Demultiple of Seismic Data in Wavelet Transform Domain

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Abstract

In this paper, we present a novel approach to attenuate reverberations and multiples from reflection seismic data in wavelet transform domain. The method is implemented on pre-stack reflection seismic data which exploits velocity discrimination between primaries and multiples in common mid-point (CMP) gathers. Move-out corrected multiples in CMP gathers are correlatable from one trace to another. These gathers are then decomposed at different scales using 2D discrete wavelet transform. Scales having correlatable energies are modulated before reconstruction with inverse wavelet transform, thus, effectively removing reverberations and multiples from the gathers. This technique is implemented on a synthetic data set as well as a real seismic dataset where water bottom multiples are removed from the data.

Introduction

Seismic data is often contaminated with various types of noise. In general, noise is categorized into two classes: random noise and coherent noise (Yilmaz, 2001). A technique to remove random noise from seismic data using wavelet transform was developed by Sinha and Sain (2015). For non-stationary seismic signal, Sinha (2014) showed that seismic signal could be enhanced in wavelet domain while reducing random noise from the data.

Multiples and reverberations in seismic data are considered as coherent noise that are correlated from one trace to another. Layers or interfaces with strong impedance contrast such as free surface and water bottom cause multiple reflections to be observed on reflection seismic data. Readers are referred to Yilmaz (2001) for details. Multiples are identified on seismic data based on velocities in pre-stack domain and periodicity on pre-stack and stack section. Multiples have same normal move-out (NMO) velocity as that of its primary reflector. Periodicity and move-out of multiples are exploited to attenuate them in common mid-point (CMP) domain.

There are several methods of multiple attenuation in CMP domain. Velocity discrimination has been exploited in the f-k, τ-p and Radon transform domains to attenuate multiples (Yilmaz, 2001). Periodicity has been utilized to estimate predictive deconvolution filter and thus, attenuate multiples in CMP domain as well as in τ-p domain. Furthermore, a much more powerful technique based on Karhunen-Loeve (K-L) transform uses velocity discrimination where singular-value decomposition (SVD) is used to decompose a gather or an image to separate correlatable energies from non-correlatable energies (Jones and Levy, 1987).

We have developed a novel technique where discrete wavelet transform (DWT) is used to separate primaries from multiples using velocity discrimination. Since wavelet transform retains spatial information in the transformed domain, filtering in the wavelet domain is preferred over that in the Fourier domain. Image decomposition based on 2D-DWT keeps the location information of multiples in the transformed domain. Thus, decomposed CMP gathers in wavelet transform domain having correlatable energies with multiples are removed/ attenuated from the data. Effectiveness of the new technique is first shown on a synthetic data with water bottom multiples. The algorithm is then implemented on a 2D marine seismic data from Krishna-Godavari basin to remove multiples.

Methodology

The proposed method essentially uses velocity discrimination between primaries and multiples to attenuate the multiples. As shown in Figure 1, reverberations and multiples in the CMP gathers are identified based on their move-out velocities and periodicity. After move-out correction of multiples, a CMP gather is decomposed into several scales using 2D-DWT. The scales having multiple energies in the same velocity field is modulated before reconstruction of the CMP gather with inverse 2D-DWT. Move-out velocities are then removed from the gather. Thus,

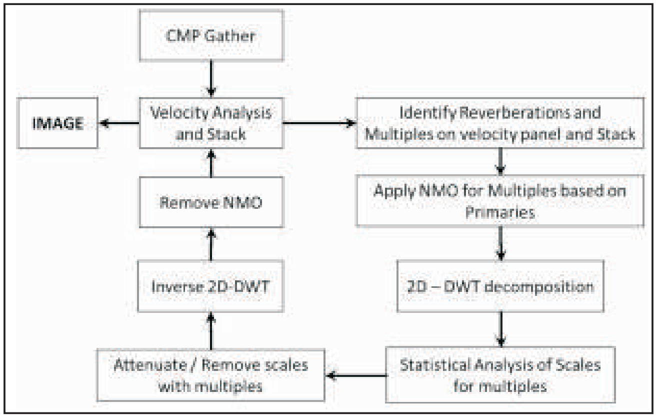

Fig. 1: Workflow showing the steps involved in removing reverberations and multiples from seismic data using wavelet transform.

we get CMP gathers with reverberations and multiples attenuated or removed.

