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DUET Algorithm Exploiting Sparsity for Effective Seismic Source Separation

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Abstract:
Seismic Signal processing involves the separation of seismic sources from a mixture of signal sources. Seismic source separation is gaining importance today, as we require separation techniques for modeling a seismic activity and thus predicting the occurrence of seismic activity. Despite the vast amount of research in this field, the signal processing and event parameters discrimination algorithms have not yet fully come of age. This paper gives a description of different methods for seismic source separation and comparison of commonly adopted algorithms for these methods. This paper also overview the need of sparsity which makes signal separation effective. The problem with seismic sources is that its origin is unknown due to the fact that multiple sources are simultaneously active. The task is to separate out these sources and reconstruct the signals back. Here the idea of sparsity is employed in order for efficient reconstruction of signals. An important property of sparse signal processing, that allows efficient signal reconstruction, is that the information rate of a continuous time signal may be much smaller than that suggested by its bandwidth.

***Keywords**: DUET, SEISMIC SEPARATION, SHORT TIME FOURIER TRANSFORM, SPARSE SIGNALS,WAVELET*

1. Introduction

Seismic survey is a program for mapping geological structure by observation of Seismic wave. This is done by creating seismic wave with artificial sources and observing the arrival time of the waves reflected from acoustic impedance which contrasts or refracted through high velocity members. The dynamic nature of earth creates uncertainty in the occurrence of any seismic activities. Once if we are able to understand the characteristics of earth, we can model the seismic sources and there by predict the occurrence of seismic activities. There are many types of seismic sources[1] such as Rapid Stress drop ,as a result of brittle material failure in earth, Continuous tremor events, as a result of seismic activities such as volcanoes, earth quakes etc., Microseisms events, as a result of seismic action on water bodies such as oceans, and also manmade events. The main problem encountered is that the origins of these sources are unknown. This is because of the fact that multiple sources are simultaneously active. This problem makes seismic modeling more difficult. Once if we are able to separate out these sources from mixture we can model it easily by using appropriate algorithms. Sources of seismic energy come in a variety of size and shapes. Virtually anything that impacts or cause motion on the surface of earth will be a source of seismic energy. There are many methods available for the separation of seismic sources from mixture of sources. Some of them are listed here

1.1. Single Channel Seismic Acoustic Signal Blind Source Separation Method

In this method first the observed signals are decomposed into intrinsic mode matrix by ensemble empirical mode decomposition[2]. Then the signal under each channel is transformed into multichannel positive definite problem .The input for Blind Source Separation[3] are made and by using any of the appropriate algorithm the source is separated out. The main problem associated with this method is the amount of noise associated with the signal.

1.2. Coda Wave Interferometry Source Separation Method

Here two identical waves are separated out by means of correlation of waveforms recorded at a single receiver. Superpositions of two identical waves are called Coda Waves[4]. In this method an assumption is made that, the scattering properties (displacement of sources) of the medium are constant, which is not true in practice. As a result of this assumption serious mismatch in the result may occur. There is a possibility of change in phase shift of Coda Waves which may seriously affect the original results.

1.3. Vibroseis Correlation Method For Seismic Separation

In this method of source separation, seismic sources are assumed linear and digital signal processing is carried out as in LTI systems[5]. The time and frequency domain information are extracted from the representations of the sources. This is an effective

method where we apply techniques such as windowing, truncation, smoothening etc. Noise correction is achieved to a greater degree than in any other method.
In all of these methods explained above, we need to use an effective algorithm[6]-[10] for the proper separation of seismic sources from a mixture. The aim of this paper is to compare the available algorithms at present and to suggest the effective one. It also focuses to find out the effective signal processing technologies that can be adopted to these algorithms.

2. Effective Signal Processing Methods for Seismic Analysis

2.1. Short Time Fourier Transform

The short time fourier transform (STFT) also known as windowed fourier transform[3] is an approach to solve the problem encountered with fourier transform. STFT uses a sliding window to compute the windowed discrete-time Fourier transform of a signal. The function mentioned above is available as a toolbox in MATLAB[1] which is an added advantage of this method. The MATLAB signal processing toolbox provides a function known as the *Spec gram*, that provides the time-dependent Fourier transform[11]. The *Specgram* uses a sliding window to compute the windowed discrete-time Fourier transform of a signal. The spectrogram is the magnitude of this function. Any short-time analysis T{} of signal x[m] is preceded by a windowing of the seismic mixture sequence.

$$Xn = \sum_{m=-\infty}^{\infty} T\{x[m].w[n-m]\} \qquad (2)$$

Hamming window is usually used where the approximation error is found to be minimum[1]. The advantage of the STFT over the conventional Fourier transform, as shown in this example, is that the time information of the signal is saved after the Fourier transform. The STFT is very useful for identifying newly arrived signals for seismic signal data processing.DUET algorithm which is the most advanced algorithm available for seismic signal separation uses this transform for the efficient separation of seismic signals from a mixture of seismic sources. In the algorithm first, the discrete Short Time Fourier Transform of signals are constructed and the algorithm is applied to it. After proper separation of signals inverse STFT is then applied to convert back the signals into time domain.

