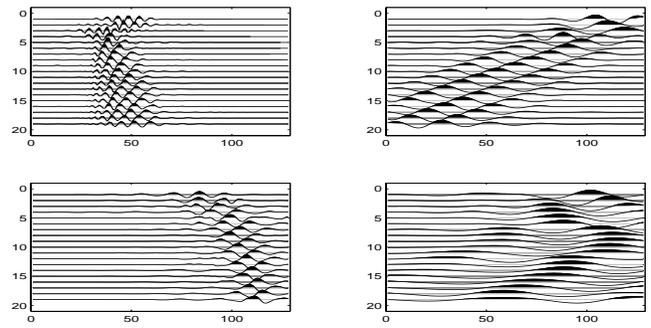


Figure 7: Seismic profile after separation process

spective, this could be generalized to 3C sensors (sensors with 3 components).

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