Discrete Wavelet Transform (DWT)

In wavelet transform domain, a function $f(x) \in L^2(\Re)$ can be expressed as an infinite summation of an orthonormal set of basis functions $\{\phi_n(x)\}_{n \in z} \in L^2(\Re)$. It can be expressed as

$$f(x) = \Sigma_{n=-\infty}^{\infty} a_n \phi_n(x). \tag{1}$$

The coefficients (a_n) are computed by taking the inner product of the function with the basis function.

$$a_n = \langle f, \phi_n \rangle \tag{2}$$

These multi-resolution wavelet basis functions have compact support which can be scaled to different sizes and frequencies. Thus, wavelet transform retains both spatial and frequency information of the signal. In discrete dyadic grid, a signal is decomposed into low and high frequency where low frequency (approximation) is fragmented recursively while keeping the high frequency (detail) components unchanged.

The dyadic grid facilitates the most efficient algorithm for discrete wavelet transform. The construction of an orthonormal wavelet basis for the dyadic grid can be written as

$$\Psi_{m,n}(x) = 2^{-m/2}\Psi(2^{-m}x - n) \tag{3}$$

where the integers m and n are used for wavelet dilatation and translation, respectively. The wavelet coefficients $D_{m,n}$ are obtained by convolving the signal with the wavelet functions as

$$D_{m,n} = \int_{-\infty}^{\infty} f(x)\, \psi_{m,n}(x)dx, \tag{4}$$

and they represent *details* at different scales. Scaling functions associated with these discrete wavelets are given by

$$\phi_{m,n}(x) = 2^{-m/2}\phi(2^{-m}x - n). \tag{5}$$

Convolution of the scaling function with the signal produces *approximation coefficients* and can be written as

$$A_{m,n} = \int_{-\infty}^{\infty} f(x)\, \phi_{m,n}(x)dx, \tag{6}$$

In multi-resolution analysis, a decomposed signal in DWT to the level M can be reconstructed using both the *approximations* and the *details* as follows:

$$f(x) = \Sigma_n A_{M,n}\, \phi_{M,n}(x) + \Sigma_{m=1}^{M} \Sigma_n D_{m,n} \psi_{m,n}(x) \tag{7}$$

Noise from the signal is removed before reconstruction in wavelet domain.

Pre-stack gathers (or CMP gathers) are represented by two-dimensional arrays of digital numbers. Therefore, in order to demultiple / denoise the seismic gather in wavelet transform domain, we must perform two-dimensional wavelet decomposition. A discrete wavelet transform of a 2D signal $f(x,t)$ produces a set of four coefficient bands A, D^h, D^v and D^d at a single scale, where A is the *approximation coefficients*, and *D's* are the *details* with superscripts *h, v,* and *d* meant for horizontal, vertical and diagonal components, respectively. The 2D image $f(x,t)$ can be reconstructed with the wavelet coefficients from DWT using two-dimensional wavelets as follows:

$$\begin{aligned} f(x,t) = {} & \sum_{n1}\sum_{n2} A_{M,(n1,n2)}\, \phi_{M,(n1,n2)}(x,t) \\ & + \sum_{m=1}^{M}\sum_{n1}\sum_{n2} D^{h}_{m,(n1,n2)}\, \Psi^{h}_{m,(n1,n2)}(x,t) \\ & + \sum_{m=1}^{M}\sum_{n1}\sum_{n2} D^{v}_{m,(n1,n2)}\, \Psi^{v}_{m,(n1,n2)}(x,t) \\ & + \sum_{m=1}^{M}\sum_{n1}\sum_{n2} D^{d}_{m,(n1,n2)}\, \Psi^{d}_{m,(n1,n2)}(x,t) \end{aligned} \tag{8}$$

Here, n_1, n_2 are location indices at scale m. In a multi-resolution wavelet analysis of an image / gather, it is decomposed at several levels ($m = 1, \ldots\ldots, M$) where the number of coefficients in each band of $m+1^{th}$ level is one fourth of the number of coefficients in its m^{th} band.

Scales containing reverberation and multiples are modulated before reconstruction of the image / gather.

Results and Discussions

Model Data and Multiples

We construct a synthetic CMP gather using Seismic Unix (SU) which includes water bottom multiples (Figure 2a). In this CMP gather, the sea floor is at 0.5 sec TWT. Therefore, water bottom multiples are seen at the integer multiples of 0.5 sec TWT (i.e. at 1.0s, 1.5s, ….., 5.5s).Corresponding velocity map is shown in Figure 2b. In this model 1500 m/s velocity corresponds to water velocity. Real reflectors have continuously increasing velocity. Gaussian noise is added randomly to the data with signal-to-noise ratio as 10.