2.2. Wavelet Transform

Seismic signals are non-stationary in their frequency and amplitude statistics. Seismic signals usually vary in both amplitude and frequency over long periods of time. Ideally, for the seismic signal analysis, one would like to separate short period oscillations from long period ones. One solution would be to use a Short Time Fourier Transform (STFT), which was already explained. The STFT uses a window with a fixed size, slides it along in time, and computes the Fourier transform each time, using only the data within the window. The main problem with this technique is the inconsistent treatment of different frequencies. The frequency localization may be lost for low frequency signals, as there are few oscillations within the window and for high frequency signals as there are too many oscillations within the window.
Wavelet analysis is used to solve these problems by decomposing a signal into time and frequency space simultaneously[8][9]. With wavelet analysis, one can get information on the frequency of a signal, and how this frequency varies with time. Also, the wavelet transform is more precise than the STFT to focus on phenomena with a very short time period and high frequencies, such as transient signals. The information of time frequency localization provided by the wavelet transform helps with analyzing the dispersion characteristics of the seismic waves and the identification of the reflection signal.
The disadvantage of wavelet which pulls it backward in seismic analysis is obviously the complexity in applying wavelet in analysis as result of shift sensitivity, in which wavelet coefficient fail to distinguish between input-signal shifts and poor directionality, in which phase information is not present at many significant frequencies.
The application of wavelet in seismic signal separation is still under research and in a short period wavelet will overpower other methods and will emerge as the most powerful tool for separation of seismic signals.

3. Duet Algorithm for Seismic Signal Processing

The most powerful and robust algorithm in seismic signal separation so far identified is DUET algorithm[1]. DUET, the Degenerate Unmixing Estimation Technique, solves the degenerate unmixing problem in an efficient and robust manner. The underlying principle behind DUET can be summarized as follows:
'It is possible to blindly separate an arbitrary number of sources given just two anechoic mixtures provided the time–frequency representations of the sources do not overlap too much, which is true for speech'.[1] The way that DUET separates degenerate mixtures is by partitioning the time–frequency representation of one of the mixtures. In other words, DUET assumes the sources are already 'separate' in that, in the time–frequency plane, the sources are *disjoint*. The 'unmixing' process is then simply a partitioning of the time–frequency plane.[3] Although the assumption of disjointness may seem unreasonable for simultaneous speech, it is approximately true, i.e. the time–frequency points which contain significant contributions to the average energy of the mixture are very likely to be dominated by a contribution from only one source. Stated another way, two people rarely excite the same frequency at the same time.
In DUET unmixing of mixture of seismic source is done by Blind source separation of Speech signals[10]. The recordings of the speech signals are sparse in the time domain and this property results in the efficient implementation of these algorithm. Sparsity is defined in speech signals as each of the signals has different characteristics such as pitch, bass etc. This algorithm works very effectively when there is no or little overlap between the two sources in time frequency domain[1].

3.1. Steps in DUET Algorithm[1]

- Construct the discrete short time fourier transform of seismic signals using any appropriate window.
- Ratios of mixtures are found out and with this a local delay estimate is extracted.
- Generation of histogram using matlab.
- Creation of a binary time frequency mask which is applied to the mixture.
- Separation of mixtures are done and it is undergone proper transformation to obtain the results in time domain.(inverse STFT used).

The disadvantage of DUET algorithm is the assumption of anechoic mixing, which will result in poor echo cancellation and won't give results if there is any sort of attenuation.

4. Sparsity and its Advantages

Seismic sources can exhibit sparsity in the time-frequency domain, and this property allows DUET to successfully separate seismic signals[1]. A discrete signal is said to be sparse depending on the number of non zero elements present in that signal, i.e. a signal of length 'N' is said to be 'K' sparse if it contains at most 'K' non zero elements where K<<N. If a signal is sparse in one domain, then it is dense in other domain. The idea conveyed by sparsity is that the information rate of a continuous time signal may be much smaller than that is suggested by its bandwidth or a discrete time signals depends on a number of degrees of freedom which is comparably much smaller than its length[10].

In sampling a signal the most common approach is to follow Shannon Nyquist criteria i.e. sampling frequency $Fs \geq 2Fm$,where Fm is maximum frequency of the signal. The problem associated with this approach is the consumption of bandwidth. Two times the maximum frequency is seriously a disadvantage. The importance of the Sparsity lies in this fact that information rate of a continuous time signal may be much smaller than suggested by its bandwidth, i.e. the signals can be undergone compressive sampling. Here sparsity is defined in the speech signals as each of the speech signals has different characteristics. Recordings of the speech signals are sparse in the time domain and this property results in efficient implementation of seismic source separation algorithm.

5. Proposed Method

Seismic separation techniques will be more effective if we can use multirate wavelet transform as the signal processing techniques. The robustness of wavelet transform will open a wide path for effective seismic source separation. Applying DUET algorithm along with Wavelet transform will be of a great use as far as seismic separation is concerned. The proposed method is to adopt DUET along with Wavelet transform exploiting the sparsity properties by the use of Matlab to get a well accomplished result for the prediction of these natural seismic activities.

6. Conclusion

In this paper different seismic separation techniques are explained and compared. After that the signal processing techniques such as STFT and Wavelet that are applicable to these methods are described.Though wavelet transform is powerful tool for seismic analysis, Short Time Fourier Transform is being adopted in most of methods due to its high flexibility when compared to wavelet. The most effective algorithm used is Degenerate Unmixing Estimation Technique algorithm which also uses Short Time Fourier Transform and also importance of sparsity is mentioned which applied in DUET algorithm for effective signal reconstruction.Finally a proposal is given which combines advantages of DUET,Wavelet and Sparsity for effective Separation of seismic signals.

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