Automatic velocity analysis using complex seismic traces

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Abstract

We present a method of automatic picking of the stacking velocities. The method consists in calculating the stacking velocities associated to the primary reflections inside a corridor (guide function) in the velocity spectrum. To generate the velocity spectrum, we use the signal power of the complex seismic trace and the logarithm of the MUSIC (Multiple Signal Classification) coherence measure to improve the resolution of the spectra and to enhance the energies related to the reflections. The method may be applied to each CMP gather and allows to build the stacking velocity field and to obtain the zero-offset section. We applied the method in CMP gathers of the Jequitinhonha Basin to generate a velocity field and the corresponding zero-offset section. The method is easier to implement and computationally faster than the conventional method that uses the semblance coherence measure.

Introduction

The estimation of the stacking velocities is one of the most important steps in the CMP seismic processing. This is because the better the estimation of the stacking velocities, the better the quality of zero-offset section obtained. Currently, the most conventional method of velocity analysis consists in the manual picking of the stacking velocities in the velocity spectrum, using the semblance as a coherence measure. This procedure is usually laborious, due to the large amount of CMP gathers. Additionally, depending on the signal / noise ratio or the presentation of the events, the semblance may not be a coherence measure that presents a good resolution.

Trying to solve this problem, Souza, 2014 developed a new method of automatic picking to obtain the velocity field and the zero-offset section, determining the stacking velocity for each time sample, by calculating an average weighted by the coherence values, inside a corridor in the velocity spectrum. In this work, we use a similar idea, but we get the stacking velocities associated with the maximum coherence from the velocity spectrum. We also use the signal power of the complex seismic trace, associated with the logarithm of the MUSIC coherence measure, getting a velocity spectrum with an improved resolution to evaluate the reflections and pick the related velocities.

The complex seismic trace and its attributes have been utilized as a tool to aid in geological interpretation of seismic data (Taner et al., 1979, Meneses, A.R.A.S, 2010). In velocity analysis, Taner et al., 1979, Sguazzero, et al., 1987 and Vesnaver, et al., 1988 used the complex seismic trace to improve the stacking velocity estimation and to generate complex-valued coherences in the velocity spectrum.

The MUSIC coherence measure has been used to improve the resolution of the velocity spectrum (Smith, 1986, Barros, 2012). Ursin et al., 2014 applied the logarithm of the MUSIC, used in this work, associated to the singular value decomposition to define types of generalized semblance.

Results on real data of Jequitinhonha Basin illustrate the effectiveness of the proposed method.

Theory

The velocity spectrum

The generation of the velocity spectrum is made from CMP panels corrected for normal moveout using constant velocity. These panels are obtained re-sampling the traces of the CMP gathers along hyperbolic curves, starting in $t_{0,n}$ time. Using a moving window, coherence measures are calculated over the time for each velocity, from v_{min} to v_{max}, forming the velocity spectrum. Thus, we can analyze the energy of the reflections in $t_0 \times v_{rms}$ domain.

The most utilized coherence measure is the semblance, given by

$$S = \frac{1}{M}\frac{\sum_t s_t^2}{\sum_t \sum_{i=1}^{M} a_{i,t(i)}^2}. \tag{1}$$

It is defined as the ratio between the energy of the estimated signal and the energy of the data in the analysis window, and it is normalized to be between zero and one (Taner and Koehler, 1969).

The complex trace and its signal power

Complex trace analysis treats a seismic trace as the real part of an analytical signal or complex trace (Taner et al., 1979), ie

$$F(t) = f(t) + jf^*(t) \tag{2}$$

being $f(t)$ and $f^*(t)$ the real and imaginary part of the analytical signal, respectively.

The Hilbert transform relates $f(t)$ and $f^*(t)$ and is given by

$$H[f(t)] = \frac{1}{\pi} V.P. \int_{-\infty}^{+\infty} \frac{f(t')}{t-t'} dt \tag{3}$$

where P.V. means the Cauchy pinciple value and

$$F(t) = f(t) + jH[f(t)] \tag{4}$$

The signal and its Hilbert Transform are orthogonal. The Hilbert transform can be used to generate the quadrature trace from the real trace or vice versa (Taner et al., 1979). The projection of complex trace $F(t)$ onto the real plane is the actual seismic trace $f(t)$; the projection of $F(t)$ onto the imaginary plane is the Hilbert Transform trace $H[f(t)]$.

