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Using a Novel Method for Attenuating Random Noises from Seismic Data

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Abstract

Random or incoherent noise is an important type of seismic noise, which can seriously affect the quality of the data. Therefore, decreasing the level of this category of noises is necessary for increasing the signal-to-noise ratio (SNR) of seismic records. Random noises and other events overlap each other in time domain, which makes it difficult to attenuate them from seismic records. In this research, a new technique is produced, by joining FX deconvolution (FXD) and a special kind of median filter in order to suppress random noise from seismic records. The technique is operated in some stages; firstly, FXD is tried to eliminate the Gaussian noise, and the median filter is fixed to diminish the spike-like noise. The synthetic dataset and field data examples (from an oil field in the southwest of Iran) have been employed to demonstrate that random noise reduction can be attained, while the signal content will not be destroyed considerably. The final results indicate the authority of the proposed strategy in suppressing random noises, whereas signal information is almost protected during the filtering.

Keywords: Median Filter, Deconvolution, Signal-to-noise Ratio (S/N), Seismic Data, Random Noise

1. Introduction

Seismic noise can be categorized as coherent and random (incoherent). The random noise which a trace can contain can be known as the temporal and spatial directions random noise. The amplitude spectrum of the seismic trace illustrates that a random type is generally robust in a high-frequency area. Most of seismic noises, including random types, could be recorded in data acquisition. Using a time-variant band-pass filter could result in the elimination of random noises. The coherent type can be specified as linear events in offshore surveying for instance reverberations and multiples. Nowadays, numerous algorithms have been presented by different researchers for seismic noise suppression (Sacchi and Naghizadeh, 2009; Spitz, 1991; Cai et al., 2008; Bekara and Baan, 2009). All the strategies try to diminish incoherent noise without affecting the signal information content.

Discrete curvelet transform (DCT) was applied to the reduction of coherent and incoherent noises simultaneously (Candes et al., 2006). Singular value decomposition (SVD) has been implemented for random and spike-like noise suppression (Lu, 2006). Decision based median (DBM) filter is a robust filter for incoherent seismic noise elimination. Increasing the S/N of the data and therefore improving the quality of the seismic records were the results of the application of this method. In

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conventional median filter, the signal is destroyed during operation, but DBM method mainly affects the noisy pixels. Frequency-offset deconvolution is a well-known method in processing seismic records to diminish noise (Spitz and Deschizeaux, 1994).

In the following, the proposed technique is applied to a synthetic model and a real data, which mainly consists of two stages. The outputs and the final results conclude that a combination strategy has more ability for random noise elimination from different types of seismic data in comparison with when each method is used alone.

2. Methodology

FX-decon is a simple process that predicts linear events by making predictions in the frequency-offset space (Canales, 1984). The FX-decon is based on a prediction technique in frequency versus *x*, *x* being the space direction. The process of applying FX-decon starts by partitioning the data into windows small enough so that the events of interest appear linear. Thereafter, the Fourier transform will be applied to every window. For each frequency, a prediction filter is calculated and applied twice: once forward in space and once backwards. The two predictions are summed, and the inverse Fourier transform is then applied; the windows are finally merged back into the output. It should be noted that the operations within each frequency are independent of other frequencies. This allows a large degree of freedom in the prediction of the output. Another interesting feature of the FX-decon process pointed out by Spitz 1991 involves the relationships of the response of a dip at one frequency to that of another dip at another frequency. The periodicity at a low frequency may be used to predict the shape of the higher frequency components and may be used to guide the interpolation of events that are aliased in the high frequency components, but not aliased in the low ones.

Median filter is a simple trick works based on smoothing and tries to replace a sample by the median of all the samples in the surrounding area. Median filter operates in a window, and the computation time is mainly spent on computing the median of every window. The decision based median (DBM) is a developed type of conventional median filter which detects the noisy sample at first. Then, the median filter will be operated just on noisy pixels without affecting the healthy ones (Liu et al., 2009; Rutuja et al., 2013). To implement the proposed method on the seismic data, it should be supposed as a 2D matrix (or image) and a vector prepared by the matrix elements. Noisy samples are distinguished by comparing every sample in the seismic data with its neighborhoods and by calculating the difference between them. In the situation that the data is very noisy, the chance to find a noisy sample is not high; also, if a pixel is detected as noisy, identifying the next noisy one is highly impossible. In summary, DBM is an efficient median filter which can be applied to noisy samples while leaving the others unchanged.