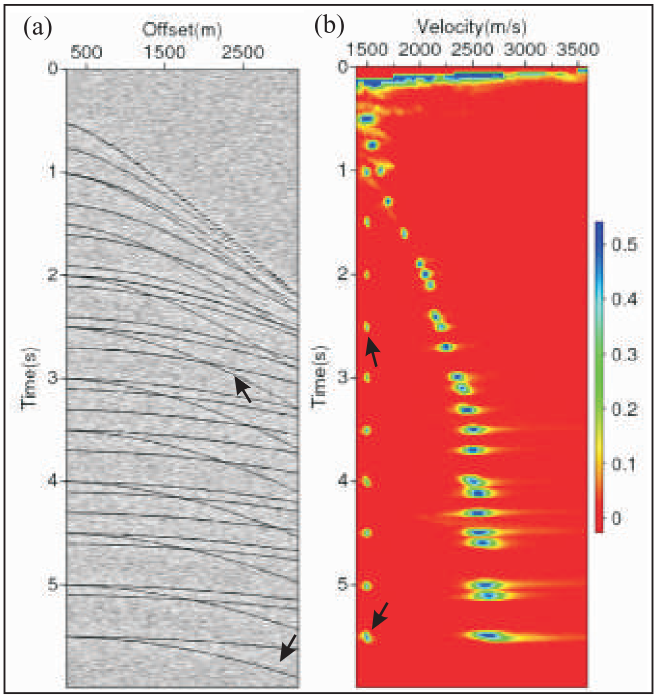

Fig. 2: (a) Synthetic CMP gather showing reflectors and water bottom multiples with random noise. The multiples are at every 0.5 sec from 1 sec onwards. Two of the multiples are indicated by arrows. (b)Velocity semblance map of the CMP gather showing water bottom multiples at 1500 m/s velocity. Reflectors have higher velocities. Two of the water bottom multiples with corresponding velocity are shown by arrows.

After removal of multiples, the data is shown in Figure 3. It is clear that the water bottom multiples have been effectively removed from the modeled data. Multiple velocities corresponding to water (i.e. 1500 m/s) have been attenuated. On the CMP gather we do not see multiple reflections. The algorithm was designed to attenuate coherent noise only and therefore, random noise remain untouched as can be seen in Figure 4b.

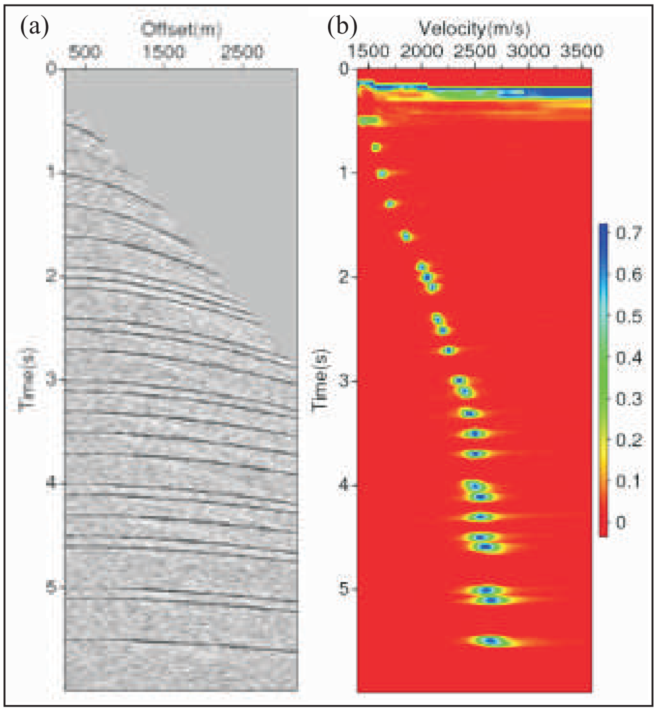

Fig. 3: After removal of multiples, CMP gather is shown in (a) and corresponding semblance velocity map is shown in (b).