The real seismic trace $f(t)$ can be expressed in terms of a time-dependent amplitude $A(t)$ and a time-dependent phase $\theta(t)$ as

$$f(t) = A(t)\cos\theta(t) \tag{5}$$

The quadrature trace $f^*(t)$ then is

$$f^*(t) = A(t)\sin\theta(t) \tag{6}$$

If $f(t)$ and $f^*(t)$ are known, one can solve for $A(t)$ (Taner et al., 1979):

$$A(t) = \sqrt{f^2(t) + f^{*2}(t)} = |F(t)| \tag{7}$$

$A(t)$ is called reflection strength that is the envelope of the seismic trace, so the signal power is:

$$|F(t)|^2 = A^2(t) = f^2(t) + f^{*2}(t) \tag{8}$$

The logarithm of the MUSIC

The MUSIC coherence measure is defined as the inverse of the data projected onto the noise subspace (Barros, 2012). Given the signal power $A^2(t)$, normalized to be between zero and one, we can define the MUSIC as:

$$M(t) = \frac{1}{1 - A^2(t)} \tag{9}$$

Applying the logarithm of the MUSIC (Ursin et al., 2014) we have

$$L(t) = \log M(t) = -\log\left(1 - A^2(t)\right) \tag{10}$$

This operation allows us to obtain a better resolution in the velocity spectrum, enhancing the greatest values of coherence.

Methodology

Obtaining the velocity spectrum

Four steps were performed to obtain the velocity spectrum using the complex trace:

1. The CMP gather is corrected for normal moveout using trial velocities ranging from v_{min} to v_{max};
2. Generation of the velocity spectrum by the horizontal sum of the amplitudes to each velocity (stacked amplitude);
3. Obtaining of the signal power applying Hilbert transform in the velocity spectrum, normalizing to be between zero and one;
4. Applying the logarithm of the MUSIC, using the normalized signal power.

An advantage of getting the velocity spectrum in this form, is that we can dispense applying a moving window to generate the velocity spectrum, reducing the computational cost. In the Figure 1a one can see a synthetic CMP gather with four events. Two events have the same zero-offset time but different velocities (2000 km/s and 2200 km/s), whereas other two events have the same velocity, but different zero-offset times (0.5s and 0.7s). In Figures b and c, we have the velocity spectra of the CMP gather using the signal power and the semblance, respectively. We can notice that the velocity spectrum obtained using complex seismic trace presents a better resolution than the conventional velocity spectrum that uses the semblance, allowing to identify the events with good precision.

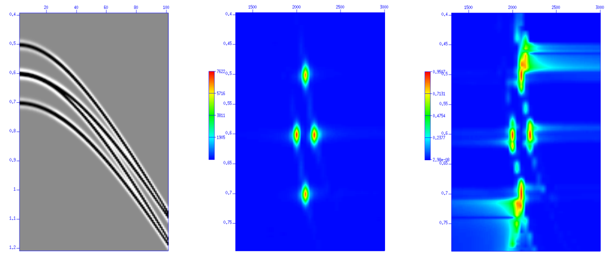
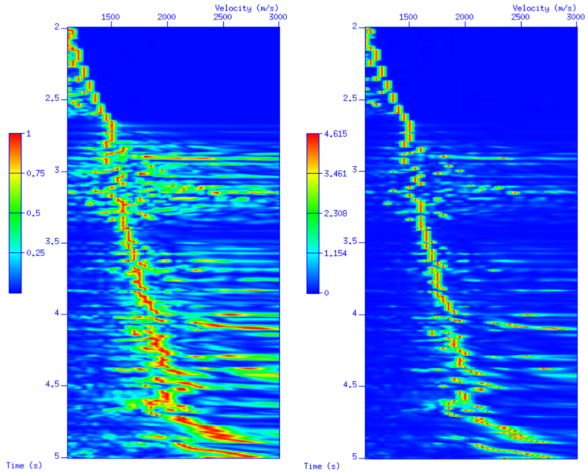

(a) (b) (c)

Figure 1: Synthetic CMP gather in (a) and its velocity spectrum using the signal power in (b) and using the semblance in (c).

Figure 2 shows the velocity spectra of a real data generated using complex seismic traces. In (a), the values are the normalized signal power. In (b), we see the spectrum after the application of the logarithm of the MUSIC. We can notice that the operation considerably improve the resolution of the spectrum.



(a) (b)

Figure 2: Velocity spectra using complex seismic traces. In (a), the values are the normalized signal power, in (b), we see the spectrum after the application of the logarithm of the MUSIC.

