UNSUPERVISED SEISMIC WAVE SEPARATION IN THE TIME/SCALE PLANE

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Abstract
This paper illustrates a methodology based on an image processing technique to remove and separate surface waves. These waves convey any useful information despite the shot and receivers sensors patterns used during the data acquisition. The elimination of such waves is always desirable to focus on underlying reflection data. Methods based on time frequency and time scale methods are now used to separate surfaces waves. But they are not so convenient because they are not automatic. The proposed method based on the watershed algorithm is an unsupervised and non parametric method which allows us to separate automatically and efficiently the surface waves.

Introduction

The economic and strategic importance of petroleum exploration has given rise to the development of techniques for seismic signal processing. Seismic prospecting mainly consists in generating very low amplitude artificial sources (like "earthquakes") at predetermined times and positions. After propagation in the subsoil, the induced seismic disturbances are recorded by a set of N sensors regularly placed on the ground.

Each sensor produces a signal, called a trace, that is a combination of several waves produced by different physical phenomena (reflection, refraction ...). The set of the N signals, recorded by the N different sensors, constitutes a seismic section (or seismic profile). The X-axis corresponds to the time dimension, and the Y-axis, corresponding to the different sensors, can be seen as a distance dimension. Figure 1 presents a real seismic profile on which several waves can be identified by geophysicists (respectively, the direct wave, a reflected one, a Rayleigh wave and a slow Rayleigh wave). This paper presents a method to automatically separate the different waves of the seismic profile.

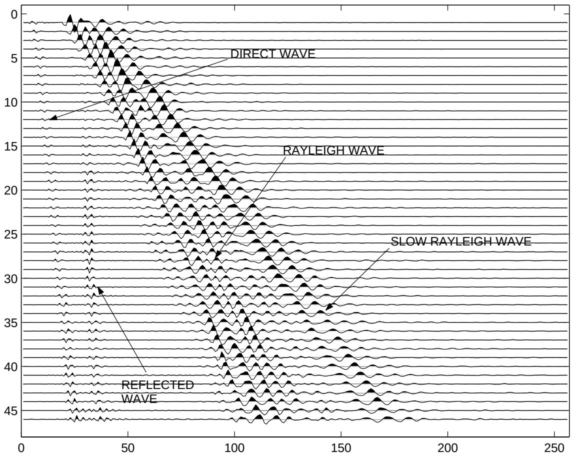

Fig. 1. Seismic profile

This method is based on image processing. During the EAGE conference of Helsinki, Nguyen [1] presented the first steps of this wave separation. It basically consists in processing and analyzing each signal of the seismic profile separately : the representation of the signal in the time-scale domain allows the separation of different waves with intersecting temporal and/or frequential supports. Section 2 of this paper briefly recalls the principle of the continuous wavelet transform used for this purpose. Isolating the different features of this time-scale representation (i.e. segmenting it) leads to the desired wave separation. We propose to perform this segmentation automatically using the watershed algorithm. This is presented in section 3. Another key-point of the paper is the tracking of the extracted features along the different sensors. Section 4 explains how the information redundancy provided by the sensors is exploited to iteratively initiate the segmentation of each signal, avoiding the oversegmentation inherent to the watershed algorithm. Finally, results obtained on real data are presented in section 5.

Continuous Wavelet Transform

The continuous wavelet transform (CWT) provides a bi-dimensional representation of a mono-dimensional signal in the time-scale domain. It basically consists in locally comparing the signal to dilated or contracted copies of the analysing wavelet. This is achieved by applying a translating factor b (time localization) and a scaling factor a (scale localization) to the wavelet ψ and computing the integral defined in the following equation :

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

The chosen analysing wavelet is the Morlet's one. This is a complex wavelet defined as :

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

It is zero mean and thus admissible. Its energy vanishes very quickly, leading to a good time localization. Furthermore, its shape is very similar to a natural seismic wave, it is therefore very often used to analyse geophysical signals. Figure 2 presents one trace of the seismic profile presented in figure 1. Figure 3 is the modulus of the corresponding wavelet transform. This time-scale representation can be processed as an image where each feature corresponds to a given wave. Using a manually set masking, Nguyen [3] isolates the different features of the image. The Inverse Wavelet Transform (IWT) applied to a separated feature then allows the reconstruction of a filtered trace with one single wave remaining. The computation of the IWT is detailed in [4]. Figure 4 illustrates this principle on one trace : firstly the wavelet transform of the signal is computed, then the feature corresponding to the Rayleigh wave is extracted, and, finally, the inverse wavelet transform of that isolated feature is computed, leading to the reconstruction of the desired wave. Of course, this process can be applied to each feature (i.e. to each wave).