3. Results and discussion

3.1. Synthetic data

Synthetic data containing reflection seismic events with different velocities are used to investigate the feasibility of employing the created algorithm (Figure 1a) in noise level reduction. For this purpose, a high level of noise is added to the data to generate a noisy synthetic record (see Figure 1b). Figure 1c shows the result of noise reduction from the synthetic data; it is obvious that the S/N is enlarged after FX deconvolution filtering, but there are still some unsuppressed noises. After applying DBM filtering to the previous output, as the second step of the proposed method, Figure 1d is resulted. From the outputs of the FX deconvolution and the joint method, it could be concluded that the created algorithm is sufficiently powerful for noise diminishing, which results in increasing the S/N of the synthetic data.

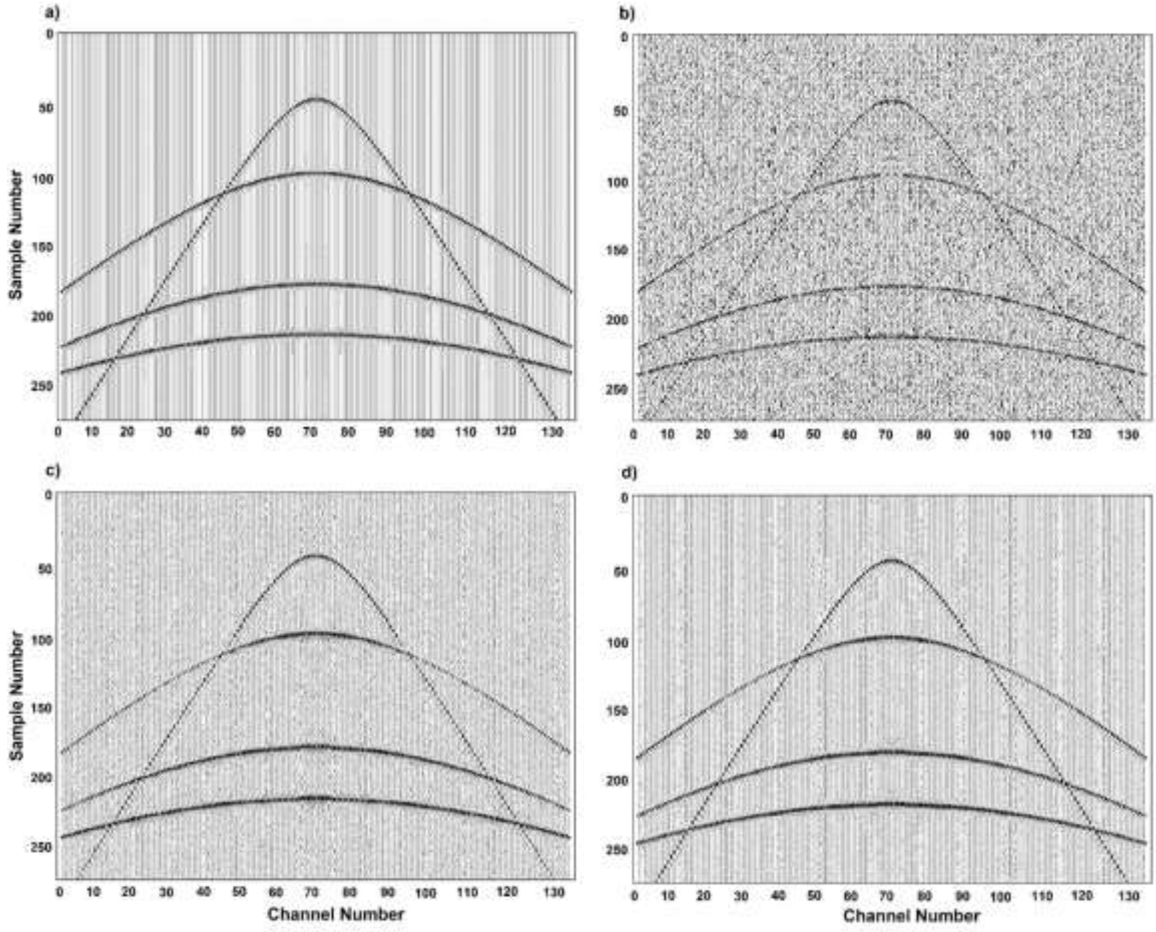

Figure 1

a) A synthetic data containing reflection seismic events with different velocities; Noise-free synthetic data consist of four hyperbola events; b) noisy data after adding a random noise; c) result of denoising data using conventional FX deconvolution; denoised synthetic data using FXD; d) denoised data by the joint strategy.