Obtaining the stacking velocities

Firstly, the determination of the stacking velocities is made defining the corridor in the velocity spectrum that span the region where are the primary reflections. Inside this corridor, the stacking velocity related to the maximum value of the signal power in each sample is taken. The velocity function to each CMP gather is used to generate the velocity field and the zero-offset section after normal moveout correction and stacking.

Results

We applied the automatic picking method in CMP gathers of the Jequitinhonha Basin, corresponding to a part of the seismic line 214-270. The Table 1 shows the field parameters used in the acquisition.

Table 1: Acquisition parameters of the seismic line 214-270 of the Jequitinhonha Basin.

Number of Shots	1039
Number of channels	120
Fold	60
Number of CMP gathers	1960
Minimum offset	-150
Maximum offset	-3100
Number of samples	1751
Sampling interval	4 ms

Figure 3 shows side-by-side a CMP gather of the seismic line 214-270 of the Jequitinhonha Basin, its automatic picking of the stacking velocities and the CMP gather corrected for nmo in (a), (b) and (c), respectively. The curve within the corridor in Figure 3b goes exactly by the greatest coherence points to each sample, taking the associated velocity and creating a velocity function to the CMP gather. In Figure 3c, we see that the CMP gather was corrected for normal moveout properly, confirming the successful determination of the stacking velocities.

For comparison, we processed the seismic line using the free software Seismic Unix (SU), generating the velocity field and the zero-offset section. In this software, the determination of the stacking velocities is perfomed by conventional manual picking. Figure 4a shows the velocity field obtained with the SU and Figure 4b shows the velocity field derived from the automatic method application. One can consider the automatic field satisfactory, in spite of the low velocity region, meaning that the energy of the multiple reflection was taken into account.

Figure 5a shows the zero-offset section obtained by the SU. In Figure 5b, we have the zero-offset section obtained by the automatic method. Comparing the results, we realize that both conventional and automatic method imaged the subsurface well. The conventional method better imaged the shallowest parts whereas the automatic method imaged more reflectors in the deepest parts, being the latter more sensitive to multiple reflections. It's important to say that the automatic method allows us to apply a muting to remove the part that suffered stretching, after nmo correction, before stacking, which is essential in the shallow parts.

Conclusions

The automatic method for obtaining the stacking velocities is a helpful tool to generate of the velocity field and the zero-offset section. The method considerably reduce the manual workload in the velocity analysis stage and the generation of the velocity field, getting the velocity function for each CMP gather.

Results of the automatic method show that the velocity field and the zero-offset section are satisfactory, but with the problem of the multiples reflections.

The use of the signal power of the complex seismic trace helped considerably on achieving a better resolution in the velocity spectrum, allowing to recognize the reflections in a better way. Furthermore, this way of getting the velocity spectrum is easier to implement than the conventional semblance. This method is very promising and need additional studies as in the calculus of the velocity function within the corridor.