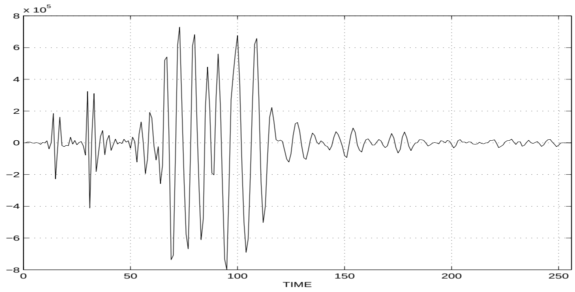

Fig. 2. Time representation of the 22nd trace

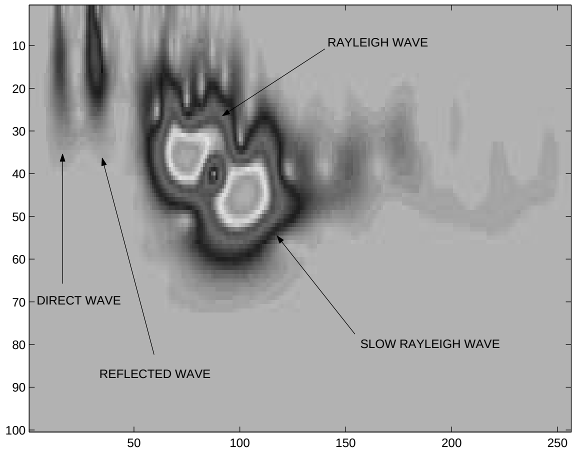

Fig. 3. Time/Scale representation

Segmentation algorithm

The segmentation operation enables the unsupervised determination of the best mask corresponding to the image of figure 3. This enables the feature extraction and thus the wave separation. The segmentation algorithm chosen is the watershed algorithm, described in [5] by Vincent and Soille.

Remembering the figure 3, the purpose of the algorithm is to cut the image into 5 zones, one for each of the 4 waves and one for the background as shown on figure 4. It is based on the simulation of an immersion process. By reversing the image, each wave (which corresponded to a “mountain”) corresponds to a catchment basin. The topography defined by the reversed image is flooded through holes (called seeds) pierced at the local minima of the reversed image, which are the lowest altitude pixels of each catchment basin.

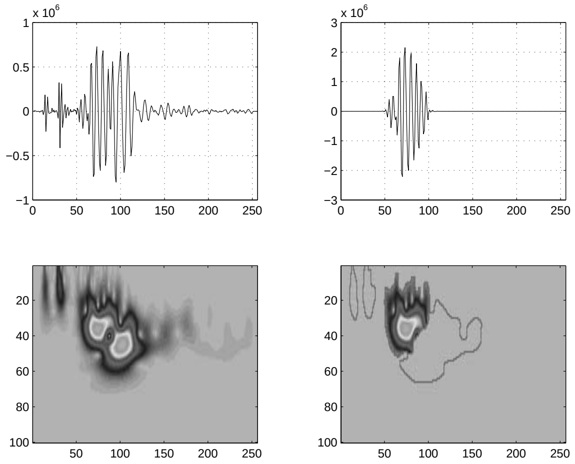

Fig.4. Isolation of Rayleigh wave

As illustrated in 1 dimension on figure 5, the flooding progresses from each seeds. At the point where the regions would mix, a dam is built. When the water reaches the top of the image, all the dams form the watershed of the image.

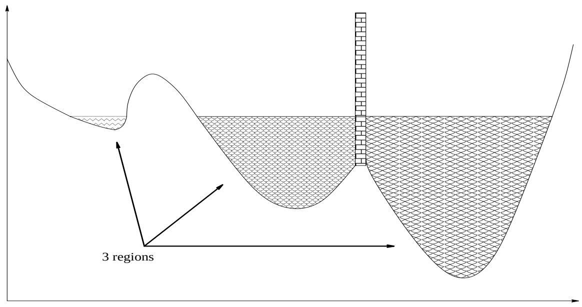

Fig.5. Immersion in 1 dimension

A drawback with this method is that any local minimum is considered as a new seed. Since, there are a lot of minima due to the noise, there will be an over segmentation. To solve this problem, the most easy way, is to choose in advance the number and the position of the seeds. In this way if a catchment basin has no seed, the flood will come from a neighboring seeded catchment basin. Note that assuming the number of seeds and their position are known, the algorithm can only look for the good number of regions, i.e. waves, which is an evidence of its stability.

Applying this segmentation and feature selection on each trace of the seismic profile leads to the construction of new seismic profiles, one for each separated wave. The next section explains how to track the different features from trace to trace, and especially the position of those seeds.

Tracking of the seeds of the segmentation

The segmentation is done on the N images of the time/scale representation (figure 3). On these images, the waves move in both time and scale directions. Since the waves move slowly, by stacking all the pictures, some “tunnels” are formed by the different waves, (figure 6). Looking at these tunnels, they seem to be like cylinders whose axes are the directions of propagation, i.e. the core of each region has a straight direction, which means that these cores have approximately a constant speed. In practice, the core of a wave is characterized as the barycenter of the region weighted by the intensity of the pixel.