To affirm that the method preserves the signal, the difference between the noise-free synthetic data (Figure 1a) and the denoised data using FXD and FXD+DBM filtering are provided in Figures 2a and 2b. The residual in Figure 2a shows that although the energy of the seismic events is removed after FXD filtering, there are still some residual noises. However, it is inferred from Figure 2b that the signal is almost preserved after denoising using FXD+DBM, and the level of the remained noise is very low.

To examine the presented method well, the trace number 130 as a noise-free data is selected from Figure 1a. Random noise and spikes are then added to the noise-free trace number 130 simultaneously (Figure 3b). The FXD filter is applied to the new created trace, and Figure 3c is then resulted. From this figure, it is obvious that FXD is not sufficiently powerful because two types of noise with different natures are added together, and removing them using a filter with the same operation factors is hard. To solve this problem, the combination of FXD and DBM is applied; FXD focuses on random noise suppression, and DBM emphasizes spikes removing. The result of the proposed technique (see Figure 3d) confirms its high ability to remove random and impulsive noises simultaneously.

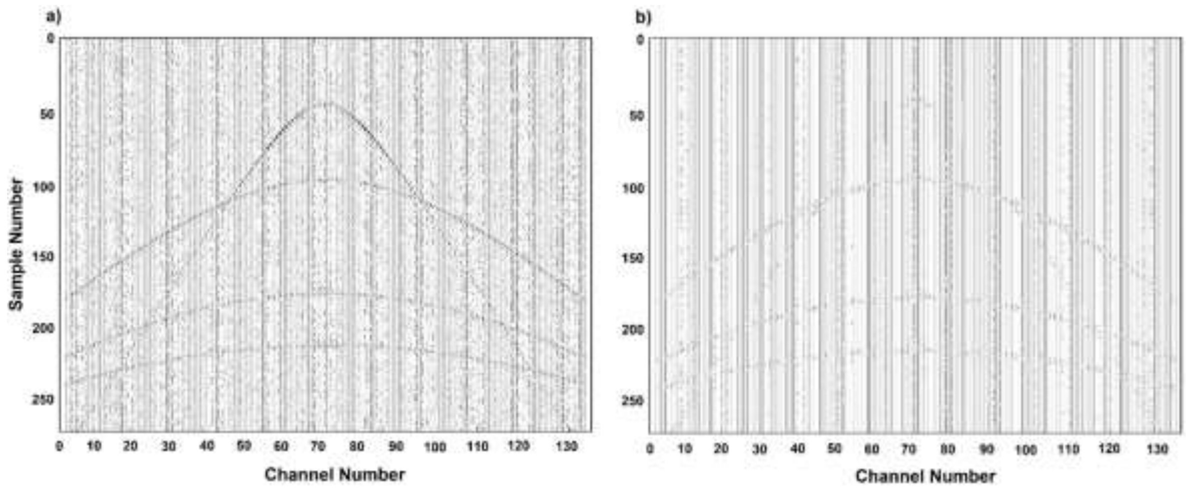

Figure 2
a) Difference between noise-free synthetic data (Figure 1a) and denoised data using FXD; b) difference between noise-free synthetic data (Figure 1a) and denoised data using FXD+DBM filtering.