Acknowledgments

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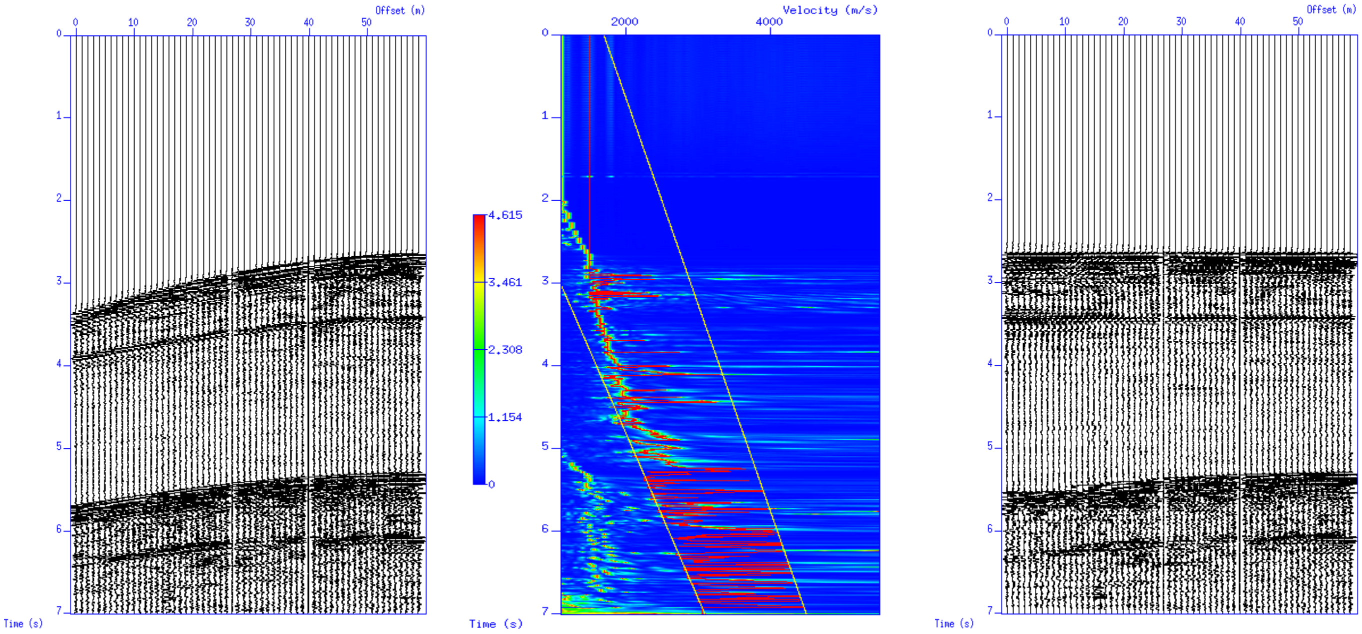
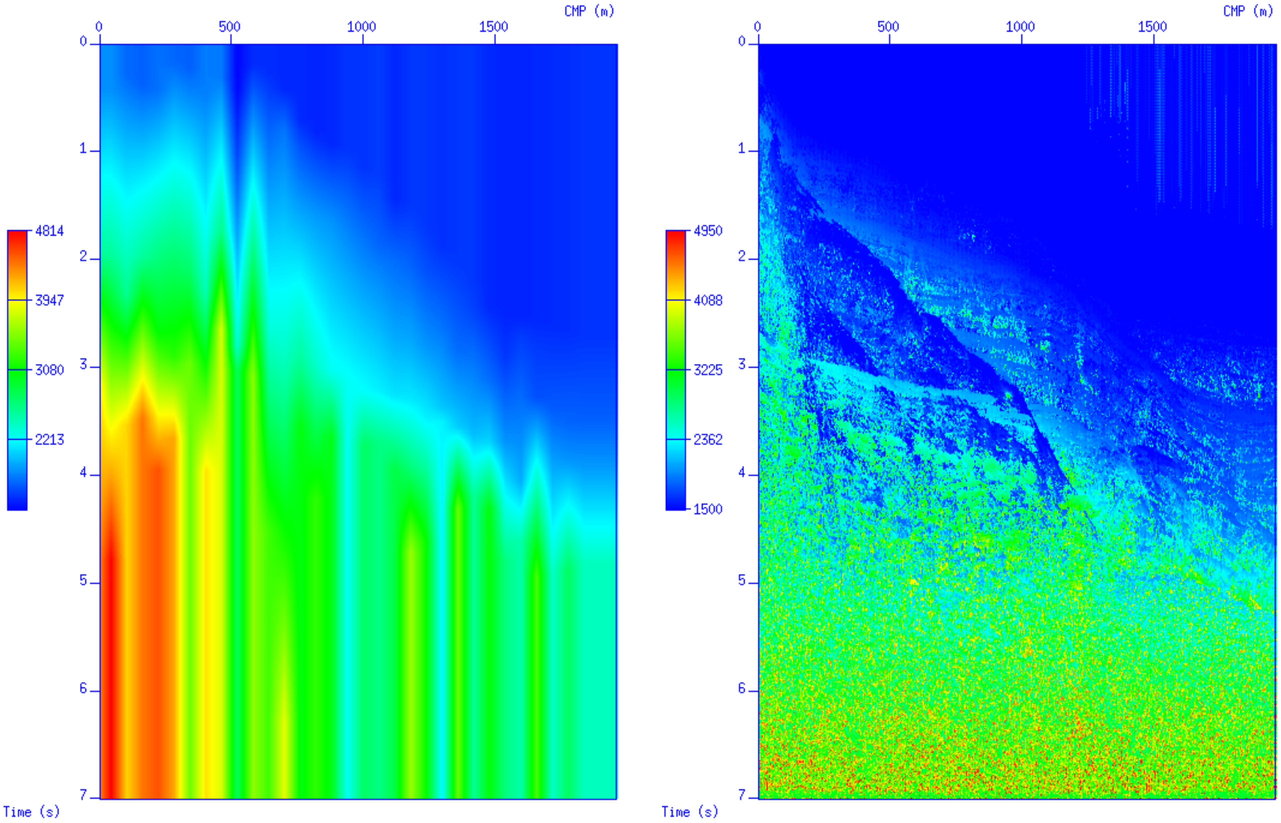


(a) (b) (c)

Figure 3: The CMP gather of the Jequitinhonha Basin in (a), its automatic picking in (b) and the CMP gather corrected for normal moveout in (c).