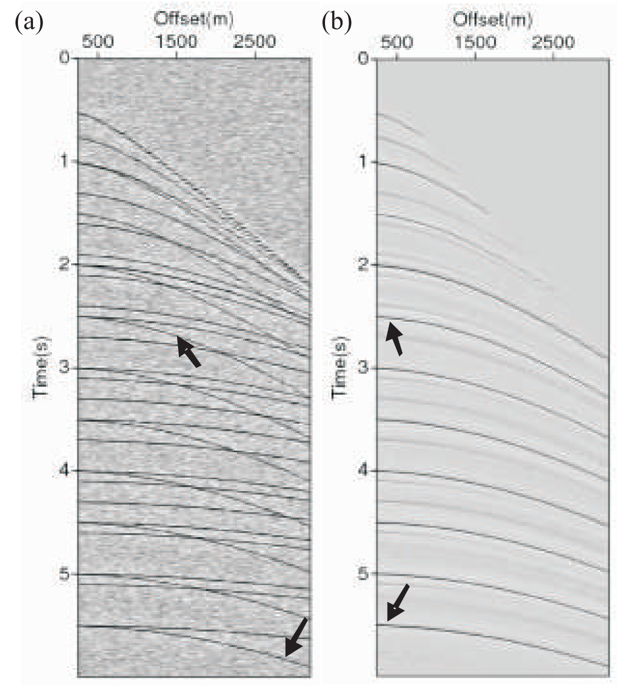

Fig. 4: (a) Modeled CMP gather including water bottom multiples (as in Figure 2a). (b) Multiple energy that has been removed in wavelet domain. Arrows are to show correspondence between the two subfigures.

Note that small energy from the reflectors has also been attenuated depending upon the velocity differences between the true reflectors and multiples. This can be observed at TWT of 0.75s where the NMO velocity difference is only 50 m/s.

Real Seismic Data from K-G Basin

Marine 2D seismic data from Krishna-Godavari basin is processed in the wavelet transform domain to attenuate multiples. A CMP gather from the seismic data is shown in Figure 5a. The data was already compensated for attenuation. Multiple shown by the yellow arrow is basically a sea-floor multiple (sea floor is at ~1.4 sec and the multiple is at ~2.8 sec).

Note the move-out velocity peak shown by the yellow arrow (Figure 6a). After application of the proposed demultiple algorithm in wavelet domain, the CMP gather is plotted in Figure 5b. Multiples have been effectively removed. Corresponding semblance map for NMO velocity is shown in Figure 6a.

Also, on velocity semblance map (Figure 6b), one can see that the NMO velocity related to the multiple has been removed. Notice that the velocity semblance map after demultiple has significantly improved for velocity picking. Also note that the velocity associated with peg-leg multiple is suppressed.

On the stack section (Figure 7), one can see peg-leg multiple and sea-bed multiple shown by green arrow and yellow arrow, respectively. The peg-leg multiple is coming from the reverberation between two reflectors shown by black arrows. Sea-bed multiple is double the time of water column.

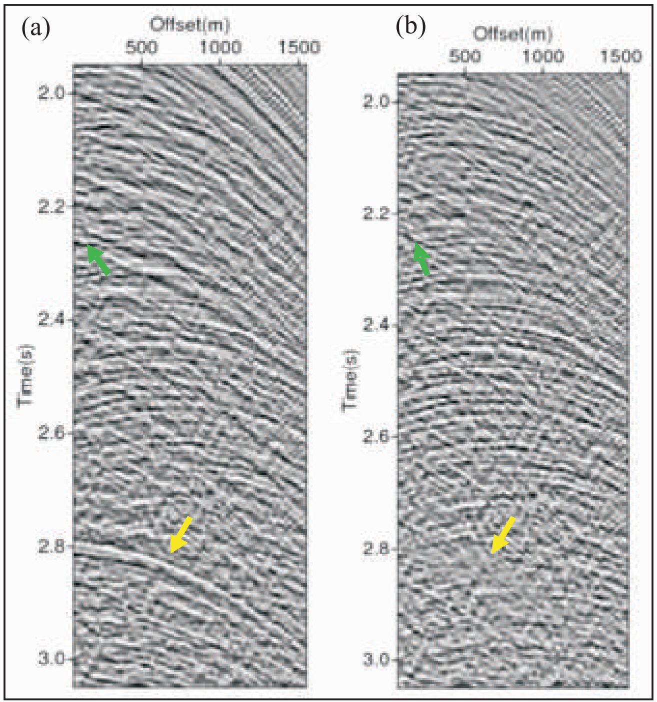

Fig. 5: This is a CMP gather showing peg-leg multiple (green arrow) and sea-bed multiple (yellow arrow) before removal as in (a) and after removal using wavelet transform in (b).