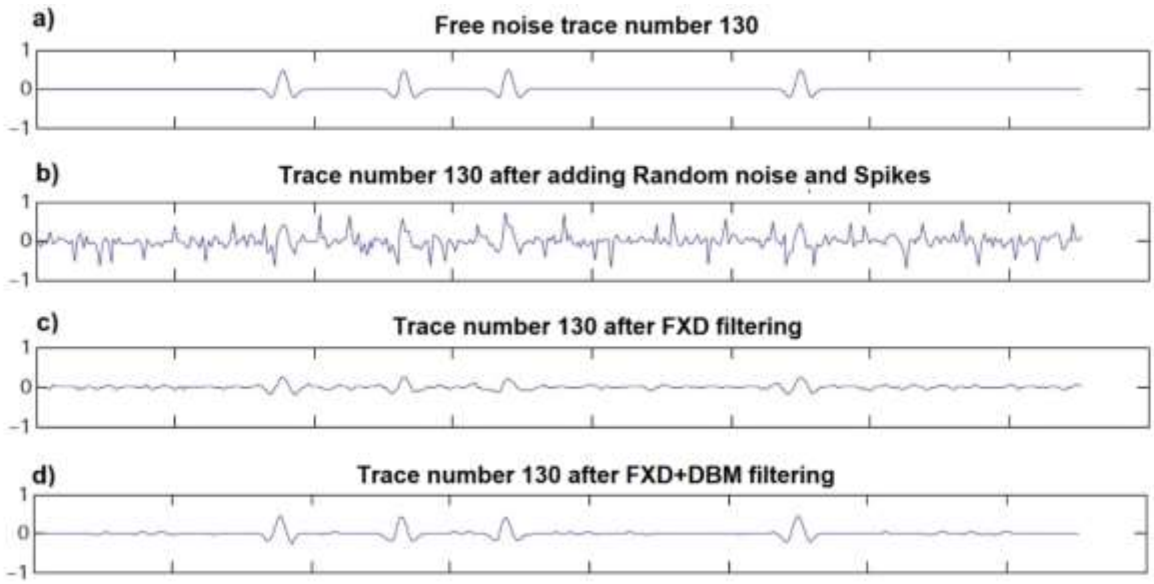

Figure 3
a) Noise-free trace number 130; b) random noise and spikes are added to the noise-free trace together; c) denoised trace by FXD; the method is not sufficiently powerful to remove both types of noises simultaneously; d) Using the combined method (FXD+DBM) to remove random and impulsive noises; the outcome confirms the high ability of the method.

Finally, for a quantitative evaluation of the outputs, the SNR values are calculated for each denoised data using the applied algorithms. The results are tabulated in the Table 1. SNR is calculated as given below (Johnson, 2006):

$$SNR(dB) = 10 \log_{10} \left(\frac{Power\ of\ Signal}{Power\ of\ Noise} \right) \tag{1}$$

The SNR values of the data before and after denoising by both filtering methods are calculated using Equation 1 (Table 1) for a quantitative analysis. Table 1 indicates that both FXD and FXD-DBM filtering methods increase the S/N, but the proposed method is more successful for S/N improvement. Therefore, it could be said that FXD-DBM filter is a more powerful approach for noise elimination in comparison with FXD in seismic data. In addition, the S/N of the designed synthetic model is greatly improved by the strategy.

Table 1
S/N calculation before and after denoising data using different methods.

Data	Noisy record	FXD denoising	FXD-DBM denoising
S/N calculation (dB)	1.7	8.6	13.8

3.2. Real data

To investigate and analyze the performance of the methodology, a section linked to an oil field in the Southwest of Iran is selected (Figure 4a). Asmari is the main reservoir of this oilfield, which includes sequences of sandstone, shale, and limestone. The data contain 250 traces by the spatial sampling of 50 meters and a time interval of 4 milliseconds. The section is really noisy and tracking and interpreting the seismic events are challenging. Therefore, FXD and a combination method are implemented for noise attenuation, and the results are shown in Figures 4b and 4c. From the results, after denoising, the SNR is improved using both approaches, but FXD+DBM method shows higher performance in comparison with FXD (Figures 4b and 4c). Then, the interpretation of the record is enhanced after denoising by using the combined strategy.