(a) (b)

Figure 4: Comparison between velocity fields. Velocity field generated by conventional velocity analysis in (a) and the velocity field obtained by the automatic method in (b).

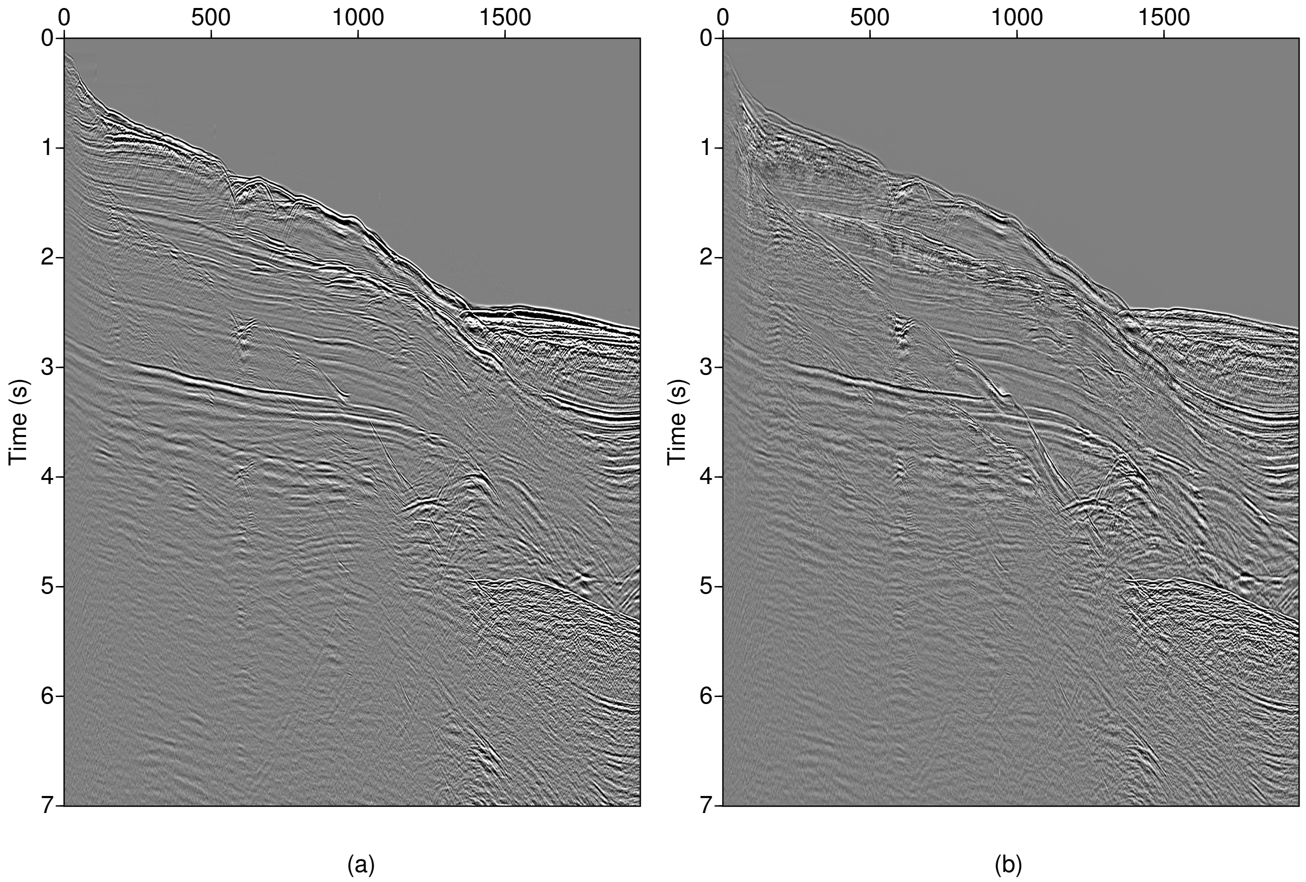


Figure 5: Comparison betwenn zero-offset sections: obtained by conventional velocity analysis in (a) and by the automatic method in (b).