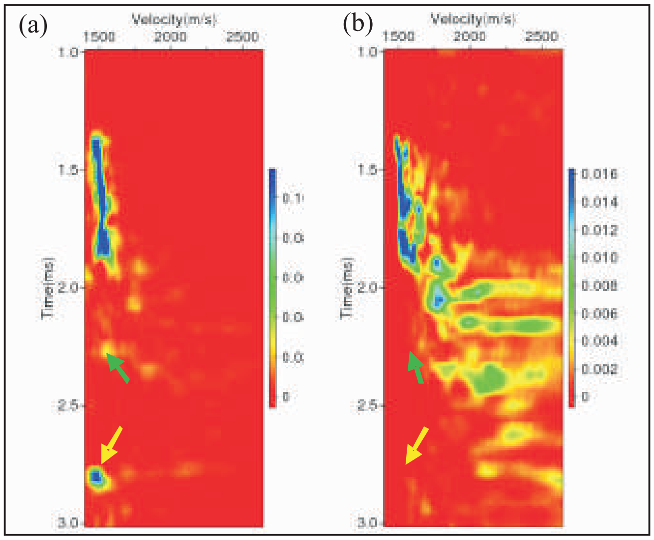

Fig. 6: Semblance map of velocity analysis of the CMP gather shown in Figure 2. Subfigures (a) and (b) correspond to the subfigures (a) and (b) of Figure 2. Arrows indicate the velocities corresponding to peg-leg multiple and sea-bed multiple.

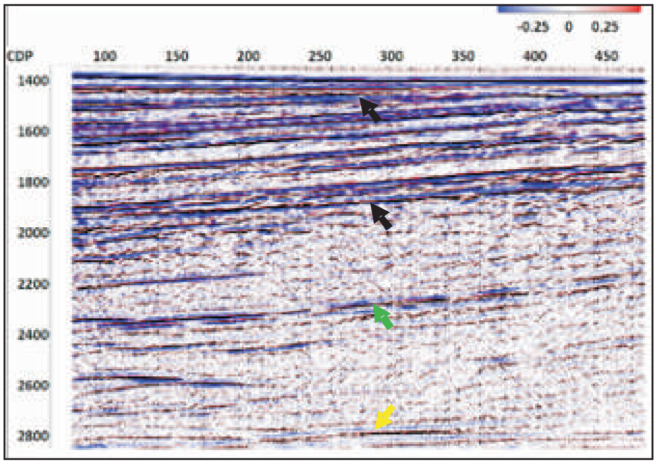

Fig. 7: The reflector shown by green arrow is a peg-leg multiple caused by the reflection within two reflectors shown by black arrows above and the yellow arrow is showing sea-floor multiple

Thus, there is periodicity for both peg-leg multiple and sea-bed multiple. After demultiple process, new velocity profile is picked and the data is stacked after NMO correction. The resulting stack section is shown in Figure 8. Clearly, both peg-leg multiple and sea-bed multiple have been attenuated.

Since the available data has multiples in the basement rocks, further testing is warranted where multiples are within the primaries. The available data clearly has multiples of long periodicity where the demultiple technique has been effective. Therefore, it also needs to be tested on multiples of short periodicity.

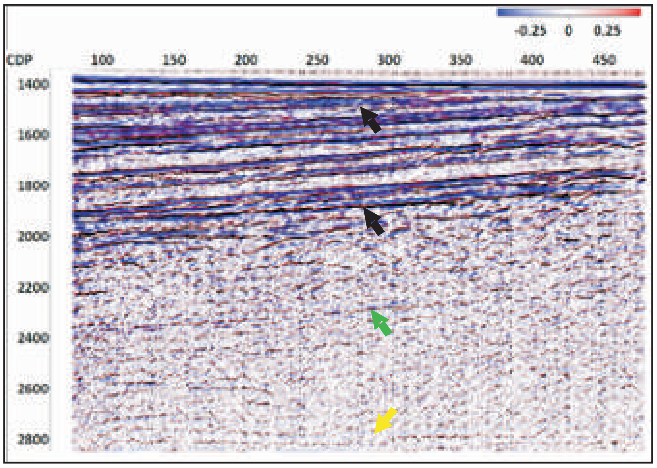

Fig. 8: The peg-leg multiples and sea-floor multiple seen in Figure 7 have been attenuated in this figure.

Conclusions

Velocity discrimination and periodicity of reverberations and multiples in seismic data can be utilized in wavelet transform domain to attenuate such a coherent noise.The fact that the spatial information of different features of an image / gather is retained in the transformed domain with wavelet transform, demultiple algorithm has been designed to target multiples only. Implementation of this novel technique on synthetic and real dataset shows promising results.

Acknowledgements

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