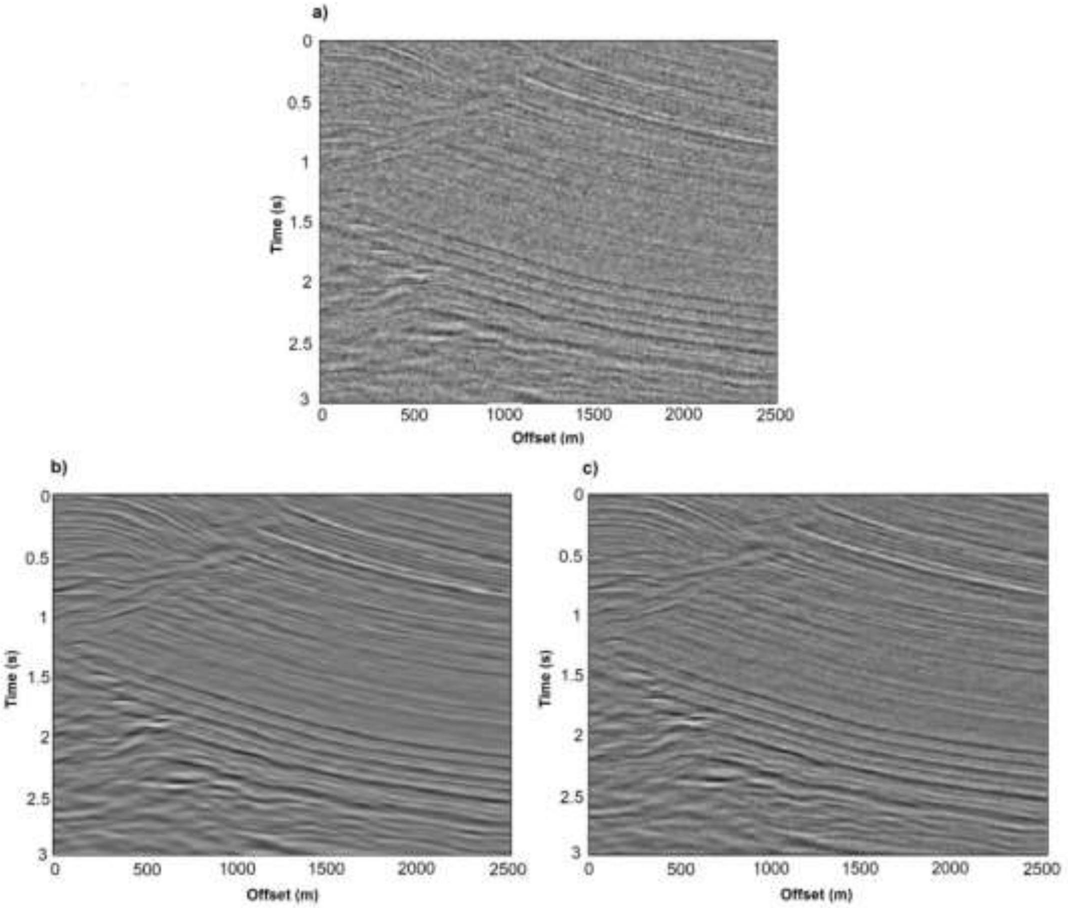

Figure 4
a) A real noisy seismic section; b) the denoised seismic section by FXD+DBM; c) the denoised seismic section by FXD; from the results, after denoising, the SNR is improved using both approaches, but FXD+DBM method shows higher performance.

A close-up of the noisy and denoised sections (which are selected in a zone containing a fault like event) by FXD+DBM method is presented in Figures 5a and 5b for a better comprehension. Considering the zoomed area in Figure 5 proves the high ability of combination methodology to improve the S/N and interpretability of the section in comparison with simple FXD algorithm. The fault-like event, which may be related to a hydrocarbon reservoir, is clarified significantly after denoising using the combined method.