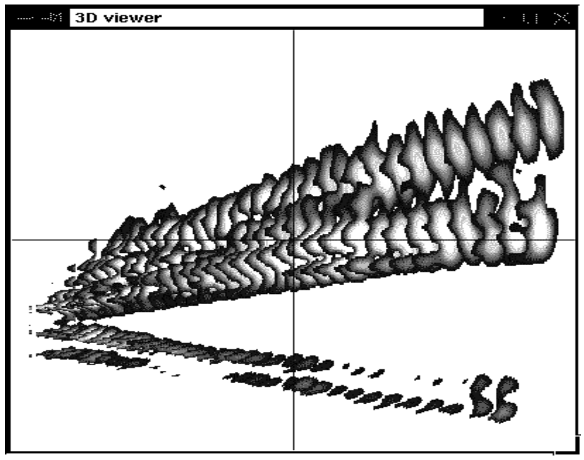

Fig.6. Time\Scale plan stacked forming tnnels

During the experiment, each sensor provides one signal. Therefore, there are N time/scale images to segment in order to reconstruct the seismic profiles associated to each wave. We chose to keep a constant number of regions for each image. Since the different waves propagate at different speeds, they will be more easily seperated in the last trace (corresponding to the furthest sensor to the explosion). As a consequence, the process is initiated on the last time/scale image : the geophysicist points on the image one extremum for each wave he wants to select.

The seeds of the next image will be linearly interpolated according to the 2 latest ones. This enables the process to be fully unsupervised after the first step of the choice of the different waves to study. Note that, this first seed estimation can also be done unsupervisely : starting from the lowest altitude, each new minimum gives a new seed.

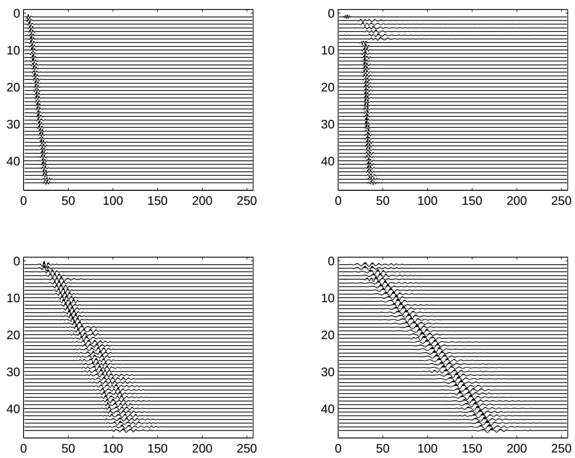

Fig.7. Time/scale plane stacked after separation

The problem is that each minimum does not correspond to one region. Therefore, a smoothing enables to get rid of most of the unrelevant candidates. But then, the algorithm becomes parametric : the value of the threshold has to be high enough to get rid of the unrelevant seeds, and low enough not to loose any true region. Moreover, the geo-physicist usually likes to do this first initiating step himself.

Results on real data

The proposed algorithm has been tested on real data. Figure 8 presents the four seismic profiles reconstructed after the separation of the four main waves of the profile presented in figure 2 . Figure 7 presents the 4 corresponding “tunnels”, i.e. the stacks of the tracked regions in the time-scale domain.

The results are quite satisfactory : the “tunnels” have been correctly segmented and the waves have been correctly separated and reconstructed, apart from the reflected wave that is badly reconstructed in the first seven traces. This is not surprising since the first sensors are very close to the source explosion and the waves cannot be correctly separated, even in the time-scale domain. Nevertheless, the obtained results are as good as those obtained by Nguyen [2] and they have been positively validated by geophysicists. We must emphasize that the whole process is now fully automatic.

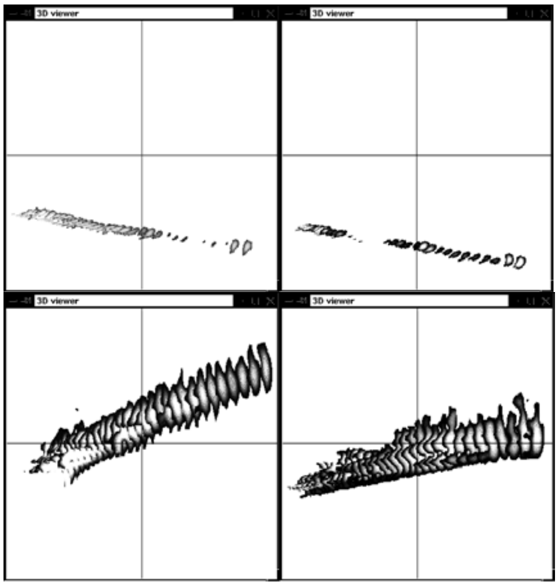

Fig.8. Seismic profiles after separation

Conclusion

The watershed algorithm turned out to be a powerful segmentation tool for time-scale images of seismic signals. The proposed method, which is unsupervised and non parametric, led to a robust and accurate wave separation. In the future, the coefficients computed for the iterative linear interpolation of the segmentation seeds could be used to further characterize the properties of the separated waves (speed of propagation, evolution of the frequency...). Moreover, the presented separation technique only uses the modulus of the CWT ; the information provided by its phase could also be used to improve the separation and the physical characterization of the waves.

References

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