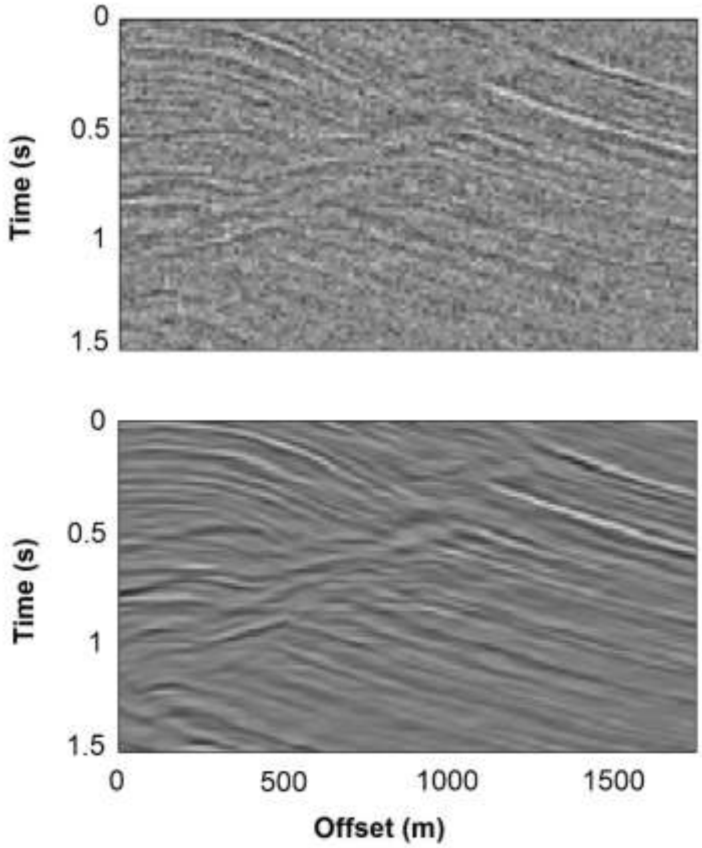

Figure 5
a) The close-up of a part of noisy seismic section containing an event like fault before denoising; b) the zoom of noisy seismic section after denoising by FXD+DBM; the high ability of combination strategy to improve the S/N ratio and interpretability of the section in comparison to the simple method is clear.

In order to increase the SNR, an essential challenge in processing seismic records is the attenuation of random noises. Incoherent or random noises could be recorded in seismic data from different sources. Noises like rain, wind, tides, vibrations of machinery, and noises from production platforms etc. are generally considered as random noises, which are characterized by high frequencies. Stacking can effectively diminish the incoherent noises, but there are still some residual noises after stacking, which will reduce the quality and interpretability of records.

In seismic data processing, noise attenuation techniques can be performed in different domains, namely shot domain, common offset (CO) domain, or common depth point (CDP) domain. Some seismic noises are coherent in the shot gather but incoherent in the receiver gather. Also, sorting data from the shot domain into another domain, e.g. CDP and/or CO domain, can break up the neighborhood traces affected by large amplitudes; thus, a better estimate of the data signal can be obtained, so superior noise attenuation could be performed.

In this work, a technique is created in two steps; first frequency-offset deconvolution is used to remove random noises. Second, spike-like noises will be suppressed by decision-based median filtering. FX deconvolution adaptively predicts the seismic events by *f-x* auto-regression with the assumption of linearity. In case of non-linear events, the windowing trick is considered. DBM is a special type of median filter, which is applied just to noisy pixels and leaves noise-free ones unchanged.

4. Conclusions

Noise attenuation is a main step in seismic data processing for increasing the S/N of the data, which results in seismic interpretation development. In other words, noise attenuation of seismic data tries to increase the quality of records and to provide more reliable results for hydrocarbon exploration, thereby decreasing the risk of extraction well drilling. Also, noise elimination has a direct role in the correctness results of other seismic processing steps such as static correction, velocity analysis and solving the inverse problems. Understanding the origin and the source of different noises is the first and the most important step of data processing, which helps to study the noise characteristics, and consequently better noise suppression.

For seismic random noise attenuation, a novel method was developed herein by joining decision-based median filter and frequency offset deconvolution to diminish the level of random and spike-like noises in seismic data. The method was applied to a synthetic model and a field seismic record, and the results were compared with the conventional *f-x* deconvolution. A proper strategy was employed for the attenuation of random noises, due to different natures of signal and noise. The results confirmed the efficiency of the method developed in this work for the attenuation of spike-like and incoherent noises, while the simple FXD was not able to suppress noises completely. Unlike conventional methods, the proposed method slightly affected signals. The point is the accuracy of random noise estimation using our technique. All in all, the results showed that our combined technique, in comparison with the conventional frequency-offset deconvolution, had a higher ability to suppress spike-like and random noises; meanwhile, other types of seismic events are not influenced significantly.

Acknowledgments

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Nomenclatures

CDP	: Common depth point
CO	: Common offset
DBM	: Decision-based median
DCT	: Discrete Curvelet transform
FXD	: Frequency offset deconvolution
SNR or S/N	: Signal to noise ratio
SVD	: Singular value decomposition

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